PROJ coordinate transformation software library

Release 8.0.1

PROJ contributors

May 2021

CONTENTS

CHAPTER

ONE

ABOUT

PROJ is a generic coordinate transformation software that transforms geospatial coordinates from one coordinate reference system (CRS) to another. This includes cartographic projections as well as geodetic transformations. PROJ is released under the *X/MIT open source license*

PROJ includes *command line applications* for easy conversion of coordinates from text files or directly from user input. In addition to the command line utilities PROJ also exposes an *application programming interface*, or API in short. The API lets developers use the functionality of PROJ in their own software without having to implement similar functionality themselves.

PROJ started purely as a cartography application letting users convert geodetic coordinates into projected coordinates using a number of different cartographic projections. Over the years, as the need has become apparent, support for datum shifts has slowly worked its way into PROJ as well. Today PROJ supports more than a hundred different map projections and can transform coordinates between datums using all but the most obscure geodetic techniques.

1.1 Citation

To cite PROJ in publications use:

> PROJ contributors (2021). PROJ coordinate transformation software library. Open Source Geospatial Foundation. URL https://proj.org/.

A BibTeX entry for LaTeX users is

```
@Manual{,
  title = {{PROJ} coordinate transformation software library},
  author = {{PROJ contributors}},
  organization = {Open Source Geospatial Foundation},
  year = {2021},
  url = {https://proj.org/},
}
```

1.2 License

PROJ uses the MIT license. The software was initially released by the USGS in the public domain. When Frank Warmerdam took over the development of PROJ it was moved under the MIT license. The license is as follows:

CHAPTER

TWO

NEWS

2.1 8.0.1 Release Notes

May 5th 2021

2.1.1 Updates

- Database: update to EPSG v10.018 (#2636)
- Add transformations for CHGeo2004, Swiss geoid model (#2604)
- Additions to the norwegian NKG2020 transformation (#2600)

2.1.2 Bug fixes

- `pj_vlog()`: fix buffer overflow in case of super lengthy error message (#2693)
- Revert "*`proj_create_crs_to_crs_from_pj()`*: do not use PROJ_SPATIAL_CRITERION_PARTIAL_INTERSECTION if area is specified" (#2679)
- UTM: error out when value of `+zone=` is not an integer (#2672)
- `getCRSInfoList()`: make result order deterministic (by increasing auth_name, code) (#2661)
- `createOperation()`: make sure no to discard deprecated operations if the replacement uses an unknow grid (#2623)
- Fix build on Solaris 11.4 (#2621)
- Add mapping of ESRI Equal_Area projection method to EPSG (#2612)
- Fix incorrect EPGS extent code for EPSG:7789>EPSG:4976 NKG transformation (#2599)
- fix wrong capitalization of CHENyx06_ETRS.gsb (#2597)
- `createOperations()`: improve handling of vertical transforms when when compound CRSs are used (#2592)
- `CRS::promoteTo3D()`: propagate the extent from the 2D CRS (#2589)
- `createFromCRSCodesWithIntermediates()`: improve performance when there is no match (#2583)
- Fix `proj_clone()` to work on 'meta' coordinate operation `PJ*` objects that can be returned by *`proj_create_crs_to_crs()`* (#2582)
- add `PROJ_COMPUTE_VERSION`, `PROJ_VERSION_NUMBER`, `PROJ_AT_LEAST_VERSION` macros (#2581)
- Make *`proj_lp_dist()`* and *`proj_geod()`* work on a `PJ*` CRS object (#2570)

- Fix gcc 11 -Wnonnull compilation warnings (#2559)
- Fix use of uninitialized memory in gie tests (#2558)
- createOperations(): fix incorrect height transformation between 3D promoted RGF93 and CH1903+ (#2555)

2.2 8.0.0 Release Notes

March 1st 2021

With the release of PROJ 8 the proj_api.h API is finally removed. See *Version 4 to 6 API Migration* for more info on how to migrate from the old to the proj.h API.

With the removal of proj_api.h it has been possible to simplify error codes and messages given by the software. The error codes are exposed in the API.

Several improvements has been made to the command line utilities as well as tweaks in the underlying API.

2.2.1 Updates

- Public header file proj_api.h removed (#837)
- Improved accuracy of the Mercator projection (#2397)
- Copyright statement wording updated (#2417)
- Allow **cct** to instantiate operations via object codes or names (#2419)
- Allow @filename syntax in **cct** (#2420)
- Added *Geocentric to topocentric conversion* (+proj=topocentric) (#2444)
- Update GeographicLib to version 1.51 (#2445)
- Added option to allow export of Geographic/Projected 3D CRS in WKT1_GDAL (#2450)
- Added --area and --bbox options in **cs2cs** to restrict candidate coordinate operations (#2466)
- Added build time option to make *PROJ_LIB* env var tested last (#2476)
- Added --authority switch in **cs2cs** to control where coordinate operations are looked for. C API function *proj_create_crs_to_crs_from_pj()* updated accordingly (#2477)
- Error codes revised and exposed in the public API (#2487)
- Added --accuracy options to **projinfo**. C API function *proj_create_crs_to_crs_from_pj()* updated accordingly (#2488)
- Added proj_crs_is_derived() function to C API (#2496)
- Enabled linking against static cURL on Windows (#2514)
- Updated ESRI CRS database to 12.7 (10.8.1/2.6) (#2519)
- Allow a WKT BoundCRS to use a PROJ string transformation (#2521)
- Update to EPSG v10.015 (#2539)
- Default log level set to PJ_LOG_ERROR (#2542)
- CMake installs a pkg-config file proj.pc, where supported (#2547)

2.2.2 Bug fixes

- Do not restrict longitude to [-90;90] range in spherical transverse Mercator forward projection (#2471)
- `createOperations()`: fix Compound to Geog3D/Projected3D CRS with non-metre ellipsoidal height (#2500)
- Avoid error messages to be emitted log level is set to `PJ_LOG_NONE` (#2527)
- Close database connection when autoclose set to True (#2532)

2.3 7.2.1 Release Notes

January 1st 2021

2.3.1 Updates

- Add metadata with the version number of the database layout (#2474)
- Split `coordinateoperation.cpp` and `test_operation.cpp` in several parts (#2484)
- Update to EPSG v10.008 (#2490)
- Added the NKG 2008 and 2020 transformations in `proj.db` (#2495)

2.3.2 Bug fixes

- Set `CURL_ENABLED` definition on projinfo build (#2405)
- `createBoundCRSToWGS84IfPossible()`: make it return same result with a CRS built from EPSG code or WKT1 (#2412)
- WKT2 parsing: several fixes related to map projection parameter units (#2428)
- `createOperation()`: make it work properly when one of the CRS is a BoundCRS of a DerivedGeographicCRS (`+proj=ob_tran +o_proj=lonlat +towgs84=....`) (#2441)
- WKT parsing: fix ingestion of WKT with a Geocentric CRS as the base of the projected CRS (#2443)
- `GeographicCRS::_isEquivalentTo(EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS)`: make it work when comparing easting,northing,up and northing,easting,up (#2446)
- `createOperation()`: add a ballpark vertical transformation when dealing with `GEOIDMODEL[]` (#2449)
- Use same arguments to printf format string for both radians and degrees in output by cct (#2453)
- PRIMEM WKT handling: fixes on import for 'sexagesimal DMS' or from WKT1:GDAL/ESRI when GEOGCS UNIT != Degree; morph to ESRI the PRIMEM name on export (#2455)
- `createObjectsFromName()`: in exact match, make looking for 'ETRS89 / UTM zone 32N' return only the exact match (#2462)
- Inverse tmerc spherical: fix wrong sign of latitude when lat_0 is used (#2469)
- Add option to allow export of Geographic/Projected 3D CRS in WKT1_GDAL (#2470)
- Fix building `proj.db` with SQLite built with `-DSQLITE_DQS=0` (#2480)
- Include JSON Schema files in CMake builds (#2485)
- `createOperations()`: fix inconsistent chaining exception when transforming from BoundCRS of projected CRS based on NTF Paris to BoundCRS of geog CRS NTF Paris (#2486)

2.4 7.2.0 Release Notes

November 1st 2020

2.4.1 Updates

- **Command line tools**
  - Add multi-line PROJ string export capability, and use it by default in **projinfo** (unless `--single-line` is specified) (#2381)
- **Coordinate operations**
  - *Colombia Urban* projection, implementing a EPSG projection method used by a number of projected CRS in Colombia (#2395)
  - *Triangulated Irregular Network based transformation* for triangulation-based transformations (#2344)
  - Added ellipsoidal formulation of *Orthographic* (#2361)
- **Database**
  - Update to EPSG 10.003 and make code base robust to dealing with WKT CRS with DatumEnsemble (#2370)
  - Added Finland tinshift operations (#2392)
  - Added transformation from JGD2011 Geographic 3D to JGD2011 height using GSIGEO2011 (#2393)
  - Improve CompoundCRS identification and name morphing in VerticalCRS with ESRI WKT1 (#2386)
  - Added OGC:CRS27 and OGC:CRS83 CRS entries for NAD27 and NAD83 in longitude, latitude order (#2350)
- **API**
  - Added temporal, engineering, and parametric datum `PJ_TYPE` enumerations (#2274)
  - Various improvements to context handling (#2329, #2331)
  - `proj_create_vertical_crs_ex()`: add a `ACCURACY` option to provide an explicit accuracy, or derive it from the grid name if it is known (#2342)
  - `proj_crs_create_bound_crs_to_WGS84()`: make it work on verticalCRS/compoundCRS such as EPSG:4326+5773 and EPSG:4326+3855 (#2365)
  - `promoteTo3D()`: add a remark with the original CRS identifier (#2369)
  - Added `proj_context_clone()` (#2383)

2.4.2 Bug fixes

- Avoid core dumps when copying contexts in certain scenarios (#2324)
- `proj_trans()`: reset errno before attemptying a retry with a new coordinate operation (#2353)
- PROJJSON schema corrected to allow prime meridians values with explicitly stating a unit (degrees assumed) (#2354)
- Adjust `createBoundCRSToWGS84IfPossible()` and operation filtering (for POSGAR 2007 to WGS84 issues) (#2357)
- `createOperations()`: several fixes affecting NAD83 -> NAD83(2011) (#2364)

- WKT2:2019 import/export: handle DATUM (at top level object) with PRIMEM
- WKT1_ESRI: fix import and export of CompoundCRS (#2389)

2.5 7.1.1 Release Notes

September 1st 2020

2.5.1 Updates

- Added various Brazilian grids to the database (#2277)
- Added geoid file for Canary Islands to the database (#2312)
- Updated EPSG database to version 9.8.15 (#2310)

2.5.2 Bug fixes

- WKT parser: do not raise warning when parsing a WKT2:2015 TIMECRS whose TIMEUNIT is at the CS level, and not inside (#2281)
- Parse '+proj=something_not_latlong +vunits=' without +geoidgrids as a Projected3D CRS and not a compound CRS with a unknown datum (#2289)
- C API: Avoid crashing due to missing SANITIZE_CTX() in entry points (#2293)
- CMake build: Check "target_clones" before use (#2297)
- PROJ string export of +proj=krovak +czech: make sure we export +czech… (#2301)
- Helmert 2D: do not require a useless +convention= parameter (#2305)
- Fix a few spelling errors ("vgridshit" vs. "vgridshift") (#2307)
- Fix ability to identify EPSG:2154 as a candidate for 'RGF93_Lambert_93' (#2316)
- WKT importer: tune for Oracle WKT and 'Lambert Conformal Conic' (#2322)
- Revert compiler generated Fused Multiply Addition optimized routines (#2328)

2.6 7.1.0 Release Notes

July 1st 2020

2.6.1 Updates

- **New transformations**
  - Add a +proj=defmodel transformation for multi-component time-based deformation models (#2206):
- **New projections**
  - Add square conformal projections from libproject (#2148):
    * *Adams Hemisphere in a Square*
    * *Adams World in a Square I*

  * *Adams World in a Square II*
  * *Guyou*
  * *Peirce Quincuncial*
- Adams Square II: map ESRI WKT to PROJ string, and implement iterative inverse method (#2157)
- Added *Interrupted Goode Homolosine (Oceanic View)* projection (#2226)
- Add *Winkel II* inverse by generic inversion of forward method (#2243)

- **Database**
  - Update to EPSG 9.8.12, ESRI 10.8.1 and import scope and remarks for conversion (#2238) (#2267)
  - Map the Behrmann projection to `cae` when converting ESRI CRSes (#1986)
  - Support conversion of Flat_Polar_Quartic projection method (#1987)
  - Register 4 new Austrian height grids (see https://github.com/OSGeo/PROJ-data/pull/13) and handle 'Vertical Offset by Grid Interpolation (BEV AT)' method (#1989)
  - Add ESRI projection method mappings for Mercator_Variant_A, Mercator_Variant_B and Transverse_Cylindrical_Equal_Area and various grid mappings (#2020) (#2195)
  - Map ESRI Transverse_Mercator_Complex to Transverse Mercator (#2040)
  - Register grids for New Caledonia (see https://github.com/OSGeo/PROJ-data/pull/16) (#2051) (#2239)
  - Register NZGD2000 -> ITRF96 transformation for NZGD2000 database (#2248)
  - Register geoid file for UK added (see https://github.com/OSGeo//PROJ-data/pull/25() (#2250)
  - Register Slovakian geoid transformations with needed code changes (#2259)
  - Register Spanish SPED2ETV2 grid for ED50->ETRS89 (#2261)
- **API**
  - Add API function `proj_get_units_from_database()` (#2065)
  - Add API function `proj_get_suggested_operation()` (#2068)
  - Add API functions `proj_degree_input()` and `proj_degree_output()` (#2144)
  - Moved `proj_context_get_url_endpoint()` & `proj_context_get_user_writable_directory()` from `proj_experimental.h` to `proj.h` (#2162)
  - `createFromUserInput()`: allow compound CRS with the 2 parts given by names, e.g. 'WGS 84 + EGM96 height' (#2126)
  - `createOperations()`: when converting CompoundCRS<–>Geographic3DCrs, do not use discard change of ellipsoidal height if a Helmert transformation is involved (#2227)
- **Optimizations**
  - `tmerc/utm`: add a +algo=auto/evenden_snyder/poder_engsager parameter (#2030)
  - Extended `tmerc` (Poder/Engsager): speed optimizations (#2036)
  - Approximate `tmerc` (Snyder): speed optimizations (#2039)
  - `pj_phi2()`: speed-up computation (and thus inverse ellipsoidal Mercator and LCC) (#2052)
  - Inverse `cart`: speed-up computation by 33% (#2145)
  - Extended `tmerc`: speed-up forward path by ~5% (#2147)
- **Various**

  - Follow PDAL's CMake RPATH strategy (#2009)
  - WKT import/export: add support for WKT1_ESRI VERTCS syntax (#2024)
  - **projinfo**: add a `--hide-ballpark` option (#2127)
  - **gie**: implement a strict mode with `<gie-strict> </gie-strict>` (#2168)
  - Allow importing WKT1 COMPD_CS with a VERT_DATUM[Ellipsoid,2002] (#2229)
  - Add runtime checking that sqlite3 is >= 3.11 (#2235)

2.6.2 Bug fixes

- `createOperations()`: do not remove ballpark transformation if there are only grid based operations, even if they cover the whole area of use (#2155)
- `createFromProjString()`: handle default parameters of '+krovak +type=crs', and handle `+czech` correctly (#2200)
- `ProjectedCRS::identify()`: fix identification of EPSG:3059 (#2215)
- Database: add a 'WGS84' alias for the EPSG:4326 CRS (#2218)
- Fixes related to CompoundCRS and BoundCRS (#2222)
- Avoid 2 warnings about missing database indices (#2223)
- Make `projinfo --3d --boundcrs-to-wgs84` work better (#2224)
- Many fixes regarding BoundCRS, CompoundCRS, Geographic3D CRS with non-metre units (#2234)
- Fix identification of (one of the) ESRI WKT formulations of EPSG:3035 (#2240)
- Avoid using deprecated and removed Windows API function with Mingw32 (#2246)
- `normalizeForVisualization()`: make it switch axis for EPSG:5482 (RSRGD2000 / RSPS2000) (#2256)
- Fix access violation in `proj_context_get_database_metadata()` (#2260)

2.7 7.0.1 Release Notes

May 1st 2020

2.7.1 Updates

- Database: update to EPSG v9.8.9 (#2141)

2.7.2 Bug fixes

- Make tests independent of proj-datumgrid (#1995)
- Add missing projection property tables (#1996)
- Avoid crash when running against SQLite3 binary built with `-DSQLITE_OMIT_AUTOINIT` (#1999)
- `createOperations()`: fix wrong pipeline generation with CRS that has `+nadgrids=` and `+pm=` (#2002)
- Fix bad copy&replace pattern on HEALPix and rHEALPix projection names (#2007)

- `createUnitOfMeasure()`: use full double resolution for the conversion factor (#2014)
- Update README with info on PROJ-data (#2015)
- `utm/ups`: make sure to set errno to `PJD_ERR_ELLIPSOID_USE_REQUIRED` if `+es==0` (#2045)
- `data/Makefile.am`: remove bashism (#2048)
- `ProjectedCRS::identify()`: tune it to better work with ESRI WKT representation of EPSG:2193 (#2059)
- Fix build with gcc 4.8.5 (#2066)
- Autotools/pkg-conf: Define datarootdir (#2069)
- **cs2cs**: don't require `+to` for '{source_crs} {target_crs} filename…' syntax (#2081)
- CMake: fix bug with `find_package(PROJ)` with macOS (#2082)
- ESRI WKT import / identification: special case for NAD_1983_HARN_StatePlane_Colorado_North_FIPS_0501 with Foot_US unit (#2088)
- ESRI WKT import / identification: special case for NAD_1983_HARN_StatePlane_Colorado_North_FIPS_0501 with Foot_US unit (#2089)
- EngineeringCRS: when exporting to WKT1_GDAL, output unit and axis (#2092)
- Use jtsk03-jtsk horizontal grid from CDN (#2098)
- CMake: prefer to use use PROJ_SOURCE_DIR and PROJ_BINARY_DIR (#2100)
- Fix wrong grids file name in esri.sql (#2104)
- Fix identification of projected CRS whose name is close but not strictly equal to a ESRI alias (#2106)
- Fix working of Helmert transform between the horizontal part of 2 compoundCRS (#2111)
- Database: fix registration of custom entries of grid_transformation_custom.sql for geoid grids (#2114)
- ESRI_WKT ingestion: make sure to identify to non-deprecated EPSG entry when possible (#2119)
- Make sure that importing a Projected 3D CRS from WKT:2019 keeps the base geographic CRS as 3D (#2125)
- `createOperations()`: improve results of compoundCRS to compoundCRS case (#2131)
- hgridshift/vgridshift: defer grid opening when grid has already been opened (#2132)
- Resolve a few shadowed declaration warnings (#2142)
- ProjectedCRS identification: deal with switched 1st/2nd std parallels for LCC_2SP(#2153)
- Fix Robinson inverse projection (#2154)
- `createOperations()`: do not remove ballpark transformation if there are only grid based operations, even if they cover the whole area of use (#2156)
- `createFromCoordinateReferenceSystemCodes()`: 'optimization' to avoid using C++ exceptions (#2161)
- Ingestion of WKT1_GDAL: correctly map 'Cylindrical_Equal_Area' (#2167)
- Add limited support for non-conformant WKT1 LAS COMPD_CS[] (#2172)
- PROJ4 string import: take into correctly non-metre unit when the string looks like the one for WGS 84 / Pseudo Mercator (#2177)
- `io.hpp`: avoid dependency to `proj_json_streaming_writer.hpp` (#2184)
- Fix support of WKT1_GDAL with netCDF rotated pole formulation (#2186)

2.8 6.3.2 Release Notes

May 1st 2020

2.8.1 Bug fixes

- `validateParameters()`: fix false-positive warning on Equidistant Cylindrical (#1947)
- `proj_create_crs_to_cr()`: avoid potential reprojection failures when reprojecting area of use to source and target CRS (#1993)
- `createOperations()`: fix wrong pipeline generation with CRS that has +`nadgrids`= and +`pm`= (#2003)
- Fix bad copy&replace pattern on HEALPix and rHEALPix projection names (#2006)
- `createUnitOfMeasure()`: use full double resolution for the conversion factor (#2013)
- `data/Makefile.am`: remove bashism (#2047)
- :cpp:func:`ProjectedCRS::identify`: tune it to better work with ESRI WKT representation of EPSG:2193 (#2058)
- EngineeringCRS: when exporting to WKT1_GDAL, output unit and axis (#2091)
- Add missing entries in grid_alternatives for Portugal grids coming from ESRI entries (#2103)
- Fix working of Helmert transform between the horizontal part of 2 compoundCRS (#2110)
- ESRI_WKT ingestion: make sure to identify to non-deprecated EPSG entry when possible (#2118)
- Make sure that importing a Projected 3D CRS from WKT:2019 keeps the base geographic CRS as 3D (#2124)
- `createOperations()`: improve results of compoundCRS to compoundCRS case (#2130)
- PROJ4 string import: take into correctly non-metre unit when the string looks like the one for WGS 84 / Pseudo Mercator (#2178)
- Fix support of WKT1_GDAL with netCDF rotated pole formulation (#2187)
- `io.hpp`: avoid dependency to `proj_json_streaming_writer.hpp` (#2188)

2.9 7.0.0 Release Notes

March 1st 2020

The major feature in PROJ 7 is significantly improved handling of gridded models. This was implemented in *PROJ RFC 4: Remote access to grids and GeoTIFF grids*. The main features of the RFC4 work is that PROJ now implements a new grid format, Geodetic TIFF grids, for exchanging gridded transformation models. In addition to the new grid format, PROJ can now also access grids online using a data store in the cloud.

The grids that was previously available via the proj-datumgrid packages are now available in two places:

1. As a single combined data archive including all available resource files
2. From the cloud via https://cdn.proj.org

In Addition, provided with PROJ is a utility called **`projsync`** that can be used download grids from the data store in the cloud.

The use of the new grid format and the data from the cloud requires that PROJ is build against `libtiff` and `libcurl`. Both are optional dependencies to PROJ but it is highly encouraged that the software is build against both.

> **Warning:** PROJ 7 will be last major release version that includes the `proj_api.h` header. The functionality in `proj_api.h` is deprecated and only supported in maintenance mode. It is inferior to the functionality provided by functions in the `proj.h` header and all projects still relying on `proj_api.h` are encouraged to migrate to the new API in `proj.h`. See *Version 4 to 6 API Migration*. for more info on how to migrate from the old to the new API.

2.9.1 Updates

- Added new file access API to `proj.h` (#866)
- Updated the name of the most recent version of the WKT2 standard from WKT2_2018 to WKT2_2019 to reflect the proper name of the standard (#1585)
- Improvements in transformations from/to WGS 84 (Gxxxx) realizations and vertical <-> geog transormations (#1608)
- Update to version 1.50 of the geodesic library (#1629)
- Promote `proj_assign_context()` to `proj.h` from `proj_experimental.h` (#1630)
- Add rotation support to the HEALPix projection (#1638)
- Add C function `proj_crs_create_bound_vertical_crs()` (#1689)
- Use Win32 Unicode APIs and expect all strings to be UTF-8 (#1765)
- Improved name aliases lookup (#1827)
- CMake: Employ better use of CTest with the `BUILD_TESTING` option (#1870)
- Grid correction: fix handling grids spanning antimeridian (#1882)
- Remove legacy CMake target name `proj` (#1883)
- **`projinfo`** add `--searchpaths` switch (#1892)
- Add *+proj=set operation* to set component(s) of a coordinate to a fixed value (#1896)
- Add EPSG records for 'Geocentric translation by Grid Interpolation (IGN)' (`gr3df97a.txt`) and map them to new *+proj=xyzgridshift* (#1897)
- Remove `null` grid file as it is now a special hardcoded case in grid code (#1898)
- Add **`projsync`** utility (#1903)
- Make `PROJ` the CMake project name (#1910)
- Use relative directory to locate PROJ resource files (#1921)

2.9.2 Bug fixes

- Horizontal grid shift: fix failures on points slightly outside a subgrid (#209)
- Fix ASAN issue with SQLite3VFS class (#1902)
- tests: force use of bash for `proj_add_test_script_sh` (#1905)

2.9.3 Breaking changes

- Reject NTV2 files where `GS_TYPE != SECONDS` (#1294)
- On Windows the name of the library is now fixed to `proj.lib` instead of encoding the version number in the library name (#1581)
- Require C99 compiler (#1624)
- Remove deprecated JNI bindings (#1825)
- Remove -ld option from **proj** and **cs2cs** (#1844)
- Increase CMake minimum version from 3.5 to 3.9 (#1907)

2.10 6.3.1 Release Notes

February 11th 2020

2.10.1 Updates

- Update the EPSG database to version 9.8.6
- Database: add mapping for gg10_smv2.mnt and gg10_sbv2.mnt French grids
- Database: add mapping for TOR27CSv1.GSB

2.10.2 Bug fixes

- Fix wrong use of derivingConversionRef() that caused issues with use of +init=epsg:XXXX by GDAL (affecting R spatial libraries) or in MapServer
- fix exporting CoordinateSystem to PROJ JSON with ID
- projinfo: use No. abbreviation instead of UTF-8 character (#1828)
- CompoundCRS::identify(): avoid exception when horiz/vertical part is a BoundCRS
- createOperations(): fix dealing with projected 3D CRS whose Z units != metre
- WKT1_GDAL export: limit datum name massaging to names matching EPSG (#1835)
- unitconvert with mjd time format: avoid potential integer overflow (ossfuzz 20072)
- ProjectedCRS::identify(): fix wrong identification of some ESRI WKT linked to units
- Database: add a geoid_like value for proj_method column of grid_alternatives, fix related entries and simplify/robustify logic to deal with EPSG 'Geographic3D to GravityRelatedHeight' methods
- Fix ingestion of +proj=cea with +k_0 (#1881)
- Fix performance issue, affecting PROJ.4 string generation of EPSG:7842 (#1913)
- Fix identification of ESRI-style datum names starting with D_ but without alias (#1911)
- cart: Avoid discontinuity at poles in the inverse case (#1906)
- Various updates to make regression test suite pass with gcc on i386 (#1906)

2.11 6.3.0 Release Notes

January 1st 2020

2.11.1 Updates

- Database: tune accuracy of Canadian NTv1 file w.r.t NTv2 (#1812)
- Modify verbosity level of some debug/trace messages (#1811)
- **projinfo**: no longer call createBoundCRSToWGS84IfPossible() for WKT1:GDAL (#1810)
- *proj_trans()*: add retry logic to select other transformation if the best one fails. (#1809)
- *BoundCRS::identify()*: improvements to discard CRS that aren't relevant (#1802)
- Database: update to IGNF v3.1.0 (#1785)
- Build: Only export symbols if building DLL (#1773)
- Database: update ESRI entries with ArcGIS Desktop version 10.8.0 database (#1762)
- `createOperations()`: chain operations whose middle CRSs are not identical but have the same datum (#1734)
- import/export PROJJSON: support a interpolation_crs key to geoid_model (#1732)
- Database: update to EPSG v9.8.4 (#1725)
- Build: require SQLite 3.11 (#1721)
- Add support for GEOIDMODEL (#1710)
- Better filtering based on extent and performance improvements (#1709)

2.11.2 Bug fixes

- Horizontal grid shift: fix issue on iterative inverse computation when switching between (sub)grids (#1797)
- `createOperations()`: make filtering out of 'uninteresting' operations less aggressive (#1788)
- Make EPSG:102100 resolve to ESRI:102100 (#1786)
- `ob_tran`: restore traditional handling of `+to_meter` with `pj_transform()` and **proj** utility (#1783)
- CRS identification: use case insensitive comparison for authority name (#1780)
- `normalizeForVisualization()` and other methods applying on a ProjectedCRS: do not mess the derivingConversion object of the original object (#1746)
- `createOperations()`: fix transformation computation from/to a CRS with `+geoidgrids` and `+vunits` != m (#1731)
- Fix `proj_assign_context()/pj_set_ctx()` with pipelines and alternative coord operations (#1726)
- Database: add an auxiliary concatenated_operation_step table to allow arbitrary number of steps (#1696)
- Fix errors running gie-based tests in Debug mode on Window (#1688)

2.12 6.2.1 Release Notes

November 1st 2019

2.12.1 Updates

- Update the EPSG database to version 9.8.2

2.12.2 Bug fixes

- Fixed erroneous spelling of "Potsdam" (#1573)
- Calculate y-coordinate correctly in *Bertin 1953* in all cases (#1579)
- `proj_create_crs_to_crs_from_pj()`: make the PJ* arguments const PJ* (#1583)
- *PROJStringParser::createFromPROJString()*: avoid potential infinite recursion (#1574)
- Avoid core dump when setting `ctx==NULL` in functions `proj_coordoperation_is_instantiable()` and `proj_coordoperation_has_ballpark_transformation()` (#1590)
- `createOperations()`: fix conversion from/to PROJ.4 CRS strings with non-ISO-kosher options and `+towgs84`/`+nadgrids` (#1602)
- `proj_trans_generic()`: properly set coordinate time to `HUGE_VAL` when no value is passed to the function (#1604)
- Fix support for `+proj=ob_tran +o_proj=lonlat/latlong/latlon` instead of only only allowing `+o_proj=longlat` (#1601)
- Improve backwards compatibility of vertical transforms (#1613)
- Improve emulation of deprecated `+init` style initialization (#1614)
- **cs2cs**: autopromote CRS to 3D when there's a mix of 2D and 3D (#1563)
- Avoid divisions by zero in odd situations (#1620)
- Avoid compile error on Solaris (#1639)
- `proj_create_crs_to_crs()`: fix when there are only transformations with ballpark steps (#1643)
- PROJ string CRS ingester: recognize more unit-less parameters, and general handling of `+key=string_value` parameters (#1645)
- Only call pkg-config in configure when necessary (#1652)
- *Azimuthal Equidistant*: for spherical forward path, go to higher precision ellipsoidal case when the point coordinates are super close to the origin (#1654)
- `proj_create_crs_to_crs()`: remove elimination of Ballpark operations that caused transformation failures in some cases (#1665)
- `createOperations()`: allow transforming from a compoundCRS of a bound verticalCRS to a 2D CRS (#1667)
- Avoid segfaults in case of out-of-memory situations (#1679)
- `createOperations()`: fix double vertical unit conversion from CompoundCRS to other CRS when the horizontal part of the projected CRS uses non-metre unit (#1683)(#1683)
- `importFromWkt()`: fix axis orientation for non-standard ESRI WKT (#1690)

2.13 6.2.0 Release Notes

September 1st 2019

2.13.1 Updates

- Introduced *PROJJSON*, a JSON encoding of WKT2 (#1547)
- Support CRS instantiation of OGC URN's (#1505)
- Expose scope and remarks of database objects (#1537)
- EPSG Database updated to version 9.7.0 (#1558)
- Added C API function proj_grid_get_info_from_database() (#1494)
- Added C API function proj_operation_factory_context_set_discard_superseded() (#1534)
- Added C API function proj_context_set_autoclose_database() (#1566)
- Added C API function proj_create_crs_to_crs_from_pj() (#1567)
- Added C API function proj_cleanup() (#1569)

2.13.2 Bug Fixes

- Fixed build failure on Solaris systems (#1554)

2.14 6.1.1 Release Notes

July 1st 2019

2.14.1 Updates

- Update EPSG registry to version 9.6.3 (#1485)

2.14.2 Bug Fixes

- Take the passed authority into account when identifying objects (#1466)
- Avoid exception when transforming from NAD83 to projected CRS using NAD83(2011) (#1477)
- Avoid off-by-one reading of name argument if name of resource file has length 1 (#11489)
- Do not include *PROJ_LIB* in `proj_info().searchpath` when context search path is set (#1498)
- Use correct delimiter for the current platform when parsing PROJ_LIB (#1497)
- Do not confuse 'ID74' CRS with WKT2 ID[] node (#1506)
- WKT1 importer: do case insensitive comparison for axis direction (#1509)
- Avoid compile errors on GCC 4.9.3 (#1512)
- Make sure that pipelines including `+proj=ob_tran` can be created (#1526)

2.15 6.1.0 Release Notes

May 15th 2019

2.15.1 Updates

- Include custom ellipsoid definitions from QGIS (#1137)
- Add `-k ellipsoid` option to projinfo (#1338)
- Make cs2cs support 4D coordinates (#1355)
- WKT2 parser: update to OGC 18-010r6 (#1360 #1366))
- Update internal version of googletest to v1.8.1 (#1361)
- Database update: EPSG v9.6.2 (#1462), IGNF v3.0.3, ESRI 10.7.0 and add operation_version column (#1368)
- Add `proj_normalize_for_visualization()` that attempts to apply axis ordering as used by most GIS applications and PROJ <6 (#1387)
- Added noop operation (#1391)
- Paths set by user take priority over *PROJ_LIB* for search paths (#1398)
- Reduced database size (#1438)
- add support for compoundCRS and concatenatedOperation named from their components (#1441)

2.15.2 Bug fixes

- Have **gie** return non-zero code when file can't be opened (#1312)
- CMake cross-compilation fix (#1316)
- Use 1st eccentricity instead of 2nd eccentricity in Molodensky (#1324)
- Make sure to include grids when doing Geocentric to CompoundCRS with nadgrids+geoidgrids transformations (#1326)
- Handle coordinates outside of bbox better (#1333)
- Enable system error messages in command line automatically in builds (#1336)
- Make sure to install projinfo man page with CMake (#1347)
- Add data dir to pkg-config file proj.pc (#1348)
- Fix GCC 9 warning about useless `std::move()` (#1352)
- Grid related fixes (#1369)
- Make sure that ISO19111 C++ code sets pj_errno on errors (#1405)
- vgridshift: handle longitude wrap-around for grids with 360deg longitude extent (#1429)
- **proj/cs2cs**: validate value of `-f` parameter to avoid potential crashes (#1434)
- Many division by zero and similar bug fixes found by OSS Fuzz.

2.16 6.0.0 Release Notes

March 1st 2019

PROJ 6 has undergone extensive changes to increase its functional scope from a cartographic projection engine with so-called "early-binding" geodetic datum transformation capabilities to a more complete library supporting coordinate transformations and coordinate reference systems.

As a foundation for other enhancements, PROJ now includes a C++ implementation of the modelisation propopsed by the ISO-19111:2019 standard / OGC Abstract Specification Topic 2: "Referencing By Coordinates", for geodetic reference frames (datums), coordinate reference systems and coordinate operations. Construction and query of those geodetic objects is available through a new C++ API, and also accessible for the most part from bindings in the C API.

Those geodetic objects can be imported and exported from and into the OGC Well-Known Text format (WKT) in its different variants: ESRI WKT, GDAL WKT 1, WKT2:2015 (ISO 19162:2015) and WKT2:2018 (ISO 19162:2018). Import and export of CRS objects from and into PROJ strings is also supported. This functionality was previously available in the GDAL software library (except WKT2 support which is a new feature), and is now an integral part of PROJ.

A unified database of geodetic objects, coordinate reference systems and their metadata, and coordinate operations between those CRS is now available in a SQLite3 database file, proj.db. This includes definitions imported from the IOGP EPSG dataset (v9.6.0 release), the IGNF (French national mapping agency) geodetic registry and the ESRI projection engine database. PROJ is now the reference software in the "OSGeo C stack" for this CRS and coordinate operation database, whereas previously this functionality was spread over PROJ, GDAL and libgeotiff, and used CSV or other adhoc text-based formats.

Late-binding coordinate operation capabilities, that takes metadata such as area of use and accuracy into account, has been added. This can avoid in a number of situations the past requirement of using WGS84 as a pivot system, which could cause unneeded accuracy loss, or was not doable at all sometimes when transformation to WGS84 was not available. Those late-binding capabilities are now used by the proj_create_crs_to_crs() function and the cs2cs utility.

A new command line utility, projinfo, has been added to query information about a geodetic object of the database, import and export geodetic objects from/into WKT and PROJ strings, and display coordinate operations available between two CRSs.

2.16.1 UPDATES

- Removed projects.h as a public interface (#835)
- Deprecated the proj_api.h interface. The header file is still available but will be removed with the next major version release of PROJ. It is now required to define `ACCEPT_USE_OF_DEPRECATED_PROJ_API_H` before the interface can be used (#836)
- Removed support for the nmake build system (#838)
- Removed support for the `proj_def.dat` defaults file (#201)
- C++11 required for building PROJ (#1203)
- Added build dependency on SQLite 3.7 (#1175)
- Added **`projinfo`** command line application (#1189)
- Added many functions to `proj.h` for handling ISO19111 functionality (#1175)
- Added C++ API exposing ISO19111 functionality (#1175)
- Updated **`cs2cs`** to use late-binding features (#1182)
- Removed the `nad2bin` application. Now available in the proj-datumgrid git repository (#1236)

- Removed support for Chebyshev polynomials in **proj** (#1226)
- Removed `proj_geocentric_latitude()` from *proj.h* API (#1170)
- Changed behavior of **proj**: Now only allow initialization of projections (#1162)
- Changed behavior of *tmerc*: Now defaults to the Extended Transverse Mercator algorithm (`etmerc`). Old implementation available by adding `+approx` (#404)
- Changed behavior: Default ellipsoid now set to GRS80 (was WGS84) (#1210)
- Allow multiple directories in *PROJ_LIB* environment variable (#1281)
- Added *Lambert Conic Conformal (2SP Michigan)* projection (#1142)
- Added *Bertin1953* projection (#1133)
- Added *Tobler-Mercator* projection (#1153)
- Added *Molodensky-Badekas* transform (#1160)
- Added *push* and *pop* coordinate operations (#1250)
- Removed `+t_obs` parameter from helmert and deformation (#1264)
- Added *+dt* parameter to deformation as replacement for removed `+t_obs` (#1264)

2.16.2 BUG FIXES

- Read *+towgs84* values correctly on locales not using dot as comma separator (#1136)
- Fixed file offset for reading of shift values in NTv1 files (#1144)
- Avoid problems with `PTHREAD_MUTEX_RECURSIVE` when using CMake (#1158)
- Avoid raising errors when setting ellipsoid flattening to zero (#1191)
- Fixed lower square calculations in *rHealpix* projection (#1206)
- Allow *Molodensky* transform parameters to be zero (#1194)
- Fixed wrong parameter in `ITRF2000` init file (#1240)
- Fixed use of grid paths including spaces (#1152)
- *Robinson*: fix wrong values for forward path for latitudes >= 87.5, and fix inaccurate inverse method (#1172)

2.17 PROJ 5.2.0

September 15th 2018

2.17.1 UPDATES

- Added support for deg, rad and grad in unitconvert (#1054)
- Assume *+t_epoch* as time input when not otherwise specified (#1065)
- Added inverse Lagrange projection (#1058)
- Added *+multiplier* option to vgridshift (#1072)
- Added Equal Earth projection (#1085)
- Added "require_grid" option to gie (#1088)
- Replace *+transpose* option of Helmert transform with *+convention*. From now on the convention used should be explicitly written. An error will be returned when using the +transpose option (#1091)
- Improved numerical precision of inverse spherical Mercator projection (#1105)
- **cct** will now forward text after coordinate input to output stream (#1111)

2.17.2 BUG FIXES

- Do not pivot over WGS84 when doing cs2cs-emulation with geocent (#1026)
- Do not scan past the end of the read data in `pj_ctx_fgets()` (#1042)
- Make sure *proj_errno_string()* is available in DLL (#1050)
- Respect *+to_meter* setting when doing cs2cs-emulation (#1053)
- Fixed unit conversion factors for **geod** (#1075)
- Fixed test failures related to GCC 8 (#1084)
- Improved handling of *+geoc* flag (#1093)
- Calculate correct projection factors for Webmercator (#1095)
- **cs2cs** now always outputs degrees when transformed coordinates are in angular units (#1112)

2.18 PROJ 5.1.0

June 1st 2018

2.18.1 UPDATES

- Function *proj_errno_string()* added to `proj.h` API (#847)
- Validate units between pipeline steps and ensure transformation sanity (#906)
- Print help when calling **cct** and **gie** without arguments (#907)
- *CITATION* file added to source distribution (#914)
- Webmercator operation added (#925)
- Enhanced numerical precision of forward spherical Mercator near the Equator (#928)
- Added `--skip-lines` option to **cct** (#923)
- Consistently return `NaN` values on `NaN` input (#949)

- Removed unused `src/org_proj4_Projections.h` file (#956)
- Java Native Interface bindings updated (#957, #969)
- Horizontal and vertical gridshift operations extended to the temporal domain (#1015)

2.18.2 BUG FIXES

- Handle `NaN` float cast overflow in `PJ_robin.c` and `nad_intr.c` (#887)
- Avoid overflow when Horner order is unreasonably large (#893)
- Avoid unwanted NaN conversions in etmerc (#899)
- Avoid memory failure in **gie** when not specifying x,y,z in gie files (#902)
- Avoid memory failure when *+sweep* is initialized incorrectly in geos (#908)
- Return `HUGE_VAL` on erroneous input in ortho (#912)
- Handle commented lines correctly in cct (#933)
- Avoid segmentation fault when transformation coordinates outside grid area in deformation (#934)
- Avoid doing false easting/northing adjustments on cartesian coordinates (#936)
- Thread-safe creation of proj mutex (#954)
- Avoid errors when setting up geos with +lat_0!=0 (#986)
- Reset errno when running **proj** in verbose mode (#988)
- Do not interpolate node values at nodata value in vertical grid shifts (#1004)
- Restrict Horner degrees to positive integer values to avoid memory allocation issues (#1005)

2.19 PROJ 5.0.1

March 1st 2018

2.19.1 Bug fixes

- Handle ellipsoid change correctly in pipelines when `+towgs84=0,0,0` is set (#881)
- Handle the case where nad_ctable2_init returns NULL (#883)
- Avoid shadowed declaration errors with old gcc (#880)
- Expand `+datum` properly in pipelines (#872)
- Fail gracefully when incorrect headers are encountered in grid files (#875)
- Improve roundtrip stability in pipelines using `+towgs84` (#871)
- Fixed typo in gie error codes (#861)
- Numerical stability fixes to the geodesic package (#826 & #843)
- Make sure that transient errors are returned correctly (#857)
- Make sure that locally installed header files are not used when building PROJ (#849)
- Fix inconsistent parameter names in `proj.h/proj_4D_api.c` (#842)

- Make sure `+vunits` is applied (#833)
- Fix incorrect Web Mercator transformations (#834)

2.20 PROJ 5.0.0

February 1st 2018

This version of PROJ introduces some significant extensions and improvements to (primarily) the geodetic functionality of the system.

The main driver for introducing the new features is the emergence of dynamic reference frames, the increasing use of high accuracy GNSS, and the related growing demand for accurate coordinate transformations. While older versions of PROJ included some geodetic functionality, the new framework lays the foundation for turning PROJ into a generic geospatial coordinate transformation engine.

The core of the library is still the well established projection code. The new functionality is primarily exposed in a new programming interface and a new command line utility, *cct* (for "Coordinate Conversion and Transformation"). The old programming interface is still available and can - to some extent - use the new geodetic transformation features.

The internal architecture has also seen many changes and much improvement. So far, these improvements respect the existing programming interface. But the process has revealed a need to simplify and reduce the code base, in order to support sustained active development.

Therefore we have scheduled regular releases over the coming years which will gradually remove the old programming interface.

This will cause breaking changes with the next two major version releases, which will affect all projects that depend on PROJ (cf. section "deprecations" below).

The decision to break the existing API has not been easy, but has ultimately been deemed necessary to ensure the long term survival of the project. Not only by improving the maintainability immensely, but also by extending the potential user (and hence developer) community.

The end goal is to deliver a generic coordinate transformation software package with a clean and concise code base appealing to both users and developers.

2.20.1 Versioning and naming

For the first time in more than 25 years the major version number of the software is changed. The decision to do this is based on the many new features and new API. While backwards compatibility remains - except in a few rare corner cases - the addition of a new and improved programming interface warrants a new major release.

The new major version number unfortunately leaves the project in a bit of a conundrum regarding the name. For the majority of the life-time of the product it has been known as PROJ.4, but since we have now reached version 5 the name is no longer aligned with the version number.

Hence we have decided to decouple the name from the version number and from this version and onwards the product will simply be called PROJ.

In recognition of the history of the software we are keeping PROJ.4 as the *name of the organizing project*. The same project team also produces the datum-grid package.

In summary:

- The PROJ.4 project provides the product PROJ, which is now at version 5.0.0.
- The foundational component of PROJ is the library libproj.

- Other PROJ components include the application proj, which provides a command line interface to libproj.
- The PROJ.4 project also distributes the datum-grid package, which at the time of writing is at version 1.6.0.

2.20.2 Updates

- Introduced new API in `proj.h`.
  - The new API is orthogonal to the existing `proj_api.h` API and the internally used `projects.h` API.
  - The new API adds the ability to transform spatiotemporal (4D) coordinates.
  - Functions in the new API use the `proj_` namespace.
  - Data types in the new API use the `PJ_` namespace.
- Introduced the concept of "transformation pipelines" that makes possible to do complex geodetic transformations of coordinates by daisy chaining simple coordinate operations.
- Introduced *cct*, the Coordinate Conversion and Transformation application.
- Introduced *gie*, the Geospatial Integrity Investigation Environment.
  - Selftest invoked by `-C` flag in *proj* has been removed
  - Ported approx. 1300 built-in selftests to *gie* format
  - Ported approx. 1000 tests from the gigs test framework
  - Added approx. 200 new tests
- Adopted terminology from the OGC/ISO-19100 geospatial standards series. Key definitions are:
  - At the most generic level, a *coordinate operation* is a change of coordinates, based on a one-to-one relationship, from one coordinate reference system to another.
  - A *transformation* is a coordinate operation in which the two coordinate reference systems are based on different datums, e.g. a change from a global reference frame to a regional frame.
  - A *conversion* is a coordinate operation in which both coordinate reference systems are based on the same datum, e.g. change of units of coordinates.
  - A *projection* is a coordinate conversion from an ellipsoidal coordinate system to a plane. Although projections are simply conversions according to the standard, they are treated as separate entities in PROJ as they make up the vast majority of operations in the library.
- New operations
  - *The pipeline operator* (`pipeline`)
  - **Transformations**
    * *Helmert transform* (`helmert`)
    * Horner real and complex polynomial evaluation (`horner`)
    * *Horizontal gridshift* (`hgridshift`)
    * *Vertical gridshift* (`vgridshift`)
    * *Molodensky transform* (`molodensky`)
    * *Kinematic gridshift with deformation model* (`deformation`)
  - **Conversions**
    * *Unit conversion* (`unitconvert`)

        * *Axis swap* (`axisswap`)

    – **Projections**

        * *Central Conic projection* (`ccon`)

- Significant documentation updates, including
    – Overhaul of the structure of the documentation
    – A better introduction to the use of PROJ
    – *A complete reference to the new API*
    – a complete rewrite of the section on geodesic calculations
    – Figures for all projections
- New "free format" option for operation definitions, which permits separating tokens by whitespace when specifying key/value- pairs, e.g. `proj = merc lat_0 = 45`.
- Added metadata to init-files that can be read with the `proj_init_info()` function in the new `proj.h` API.
- Added ITRF2000, ITRF2008 and ITRF2014 init-files with ITRF transformation parameters, including plate motion model parameters.
- Added ellipsoid parameters for GSK2011, PZ90 and "danish". The latter is similar to the already supported andrae ellipsoid, but has a slightly different semimajor axis.
- Added Copenhagen prime meridian.
- Updated EPSG database to version 9.2.0.
- Geodesic library updated to version 1.49.2-c.
- Support for analytical partial derivatives has been removed.
- Improved performance in Winkel Tripel and Aitoff.
- Introduced `pj_has_inverse()` function to `proj_api.h`. Checks if an operation has an inverse. Use this instead of checking whether `P->inv` exists, since that can no longer be relied on.
- ABI version number updated to 13:0:0.
- Removed support for Windows CE.
- Removed the VB6 COM interface.

2.20.3 Bug fixes

- Fixed incorrect convergence calculation in Lambert Conformal Conic. (#16)
- Handle ellipsoid parameters correctly when using `+nadgrids=@null`. (#22)
- Return correct latitude when using negative northings in Transverse Mercator. (#138)
- Return correct result at origin in inverse Mod. Stereographic of Alaska. (#161)
- Return correct result at origin in inverse Mod. Stereographic of 48 U.S. (#162)
- Return correct result at origin in inverse Mod. Stereographic of 50 U.S. (#163)
- Return correct result at origin in inverse Lee Oblated Stereographic. (#164)
- Return correct result at origin in inverse Miller Oblated Stereographic. (#165)
- Fixed scaling and wrap-around issues in Oblique Cylindrical Equal Area. (#166)

- Corrected a coefficient error in inverse Transverse Mercator. (#174)
- Respect `-r` flag when calling **proj** with `-V`. (#184)
- Remove multiplication by 2 at the equator error in Stereographic projection. (#194)
- Allow +alpha=0 and +gamma=0 when using Oblique Mercator. (#195)
- Return correct result of inverse Oblique Mercator when alpha is between 90 and 270. (#331)
- Avoid segmentation fault when accessing point outside grid. (#396)
- Avoid segmentation fault on NaN input in Robin inverse. (#463)
- Very verbose use of **proj** (`-V`) on Windows is fixed. (#484)
- Fixed memory leak in General Oblique Transformation. (#497)
- Equations for meridian convergence and partial derivatives have been corrected for non-conformal projections. (#526)
- Fixed scaling of cartesian coordinates in `pj_transform()`. (#726)
- Additional bug fixes courtesy of Google's OSS-Fuzz program

CHAPTER

THREE

DOWNLOAD

Here you can download current and previous releases of PROJ. We only supply a distribution of the source code and various resource file archives. See *Installation* for information on how to get pre-built packages of PROJ.

3.1 Current Release

- **2021-05-05** proj-8.0.1.tar.gz (md5)
- **2021-05-05** proj-data-1.6.tar.gz

Note: The proj-datumgrid packages have been deprecated with PROJ 7.0.0. The proj-data package should be used with PROJ 7.0.0 and newer

The proj-datumgrid packages should be used with PROJ releases from the 5.x and 6.x branches.

3.2 Past Releases

- **2021-03-01** proj-8.0.0.tar.gz
- **2021-01-01** proj-7.2.1.tar.gz
- **2020-11-01** proj-7.2.0.tar.gz
- **2020-09-01** proj-7.1.1.tar.gz
- **2020-07-01** proj-7.1.0.tar.gz
- **2020-05-01** proj-6.3.2.tar.gz
- **2020-05-01** proj-7.0.1.tar.gz
- **2020-03-01** proj-7.0.0.tar.gz
- **2020-02-11** proj-6.3.1.tar.gz
- **2020-01-01** proj-6.3.0.tar.gz
- **2019-11-01** proj-6.2.1.tar.gz
- **2019-09-01** proj-6.2.0.tar.gz
- **2019-07-01** proj-6.1.1.tar.gz
- **2019-05-15** proj-6.1.0.tar.gz

- **2019-03-01** proj-6.0.0.tar.gz
- **2018-09-15** proj-5.2.0.tar.gz
- **2018-06-01** proj-5.1.0.tar.gz
- **2018-04-01** proj-5.0.1.tar.gz
- **2018-03-01** proj-5.0.0.tar.gz
- **2016-09-02** proj-4.9.3.tar.gz
- **2015-09-13** proj-4.9.2.tar.gz
- **2015-03-04** proj-4.9.1.tar.gz
- **2021-03-01** proj-data-1.5.tar.gz
- **2021-01-01** proj-data-1.4.tar.gz
- **2020-11-01** proj-data-1.3.tar.gz
- **2020-09-01** proj-data-1.2.tar.gz
- **2020-05-01** proj-data-1.1.tar.gz
- **2020-03-01** proj-data-1.0.tar.gz
- **2018-09-15** proj-datumgrid-1.8.zip
- **2020-03-01** proj-datumgrid-europe-1.6.zip
- **2020-03-01** proj-datumgrid-north-america-1.4.zip
- **2020-03-01** proj-datumgrid-oceania-1.2.zip
- **2019-03-01** proj-datumgrid-world-1.0.zip
- **2018-03-01** proj-datumgrid-1.7.zip
- **2016-09-11** proj-datumgrid-1.6.zip
- **2019-09-01** proj-datumgrid-europe-1.5.zip
- **2019-09-01** proj-datumgrid-europe-1.4.zip
- **2019-07-01** proj-datumgrid-europe-1.3.zip
- **2019-03-01** proj-datumgrid-europe-1.2.zip
- **2018-09-15** proj-datumgrid-europe-1.1.zip
- **2018-03-01** proj-datumgrid-europe-1.0.zip
- **2019-03-01** proj-datumgrid-north-america-1.3.zip
- **2019-03-01** proj-datumgrid-north-america-1.2.zip
- **2018-09-15** proj-datumgrid-north-america-1.1.zip
- **2018-03-01** proj-datumgrid-north-america-1.0.zip
- **2018-03-01** proj-datumgrid-oceania-1.1.zip
- **2018-03-01** proj-datumgrid-oceania-1.0.zip

CHAPTER

FOUR

INSTALLATION

These pages describe how to install PROJ on your computer without compiling it yourself. Below are guides for installing on Windows, Linux and Mac OS X. This is a good place to get started if this is your first time using PROJ. More advanced users may want to compile the software themselves.

4.1 Installation from package management systems

4.1.1 Cross platform

PROJ is also available via cross platform package managers.

4.1.1.1 Conda

The conda package manager includes several PROJ packages. We recommend installing from the `conda-forge` channel:

```
conda install -c conda-forge proj
```

Using `conda` you can also install the PROJ data package. Here's how to install the *proj-data* package:

```
conda install -c conda-forge proj-data
```

Available is also the legacy packages `proj-datumgrid-europe`, `proj-datumgrid-north-america`, `proj-datumgrid-oceania` and `proj-datumgrid-world`.

Tip: Read more about the various datumgrid packages available *here*.

4.1.1.2 Docker

A Docker image with just PROJ binaries and a full compliment of grid shift files is available on DockerHub. Get the package with:

```
docker pull osgeo/proj
```

4.1.2 Windows

The simplest way to install PROJ on Windows is to use the OSGeo4W software distribution. OSGeo4W provides easy access to many popular open source geospatial software packages. After installation you can use PROJ from the OSGeo4W shell. To install PROJ do the following:

Note: If you have already installed software via OSGeo4W on your computer, or if you have already installed QGIS on your computer, it is likely that PROJ is already installed. Type "OSGeo4W Shell" in your start menu and check whether that gives a match.

1. Download either the 32 bit or 64 bit installer.
2. Run the OSGeo4W setup program.
3. Select "Advanced Install" and press Next.
4. Select "Install from Internet" and press Next.
5. Select a installation directory. The default suggestion is fine in most cases. Press Next.
6. Select "Local package directory". The default suggestion is fine in most cases. Press Next.
7. Select "Direct connection" and press Next.
8. Choose the download.osgeo.org server and press Next.
9. Find "proj" under "Commandline_Utilities" and click the package in the "New" column until the version you want to install appears.
10. Press next to install PROJ.

You should now have a "OSGeo" menu in your start menu. Within that menu you can find the "OSGeo4W Shell" where you have access to all the OSGeo4W applications, including proj.

For those who are more inclined to the command line, steps 2–10 above can be accomplished by executing the following command:

```
C:\temp\osgeo4w-setup-x86-64.exe -q -k -r -A -s https://download.osgeo.org/osgeo4w/ -a␣
↪x86_64 -P proj
```

4.1.3 Linux

How to install PROJ on Linux depends on which distribution you are using. Below is a few examples for some of the more common Linux distributions:

4.1.3.1 Debian

On Debian and similar systems (e.g. Ubuntu) the APT package manager is used:

```
sudo apt-get install proj-bin
```

4.1.3.2 Fedora

On Fedora the **dnf** package manager is used:

```
sudo dnf install proj
```

4.1.3.3 Red Hat

On Red Hat based system packages are installed with **yum**:

```
sudo yum install proj
```

4.1.4 Mac OS X

On OS X PROJ can be installed via the Homebrew package manager:

```
brew install proj
```

PROJ is also available from the MacPorts system:

```
sudo ports install proj
```

4.2 Compilation and installation from source code

The classic way of installing PROJ is via the source code distribution. The most recent version is available from the *download page*.

The following guides show how to compile and install the software using the Autotools and CMake build systems.

4.2.1 Build requirements

- C99 compiler
- C++11 compiler
- SQLite3 >= 3.11 (headers, library and executable)
- libtiff >= 4.0 (headers and library)
- optional (but recommended): curl >= 7.29.0
- GNU make for autotools build or CMake >= 3.9

4.2.2 Autotools

FSF's configuration procedure is used to ease installation of the PROJ system.

Note: The Autotools build system is only available on UNIX-like systems. Follow the CMake installation guide if you are not using a UNIX-like operating system.

The default destination path prefix for installed files is `/usr/local`. Results from the installation script will be placed into subdirectories `bin`, `include`, `lib`, and `man/man1`. If this default path prefix is proper, then execute:

```
./configure
```

If another path prefix is required, then execute:

```
./configure --prefix=/my/path
```

In either case, the directory of the prefix path must exist and be writable by the installer.

If you are building from the git repository you have to first run:

```
./autogen.sh
```

which will generate a configure script that can be used as described above.

With the data files in place we can now build and install PROJ:

```
make
make install
```

The install target will create, if necessary, all required sub-directories.

Tests are run with:

```
make check
```

With a successful install of PROJ we can now install data files using the **projsync** utility:

```
projsync --system-directory
```

which will download all resource files currently available for PROJ. If less than the entire collection of resource files is needed the call to **projsync** can be modified to suit the users needs. See *projsync* for more options.

Note: The use of **projsync** requires that network support is enabled (the default option). If the resource files are not installed using **projsync** PROJ will attempt to fetch them automatically when a transformation needs a specific data file. This requires that *PROJ_NETWORK* is set to `ON`.

As an alternative on systems where network access is disabled, the *proj-data* package can be downloaded and added to the *PROJ_LIB* directory.

4.2.2.1 Autotools configure options

Most POSIX systems may not require any options to `./configure` if all PROJ requirements are met, installed into common directories, and a "default" behavior is desired.

Some influential environment variables are used by `./configure`, with no expected defaults:

CC

C compiler command.

CFLAGS

C compiler flags.

CXX

C++ compiler command.

CXXFLAGS

C++ compiler flags

See `./configure --help` for all options, here are a few key options:

--enable-lto

Enable compiler's Link Time Optimization, default disabled.

--disable-tiff

TIFF support is enabled by default to use PROJ-data resource files, but this can be disabled, if required.

--with-curl=ARG

Enable CURL support (`ARG=path` to `curl-config`).

--without-mutex

Disable real mutex locks (lacking pthreads).

4.2.3 CMake

With the CMake build system you can compile and install PROJ on more or less any platform. After unpacking the source distribution archive step into the source- tree:

```
cd proj-8.0
```

Create a build directory and step into it:

```
mkdir build
cd build
```

From the build directory you can now configure CMake, build and install the binaries:

```
cmake ..
cmake --build .
cmake --build . --target install
```

On Windows, one may need to specify generator:

```
cmake -G "Visual Studio 15 2017" ..
```

If the SQLite3 dependency is installed in a custom location, specify the paths to the include directory and the library:

```
cmake -DSQLITE3_INCLUDE_DIR=/opt/SQLite/include -DSQLITE3_LIBRARY=/opt/SQLite/lib/
↪libsqlite3.so ..
```

Alternatively, the custom prefix for SQLite3 can be specified:

```
cmake -DCMAKE_PREFIX_PATH=/opt/SQLite ..
```

Tests are run with:

```
ctest
```

With a successful install of PROJ we can now install data files using the **projsync** utility:

```
projsync --system-directory
```

which will download all resource files currently available for PROJ. If less than the entire collection of resource files is needed the call to **projsync** can be modified to suit the users needs. See *projsync* for more options.

Note: The use of **projsync** requires that network support is enabled (the default option). If the resource files are not installed using **projsync** PROJ will attempt to fetch them automatically when a transformation needs a specific data file. This requires that *PROJ_NETWORK* is set to `ON`.

As an alternative on systems where network access is disabled, the *proj-data* package can be downloaded and added to the *PROJ_LIB* directory.

4.2.3.1 CMake configure options

Options to configure a CMake are provided using `-D<var>=<value>`. All cached entries can be viewed using `cmake -LAH` from a build directory.

BUILD_CCT=ON
: Build *cct*, default ON.

BUILD_CS2CS=ON
: Build *cs2cs*, default ON.

BUILD_GEOD=ON
: Build *geod*, default ON.

BUILD_GIE=ON
: Build *gie*, default ON.

BUILD_PROJ=ON
: Build *proj*, default ON.

BUILD_PROJINFO=ON
: Build *projinfo*, default ON.

BUILD_PROJSYNC=ON
: Build *projsync*, default ON.

BUILD_SHARED_LIBS

Build PROJ library shared. Default for Windows is OFF, building only a static library. Default for all others is ON. See also the CMake documentation for BUILD_SHARED_LIBS.

Changed in version 7.0: Renamed from `BUILD_LIBPROJ_SHARED`

BUILD_TESTING=ON

CTest option to build the testing tree, which also downloads and installs Googletest. Default is ON, but can be turned OFF if tests are not required.

Changed in version 7.0: Renamed from `PROJ_TESTS`

CMAKE_BUILD_TYPE

Choose the type of build, options are: None (default), Debug, Release, RelWithDebInfo, or MinSizeRel. See also the CMake documentation for CMAKE_BUILD_TYPE.

Note: A default build is not optimized without specifying `-DCMAKE_BUILD_TYPE=Release` (or similar) during configuration, or by specifying `--config Release` with CMake multi-configuration build tools (see example below).

CMAKE_C_COMPILER

C compiler. Ignored for some generators, such as Visual Studio.

CMAKE_C_FLAGS

Flags used by the C compiler during all build types. This is initialized by the *CFLAGS* environment variable.

CMAKE_CXX_COMPILER

C++ compiler. Ignored for some generators, such as Visual Studio.

CMAKE_CXX_FLAGS

Flags used by the C++ compiler during all build types. This is initialized by the *CXXFLAGS* environment variable.

CMAKE_INSTALL_PREFIX

Default for Windows is based on the environment variable `OSGEO4W_ROOT` (if set), otherwise is `c:/OSGeo4W`. Default for Unix-like is `/usr/local/`.

ENABLE_IPO=OFF

Build library using the compiler's interprocedural optimization (IPO), if available, default OFF.

Changed in version 7.0: Renamed from `ENABLE_LTO`.

EXE_SQLITE3

Path to an `sqlite3` or `sqlite3.exe` executable.

SQLITE3_INCLUDE_DIR

Path to an include directory with the `sqlite3.h` header file.

SQLITE3_LIBRARY

Path to a shared or static library file, such as `sqlite3.dll`, `libsqlite3.so`, `sqlite3.lib` or other name.

ENABLE_CURL=ON

Enable CURL support, default ON.

CURL_INCLUDE_DIR

Path to an include directory with the `curl` directory.

CURL_LIBRARY
Path to a shared or static library file, such as `libcurl.dll`, `libcurl.so`, `libcurl.lib`, or other name.

ENABLE_TIFF=ON
Enable TIFF support to use PROJ-data resource files, default ON.

TIFF_INCLUDE_DIR
Path to an include directory with the `tiff.h` header file.

TIFF_LIBRARY_RELEASE
Path to a shared or static library file, such as `tiff.dll`, `libtiff.so`, `tiff.lib`, or other name. A similar variable `TIFF_LIBRARY_DEBUG` can also be specified to a similar library for building Debug releases.

4.2.4 Building on Windows with vcpkg and Visual Studio 2017 or 2019

This method is the preferred one to generate Debug and Release builds.

4.2.4.1 Install git

Install git

4.2.4.2 Install Vcpkg

Assuming there is a c:\dev directory

```
cd c:\dev
git clone https://github.com/Microsoft/vcpkg.git

cd vcpkg
.\bootstrap-vcpkg.bat
```

4.2.4.3 Install PROJ dependencies

```
vcpkg.exe install sqlite3[core,tool]:x86-windows tiff:x86-windows curl:x86-windows
vcpkg.exe install sqlite3[core,tool]:x64-windows tiff:x64-windows curl:x64-windows
```

Note: The tiff and curl dependencies are only needed since PROJ 7.0

4.2.4.4 Checkout PROJ sources

```
cd c:\dev
git clone https://github.com/OSGeo/PROJ.git
```

4.2.4.5 Build PROJ

```
cd c:\dev\PROJ
mkdir build_vs2019
cd build_vs2019
cmake -DCMAKE_TOOLCHAIN_FILE=C:\dev\vcpkg\scripts\buildsystems\vcpkg.cmake ..
cmake --build . --config Debug -j 8
```

4.2.4.6 Run PROJ tests

```
cd c:\dev\PROJ\build_vs2019
ctest -V --build-config Debug
```

4.2.5 Building on Windows with Conda dependencies and Visual Studio 2017 or 2019

Variant of the above method but using Conda for SQLite3, TIFF and CURL dependencies. It is less appropriate for Debug builds of PROJ than the method based on vcpkg.

4.2.5.1 Install git

Install git

4.2.5.2 Install miniconda

Install miniconda

4.2.5.3 Install PROJ dependencies

Start a Conda enabled console and assuming there is a c:\dev directory

```
cd c:\dev
conda create --name proj
conda activate proj
conda install sqlite libtiff curl cmake
```

Note: The libtiff and curl dependencies are only needed since PROJ 7.0

4.2.5.4 Checkout PROJ sources

```
cd c:\dev
git clone https://github.com/OSGeo/PROJ.git
```

4.2.5.5 Build PROJ

From a Conda enabled console

```
conda activate proj
cd c:\dev\PROJ
call "C:\Program Files (x86)\Microsoft Visual Studio\2017\Community\VC\Auxiliary\Build\
↪vcvars64.bat"
cmake -S . -B _build.vs2019 -DCMAKE_LIBRARY_PATH:FILEPATH="%CONDA_PREFIX%/Library/lib" -
↪DCMAKE_INCLUDE_PATH:FILEPATH="%CONDA_PREFIX%/Library/include"
cmake --build _build.vs2019 --config Release -j 8
```

4.2.5.6 Run PROJ tests

```
cd c:\dev\PROJ
cd _build.vs2019
ctest -V --build-config Release
```

CHAPTER

FIVE

USING PROJ

The main purpose of PROJ is to transform coordinates from one coordinate reference system to another. This can be achieved either with the included command line applications or the C API that is a part of the software package.

5.1 Quick start

Coordinate transformations are defined by, what in PROJ terminology is known as, "proj-strings". A proj-string describes any transformation regardless of how simple or complicated it might be. The simplest case is projection of geodetic coordinates. This section focuses on the simpler cases and introduces the basic anatomy of the proj-string. The complex cases are discussed in *Geodetic transformation*.

A proj-strings holds the parameters of a given coordinate transformation, e.g.

```
+proj=merc +lat_ts=56.5 +ellps=GRS80
```

I.e. a proj-string consists of a projection specifier, `+proj`, a number of parameters that applies to the projection and, if needed, a description of a datum shift. In the example above geodetic coordinates are transformed to projected space with the *Mercator projection* with the latitude of true scale at 56.5 degrees north on the GRS80 ellipsoid. Every projection in PROJ is identified by a shorthand such as `merc` in the above example.

By using the above projection definition as parameters for the command line utility **proj** we can convert the geodetic coordinates to projected space:

```
$ proj +proj=merc +lat_ts=56.5 +ellps=GRS80
```

If called as above **proj** will be in interactive mode, letting you type the input data manually and getting a response presented on screen. **proj** works as any UNIX filter though, which means that you can also pipe data to the utility, for instance by using the **echo** command:

```
$ echo 55.2 12.2 | proj +proj=merc +lat_ts=56.5 +ellps=GRS80
3399483.80      752085.60
```

PROJ also comes bundled with the **cs2cs** utility which is used to transform from one coordinate reference system to another. Say we want to convert the above Mercator coordinates to UTM, we can do that with **cs2cs**:

```
$ echo 3399483.80 752085.60 | cs2cs +proj=merc +lat_ts=56.5 +ellps=GRS80 +to +proj=utm␣
↪+zone=32
6103992.36      1924052.47 0.00
```

Notice the `+to` parameter that separates the source and destination projection definitions.

If you happen to know the EPSG identifiers for the two coordinates reference systems you are transforming between you can use those with **cs2cs**:

```
$ echo 56 12 | cs2cs +init=epsg:4326 +to +init=epsg:25832
231950.54      1920310.71 0.00
```

In the above example we transform geodetic coordinates in the WGS84 reference frame to UTM zone 32N coordinates in the ETRS89 reference frame. UTM coordinates

5.2 Cartographic projection

The foundation of PROJ is the large number of *projections* available in the library. This section is devoted to the generic parameters that can be used on any projection in the PROJ library.

Below is a list of PROJ parameters which can be applied to most coordinate system definitions. This table does not attempt to describe the parameters particular to particular projection types. These can be found on the pages documenting the individual *projections*.

Parameter	Description
+a	Semimajor radius of the ellipsoid axis
+axis	Axis orientation
+b	Semiminor radius of the ellipsoid axis
+ellps	Ellipsoid name (see `proj -le`)
+k	Scaling factor (deprecated)
+k_0	Scaling factor
+lat_0	Latitude of origin
+lon_0	Central meridian
+lon_wrap	Center longitude to use for wrapping (see below)
+over	Allow longitude output outside -180 to 180 range, disables wrapping (see below)
+pm	Alternate prime meridian (typically a city name, see below)
+proj	Projection name (see `proj -l`)
+units	meters, US survey feet, etc.
+vunits	vertical units.
+x_0	False easting
+y_0	False northing

In the sections below most of the parameters are explained in details.

5.2.1 Units

Horizontal units can be specified using the `+units` keyword with a symbolic name for a unit (i.e. `us-ft`). Alternatively the translation to meters can be specified with the `+to_meter` keyword (i.e. 0.304800609601219 for US feet). The `-lu` argument to **cs2cs** or **proj** can be used to list symbolic unit names. The default unit for projected coordinates is the meter. A few special projections deviate from this behavior, most notably the latlong pseudo-projection that returns degrees.

Vertical (Z) units can be specified using the `+vunits` keyword with a symbolic name for a unit (i.e. `us-ft`). Alternatively the translation to meters can be specified with the `+vto_meter` keyword (i.e. 0.304800609601219 for US feet). The `-lu` argument to **cs2cs** or **proj** can be used to list symbolic unit names. If no vertical units are specified, the vertical units will default to be the same as the horizontal coordinates.

Note: **proj** does not handle vertical units at all and hence the `+vto_meter` argument will be ignored.

Scaling of output units can be done by applying the +k_0 argument. The returned coordinates are scaled by the value assigned with the +k_0 parameter.

5.2.2 False Easting/Northing

Virtually all coordinate systems allow for the presence of a false easting (+x_0) and northing (+y_0). Note that these values are always expressed in meters even if the coordinate system is some other units. Some coordinate systems (such as UTM) have implicit false easting and northing values.

5.2.3 Longitude Wrapping

By default PROJ wraps output longitudes in the range -180 to 180. The +over switch can be used to disable the default wrapping which is done at a low level in pj_inv(). This is particularly useful with projections like the *equidistant cylindrical* where it would be desirable for X values past -20000000 (roughly) to continue past -180 instead of wrapping to +180.

The +lon_wrap option can be used to provide an alternative means of doing longitude wrapping within pj_transform(). The argument to this option is a center longitude. So +lon_wrap=180 means wrap longitudes in the range 0 to 360. Note that +over does **not** disable +lon_wrap.

5.2.4 Prime Meridian

A prime meridian may be declared indicating the offset between the prime meridian of the declared coordinate system and that of greenwich. A prime meridian is declared using the "pm" parameter, and may be assigned a symbolic name, or the longitude of the alternative prime meridian relative to greenwich.

Currently prime meridian declarations are only utilized by the pj_transform() API call, not the pj_inv() and pj_fwd() calls. Consequently the user utility **cs2cs** does honour prime meridians but the **proj** user utility ignores them.

The following predeclared prime meridian names are supported. These can be listed using with cs2cs -lm.

Meridian	Longitude
greenwich	0dE
lisbon	9d07'54.862"W
paris	2d20'14.025"E
bogota	74d04'51.3"E
madrid	3d41'16.48"W
rome	12d27'8.4"E
bern	7d26'22.5"E
jakarta	106d48'27.79"E
ferro	17d40'W
brussels	4d22'4.71"E
stockholm	18d3'29.8"E
athens	23d42'58.815"E
oslo	10d43'22.5"E

Example of use. The location long=0, lat=0 in the greenwich based lat/long coordinates is translated to lat/long coordinates with Madrid as the prime meridian.

```
cs2cs +proj=latlong +datum=WGS84 +to +proj=latlong +datum=WGS84 +pm=madrid
0 0
3d41'16.48"E    0dN 0.000
```

5.2.5 Axis orientation

Starting in PROJ 4.8.0, the +axis argument can be used to control the axis orientation of the coordinate system. The default orientation is "easting, northing, up" but directions can be flipped, or axes flipped using combinations of the axes in the +axis switch. The values are:

- "e" - Easting
- "w" - Westing
- "n" - Northing
- "s" - Southing
- "u" - Up
- "d" - Down

They can be combined in +axis in forms like:

- `+axis=enu` - the default easting, northing, elevation.
- `+axis=neu` - northing, easting, up - useful for "lat/long" geographic coordinates, or south orientated transverse mercator.
- `+axis=wnu` - westing, northing, up - some planetary coordinate systems have "west positive" coordinate systems

Note: The `+axis` argument does not work with the **`proj`** command line utility.

5.3 Geodetic transformation

PROJ can do everything from the most simple projection to very complex transformations across many reference frames. While originally developed as a tool for cartographic projections, PROJ has over time evolved into a powerful generic coordinate transformation engine that makes it possible to do both large scale cartographic projections as well as coordinate transformation at a geodetic high precision level. This chapter delves into the details of how geodetic transformations of varying complexity can be performed.

In PROJ, two frameworks for geodetic transformations exists, the *PROJ 4.x/5.x* / **`cs2cs`** / `pj_transform()` framework and the *transformation pipelines* framework. The first is the original, and limited, framework for doing geodetic transforms in PROJ The latter is a newer addition that aims to be a more complete transformation framework. Both are described in the sections below. Large portions of the text are based on [EversKnudsen2017].

Before describing the details of the two frameworks, let us first remark that most cases of geodetic transformations can be expressed as a series of elementary operations, the output of one operation being the input of the next. E.g. when going from UTM zone 32, datum ED50, to UTM zone 32, datum ETRS89, one must, in the simplest case, go through 5 steps:

1. Back-project the UTM coordinates to geographic coordinates
2. Convert the geographic coordinates to 3D cartesian geocentric coordinates
3. Apply a Helmert transformation from ED50 to ETRS89

4. Convert back from cartesian to geographic coordinates
5. Finally project the geographic coordinates to UTM zone 32 planar coordinates.

5.3.1 Transformation pipelines

The homology between the above steps and a Unix shell style pipeline is evident. It is there the main architectural inspiration behind the transformation pipeline framework. The pipeline framework is realized by utilizing a special "projection", that takes as its user supplied arguments, a series of elementary operations, which it strings together in order to implement the full transformation needed. Additionally, a number of elementary geodetic operations, including Helmert transformations, general high order polynomial shifts and the Molodensky transformation are available as part of the pipeline framework. In anticipation of upcoming support for full time-varying transformations, we also introduce a 4D spatiotemporal data type, and a programming interface (API) for handling this.

The Molodensky transformation converts directly from geodetic coordinates in one datum, to geodetic coordinates in another datum, while the (typically more accurate) Helmert transformation converts from 3D cartesian to 3D cartesian coordinates. So when using the Helmert transformation one typically needs to do an initial conversion from geodetic to cartesian coordinates, and a final conversion the other way round, to arrive at the desired result. Fortunately, this three-step compound transformation has the attractive characteristic that each step depends only on the output of the immediately preceding step. Hence, we can build a geodetic-to-geodetic Helmert transformation by tying together the outputs and inputs of 3 steps (geodetic-to-cartesian → Helmert → cartesian-to-geodetic), pipeline style. The pipeline driver, makes this kind of chained transformations possible. The implementation is compact, consisting of just one pseudo-projection, called `pipeline`, which takes as its arguments strings of elementary projections (note: "projection" is the, slightly misleading, PROJ term used for any kind of transformation). The pipeline pseudo projection is supplemented by a number of elementary transformations, all in all providing a framework for building high accuracy solutions for a wide spectrum of geodetic tasks.

As a first example, let us take a look at the iconic *geodetic → Cartesian → Helmert → geodetic* case (steps 2 to 4 in the example in the introduction). In PROJ it can be implemented as

```
proj=pipeline
step proj=cart ellps=intl
step proj=helmert convention=coordinate_frame
     x=-81.0703  y=-89.3603  z=-115.7526
    rx=-0.48488 ry=-0.02436 rz=-0.41321  s=-0.540645
step proj=cart inv ellps=GRS80
```

The pipeline can be expanded at both ends to accommodate whatever coordinate type is needed for input and output: In the example below, we transform from the deprecated Danish System 45, a 2D system with some tension in the original defining network, to UTM zone 33, ETRS89. The tension is reduced using a polynomial transformation (the init=./s45b… step, s45b.pol is a file containing the polynomial coefficients), taking the S45 coordinates to a technical coordinate system (TC32), defined to represent "UTM zone 32 coordinates, as they would look if the Helmert transformation between ED50 and ETRS89 was perfect". The TC32 coordinates are then converted back to geodetic(ED50) coordinates, using an inverse UTM projection, further to cartesian(ED50), then to cartesian(ETRS89), using the relevant Helmert transformation, and back to geodetic(ETRS89), before finally being projected onto the UTM zone 33, ETRS89 system. All in all a 6 step pipeline, implementing a transformation with centimeter level accuracy from a deprecated system with decimeter level tensions.

```
proj=pipeline
step init=./s45b.pol:s45b_tc32
step proj=utm inv ellps=intl zone=32
step proj=cart ellps=intl
step proj=helmert convention=coordinate_frame
      x=-81.0703  y=-89.3603  z=-115.7526
```

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```
     rx=-0.48488 ry=-0.02436 rz=-0.41321 s=-0.540645
step proj=cart inv ellps=GRS80
step proj=utm ellps=GRS80 zone=33
```

With the pipeline framework spatiotemporal transformation is possible. This is possible by leveraging the time dimension in PROJ that enables 4D coordinates (three spatial components and one temporal component) to be passed through a transformation pipeline. In the example below a transformation from ITRF93 to ITRF2000 is defined. The temporal component is given as GPS weeks in the input data, but the 14-parameter Helmert transform expects temporal units in decimalyears. Hence the first step in the pipeline is the unitconvert pseudo-projection that makes sure the correct units are passed along to the Helmert transform. Most parameters of the Helmert transform are taken from [Altamimi2002], except the epoch which is the epoch of the transformation. The last step in the pipeline is converting the coordinate timestamps back to GPS weeks.

```
proj=pipeline
step proj=unitconvert t_in=gps_week t_out=decimalyear
step proj=helmert convention=coordinate_frame
     x=0.0127 y=0.0065 z=-0.0209 s=0.00195
     rx=0.00039 ry=-0.00080 rz=0.00114
     dx=-0.0029 dy=-0.0002 dz=-0.0006 ds=0.00001
     drx=0.00011 dry=0.00019 drz=-0.00007
     t_epoch=1988.0
step proj=unitconvert t_in=decimalyear t_out=gps_week
```

5.3.2 PROJ 4.x/5.x paradigm

Parameter	Description
+datum	Datum name (see `proj -ld`)
+geoidgrids	Filename of GTX grid file to use for vertical datum transforms
+nadgrids	Filename of NTv2 grid file to use for datum transforms
+towgs84	3 or 7 term datum transform parameters
+to_meter	Multiplier to convert map units to 1.0m
+vto_meter	Vertical conversion to meters

Warning: This section documents the behavior of PROJ 4.x and 5.x. In PROJ 6.x, **cs2cs** has been reworked to use *proj_create_crs_to_crs()* internally, with *late binding* capabilities, and thus is no longer constrained to using WGS84 as a pivot (also called as *early binding* method). When **cs2cs** of PROJ 6 is used with PROJ.4 expanded strings to describe the CRS, including `+towgs84`, `+nadgrids` and `+geoidgrids`, it will generally give the same results as earlier PROJ versions. When used with AUTHORITY:CODE CRS descriptions, it may return different results.

The *cs2cs* framework in PROJ 4 and 5 delivers a subset of the geodetic transformations available with the *pipeline* framework. Coordinate transformations done in this framework were transformed in a two-step process with WGS84 as a pivot datum. That is, the input coordinates are transformed to WGS84 geodetic coordinates and then transformed from WGS84 coordinates to the specified output coordinate reference system, by utilizing either the Helmert transform, datum shift grids or a combination of both. Datum shifts can be described in a proj-string with the parameters `+towgs84`, `+nadgrids` and `+geoidgrids`. An inverse transform exists for all three and is applied if specified in the input proj-string. The most common is `+towgs84`, which is used to define a 3- or 7-parameter Helmert shift from the input reference frame to WGS84. Exactly which realization of WGS84 is not specified, hence a fair amount of uncertainty is introduced in this step of the transformation. With the +nadgrids parameter a non-linear planar correction derived from interpolation in a correction grid can be applied. Originally this was implemented as a means to transform coordinates between the North American datums NAD27 and NAD83, but corrections can be applied for any datum for which a correction grid exists. The inverse transform for the horizontal grid shift is "dumb", in the sense that the correction grid is applied verbatim without taking into account that the inverse operation is non-linear. Similar to the horizontal grid correction, `+geoidgrids` can be used to perform grid corrections in the vertical component. Both grid correction methods allow inclusion of more than one grid in the same transformation

In contrast to the *transformation pipeline* framework, transformations with the *cs2cs* framework in PROJ 4 and 5 were expressed as two separate proj-strings. One proj-string *to* WGS84 and one *from* WGS84. Together they form the mapping from the source coordinate reference system to the destination coordinate reference system. When used with the **cs2cs** the source and destination CRS's are separated by the special `+to` parameter.

The following example demonstrates converting from the Greek GGRS87 datum to WGS84 with the `+towgs84` parameter.

```
cs2cs +proj=latlong +ellps=GRS80 +towgs84=-199.87,74.79,246.62
    +to +proj=latlong +datum=WGS84
20 35
20d0'5.467"E    35d0'9.575"N 0.000
```

With PROJ 6, you can simply use the following:

Note: With PROJ 6, the order of coordinates for EPSG geographic coordinate reference systems is latitude first, longitude second.

```
cs2cs "GGRS87" "WGS 84"
35 20
35d0'9.575"N    20d0'5.467"E 0.000

cs2cs EPSG:4121 EPSG:4326
35 20
35d0'9.575"N    20d0'5.467"E 0.000
```

The EPSG database provides this example for transforming from WGS72 to WGS84 using an approximated 7 parameter transformation.

```
cs2cs +proj=latlong +ellps=WGS72 +towgs84=0,0,4.5,0,0,0.554,0.219 \
    +to +proj=latlong +datum=WGS84
4 55
4d0'0.554"E     55d0'0.09"N 0.000
```

With PROJ 6, you can simply use the following (note the reversed order for latitude and longitude)

```
cs2cs "WGS 72" "WGS 84"
55 4
55d0'0.09"N 4d0'0.554"E 0.000

cs2cs EPSG:4322 EPSG:4326
55 4
55d0'0.09"N 4d0'0.554"E 0.000
```

5.3.3 Grid Based Datum Adjustments

In many places (notably North America and Australia) national geodetic organizations provide grid shift files for converting between different datums, such as NAD27 to NAD83. These grid shift files include a shift to be applied at each grid location. Actually grid shifts are normally computed based on an interpolation between the containing four grid points.

PROJ supports use of grid files for shifting between various reference frames. The grid shift table formats are CTable, NTv1 (the old Canadian format), and NTv2 (`.gsb` - the new Canadian and Australian format).

The text in this section is based on the *cs2cs* framework. Gridshifting is off course also possible with the *pipeline* framework. The major difference between the two is that the *cs2cs* framework is limited to grid mappings to WGS84, whereas with *transformation pipelines* it is possible to perform grid shifts between any two reference frames, as long as a grid exists.

Use of grid shifts with **cs2cs** is specified using the `+nadgrids` keyword in a coordinate system definition. For example:

```
% cs2cs +proj=latlong +ellps=clrk66 +nadgrids=ntv1_can.dat \
    +to +proj=latlong +ellps=GRS80 +datum=NAD83 << EOF
-111 50
EOF
111d0'2.952"W   50d0'0.111"N 0.000
```

In this case the `/usr/local/share/proj/ntv1_can.dat` grid shift file was loaded, and used to get a grid shift value for the selected point.

It is possible to list multiple grid shift files, in which case each will be tried in turn till one is found that contains the point being transformed.

```
cs2cs +proj=latlong +ellps=clrk66 \
          +nadgrids=conus,alaska,hawaii,stgeorge,stlrnc,stpaul \
    +to +proj=latlong +ellps=GRS80 +datum=NAD83 << EOF
-111 44
EOF
111d0'2.788"W   43d59'59.725"N 0.000
```

5.3.3.1 Skipping Missing Grids

The special prefix `@` may be prefixed to a grid to make it optional. If it not found, the search will continue to the next grid. Normally any grid not found will cause an error. For instance, the following would use the `ntv2_0.gsb` file if available, otherwise it would fallback to using the `ntv1_can.dat` file.

```
cs2cs +proj=latlong +ellps=clrk66 +nadgrids=@ntv2_0.gsb,ntv1_can.dat \
    +to +proj=latlong +ellps=GRS80 +datum=NAD83 << EOF
-111 50
EOF
111d0'3.006"W   50d0'0.103"N 0.000
```

5.3.3.2 The null Grid

A special `null` grid shift file is distributed with PROJ. This file provides a zero shift for the whole world. It may be listed at the end of a nadgrids file list if you want a zero shift to be applied to points outside the valid region of all the other grids. Normally if no grid is found that contains the point to be transformed an error will occur.

```
cs2cs +proj=latlong +ellps=clrk66 +nadgrids=conus,null \
    +to +proj=latlong +ellps=GRS80 +datum=NAD83 << EOF
-111 45
EOF
111d0'3.006"W   50d0'0.103"N 0.000

cs2cs +proj=latlong +ellps=clrk66 +nadgrids=conus,null \
    +to +proj=latlong +ellps=GRS80 +datum=NAD83 << EOF
-111 44
-111 55
EOF
111d0'2.788"W   43d59'59.725"N 0.000
111dW   55dN 0.000
```

For more information see the chapter on *Other transformation grids*.

5.3.3.3 Caveats

- Where grids overlap (such as conus and `ntv1_can.dat` for instance) the first found for a point will be used regardless of whether it is appropriate or not. So, for instance, `+nadgrids=ntv1_can.dat`,conus would result in the Canadian data being used for some areas in the northern United States even though the conus data is the approved data to use for the area. Careful selection of files and file order is necessary. In some cases border spanning datasets may need to be pre-segmented into Canadian and American points so they can be properly grid shifted
- Additional detail on the grid shift being applied can be found by setting the PROJ_DEBUG environment variable to a value. This will result in output to stderr on what grid is used to shift points, the bounds of the various grids loaded and so forth

5.4 Environment variables

PROJ can be controlled by setting environment variables. Most users will have a use for the *`PROJ_LIB`*.

On UNIX systems environment variables can be set for a shell-session with:

```
$ export VAR="some variable"
```

or it can be set for just one command line call:

```
$ VAR="some variable" ./cmd
```

Environment variables on UNIX are usually removed with the `unset` command:

```
$ unset VAR
```

On windows systems environment variables can be set in the command line with:

```
> set VAR="some variable"
```

VAR will be available for the entire session, unless it is unset. This is done by setting the variable with no content:

```
> set VAR=
```

PROJ_LIB

The location of PROJ *resource files*.

Starting with PROJ 6, multiple directories can be specified. On Unix, they should be separated by the colon (:) character. on Windows, by the semi-colon (;) character.

PROJ is hardcoded to look for resource files in other locations as well, amongst those are the installation directory (usually `share/proj` under the PROJ installation root) and the current folder.

You can also set the location of the resource files using `proj_context_set_search_paths()` in the `proj.h` API header.

Changed in version 6.1.0: Starting with PROJ version 6.1.0, the paths set by `proj_context_set_search_paths()` will have priority over the *PROJ_LIB* to allow for multiple versions of PROJ resource files on your system without conflicting.

PROJ_DEBUG

Set the debug level of PROJ. The default debug level is zero, which results in no debug output when using PROJ. A number from 1-3, with 3 being the most verbose setting.

PROJ_NETWORK

New in version 7.0.0.

If set to ON, enable the capability to use remote grids stored on CDN (Content Delivery Network) storage, when grids are not available locally. Alternatively, the `proj_context_set_enable_network()` function can be used.

PROJ_NETWORK_ENDPOINT

New in version 7.0.0.

Define the endpoint of the CDN storage. Normally defined through the `proj.ini` configuration file locale in *PROJ_LIB*. Alternatively, the `proj_context_set_url_endpoint()` function can be used.

PROJ_CURL_CA_BUNDLE

New in version 7.2.0.

Define a custom path to the CA Bundle file. This can be useful if *curl* and *PROJ_NETWORK* are enabled. Alternatively, the `proj_curl_set_ca_bundle_path()` function can be used.

5.5 Known differences between versions

Once in a while, a new version of PROJ causes changes in the existing behavior. In this section we track deliberate changes to PROJ that break from previous behavior. Most times that will be caused by a bug fix. Unfortunately, some bugs have existed for so long that their faulty behavior is relied upon by software that uses PROJ.

Behavioural changes caused by new bugs are not tracked here, as they should be fixed in later versions of PROJ.

5.5.1 Version 4.6.0

The default datum application behavior changed with the 4.6.0 release. PROJ will now only apply a datum shift if both the source and destination coordinate system have valid datum shift information.

The PROJ 4.6.0 Release Notes states

> MAJOR: Rework `pj_transform()` to avoid applying ellipsoid to ellipsoid transformations as a datum shift when no datum info is available.

5.5.2 Version 5.0.0

5.5.2.1 Longitude wrapping when using custom central meridian

By default PROJ wraps output longitudes in the range -180 to 180. Previous to PROJ 5, this was handled incorrectly when a custom central meridian was set with *+lon_0*. This caused a change in sign on the resulting easting as seen below:

```
$ proj +proj=merc +lon_0=110
-70 0
-20037508.34    0.00
290 0
20037508.34     0.00
```

From PROJ 5 on onwards, the same input now results in same coordinates, as seen from the example below where PROJ 5 is used:

```
$ proj +proj=merc +lon_0=110
-70 0
-20037508.34    0.00
290 0
-20037508.34    0.00
```

The change is made on the basis that $\lambda = 290°$ is a full rotation of the circle larger than $\lambda = -70°$ and hence should return the same output for both.

Adding the `+over` flag to the projection definition provides the old behavior.

5.5.3 Version 6.0.0

5.5.3.1 Removal of `proj_def.dat`

Before PROJ 6, the `proj_def.dat` was used to provide general and per-projection parameters, when `+no_defs` was not specified. It has now been removed. In case, no ellipsoid or datum specification is provided in the PROJ string, the default ellipsoid is GRS80 (was WGS84 in previous PROJ versions).

5.5.3.2 Changes to deformation

Reversed order of operation

In the initial version of the of *deformation* operation the time span between t_{obs} and t_c was determined by the expression

$$dt = t_c - t_{obs}$$

With version 6.0.0 this has been reversed in order to behave similarly to the *Helmert operation*, which determines time differences as

$$dt = t_{obs} - t_c$$

Effectively this means that the direction of the operation has been reversed, so that what in PROJ 5 was a forward operation is now an inverse operation and vice versa.

Pipelines written for PROJ 5 can be migrated to PROJ 6 by adding `+inv` to forward steps involving the deformation operation. Similarly `+inv` should be removed from inverse steps to be compatible with PROJ 6.

Removed `+t_obs` parameter

The `+t_obs` parameter was confusing for users since it effectively overwrote the observation time in input coordinates. To make it more clear what is the operation is doing, users are now required to directly specify the time span for which they wish to apply a given deformation. The parameter `+dt` has been added for that purpose. The new parameter is mutually exclusive with `+t_epoch`. `+dt` is used when deformation for a set amount of time is needed and `+t_epoch` is used (in conjunction with the observation time of the input coordinate) when deformation from a specific epoch to the observation time is needed.

5.5.4 Version 6.3.0

5.5.4.1 projinfo

Before PROJ 6.3.0, WKT1:GDAL was implicitly calling `--boundcrs-to-wgs84`, to add a `TOWGS84[]` node in some cases. This is no longer the case.

5.5.5 Version 7.0.0

5.5.5.1 proj

Removed `-ld` option from application, since it promoted use of deprecated parameters like `+towgs` and `+datum`.

5.5.5.2 cs2cs

Removed `-ld` option from application, since it promoted use of deprecated parameters like `+towgs` and `+datum`.

5.5.5.3 UTF-8 adoption

The value of all path, filenames passed to PROJ through function calls, PROJ strings or environment variables should be encoded in UTF-8.

5.6 Network capabilities

New in version 7.0.

PROJ 7.0 has introduced, per *PROJ RFC 4: Remote access to grids and GeoTIFF grids*, the capability to work with grid files that are not installed on the local machine where PROJ is executed.

This enables to transparently download the parts of grids that are needed to perform a coordinate transformation.

5.6.1 CDN of GeoTIFF grids

Files are accessed by default through a CDN (Content Delivery Network), accessible through https://cdn.proj.org, that contains *Geodetic TIFF grids (GTG)* datasets which are mirrored and managed by the https://github.com/OSGeo/PROJ-data/ GitHub project. Files in the CDN are designed to be used by PROJ 7 or later, but any software project wishing to use the CDN for shifting support are encouraged to participate in the project and leverage the CDN.

5.6.2 How to enable network capabilities ?

This capability assumes that PROJ has been build against *libcurl*, and that the user authorizes network access.

Authorizing network access can be done in multiple ways:

- enabling / uncommenting the `network = on` line of *proj.ini*
- defining the `PROJ_NETWORK` environment variable to ON
- or using the `proj_context_set_enable_network()` with a `enabled = TRUE` value.

Note: Instead of using the *libcurl* implementation, an application using the PROJ API can supply its own network implementation through C function callbacks with `proj_context_set_network_callbacks()`. Enabling network use must still be done with one of the above mentioned method.

5.6.3 Setting endpoint

When this is enabled, and a grid is not found in the various locations where *resource files are looked for*, PROJ will then attempt at loading the file from a remote server, which defaults to https://cdn.proj.org in *proj.ini*. This location can be changed with the `PROJ_NETWORK_ENDPOINT` environment variable or with `proj_context_set_url_endpoint()`.

5.6.4 Caching

To avoid repeated access to network, a local cache of downloaded chunks of grids is implemented as SQLite3 database, `cache.db`, stored in the *PROJ user writable directory*.

This local caching is enabled by default (can be changed in *proj.ini* or with `proj_grid_cache_set_enable()`). The default maximum size of the cache is 300 MB, which is more than half of the total size of grids available, at time of writing. This size can also be customized in *proj.ini* or with `proj_grid_cache_set_max_size()`

5.6.5 Download API

When on-demand loading of grid is not desirable, the PROJ API also offers the capability to download whole grids in the *PROJ user writable directory* by using the `proj_is_download_needed()` and `proj_download_file()` functions.

5.6.6 Download utility

projsync is a tool for downloading resource files.

5.6.7 Mirroring

If you are able, you are encouraged to mirror the grids via AWS S3 command line:

```
aws s3 sync s3://cdn.proj.org .
```

If direct S3 access is not possible, you can also use wget to locally mirror the data:

```
wget --mirror https://cdn.proj.org/
```

5.6.8 Acknowledgments

The s3://cdn.proj.org bucket is hosted by the Amazon Public Datasets program. CDN services are provided by the AWS Public Dataset team via CloudFront

CHAPTER

SIX

APPLICATIONS

Bundled with PROJ comes a set of small command line utilities. The `proj` program is limited to converting between geographic and projection coordinates within one datum. The `cs2cs` program operates similarly, but allows translation between any pair of definable coordinate systems, including support for datum transformation. The `geod` program provides the ability to do geodesic (great circle) computations. `gie` is the program used for regression tests in PROJ. `cct`, a 4D equivalent to the `proj` program, performs transformation coordinate systems on a set of input points. `projinfo` performs queries for geodetic objects and coordinate operations. `projsync` is a tool for synchronizing PROJ datum and transformation support data.

6.1 cct

6.1.1 Synopsis

cct [**-cIostvz** [args]] *+opt[=arg]* … file …

or

cct [**-cIostvz** [args]] {object_definition} file …

Where {object_definition} is one of the possibilities accepted by `proj_create()`, provided it expresses a coordinate operation

- a proj-string,
- a WKT string,
- an object code (like "EPSG:1671" "urn:ogc:def:coordinateOperation:EPSG::1671"),
- an object name. e.g. "ITRF2014 to ETRF2014 (1)". In that case as uniqueness is not guaranteed, heuristics are applied to determine the appropriate best match.
- a OGC URN combining references for concatenated operations (e.g. "urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618")
- a PROJJSON string. The jsonschema is at https://proj.org/schemas/v0.2/projjson.schema.json

New in version 8.0.0.

Note: Before version 8.0.0 only proj-strings could be used to instantiate operations in `cct`.

or

cct [**-cIostvz** [args]] {object_reference} file …

where {object_reference} is a filename preceded by the '@' character. The file referenced by the {object_reference} must contain a valid {object_definition}.

New in version 8.0.0.

6.1.2 Description

`cct` is a 4D equivalent to the **proj** projection program, performs transformation coordinate systems on a set of input points. The coordinate system transformation can include translation between projected and geographic coordinates as well as the application of datum shifts.

The following control parameters can appear in any order:

-c <x,y,z,t>

Specify input columns for (up to) 4 input parameters. Defaults to 1,2,3,4.

-d <n>

New in version 5.2.0.

Specify the number of decimals in the output.

-I

Do the inverse transformation.

-o <output file name>, **--output**=<output file name>

Specify the name of the output file.

-t <time>, **--time**=<time>

Specify a fixed observation *time* to be used for all input data.

-z <height>, **--height**=<height>

Specify a fixed observation *height* to be used for all input data.

-s <n>, **--skip-lines**=<n>

New in version 5.1.0.

Skip the first *n* lines of input. This applies to any kind of input, whether it comes from `STDIN`, a file or interactive user input.

-v, **--verbose**

Write non-essential, but potentially useful, information to stderr. Repeat for additional information (`-vv`, `-vvv`, etc.)

--version

Print version number.

The *+opt* arguments are associated with coordinate operation parameters. Usage varies with operation.

`cct` is an acronym meaning *Coordinate Conversion and Transformation*.

The acronym refers to definitions given in the OGC 08-015r2/ISO-19111 standard "Geographical Information – Spatial Referencing by Coordinates", which defines two different classes of *coordinate operations*:

Coordinate Conversions, which are coordinate operations where input and output datum are identical (e.g. conversion from geographical to cartesian coordinates) and

Coordinate Transformations, which are coordinate operations where input and output datums differ (e.g. change of reference frame).

6.1.3 Use of remote grids

New in version 7.0.0.

If the *PROJ_NETWORK* environment variable is set to `ON`, **cct** will attempt to use remote grids stored on CDN (Content Delivery Network) storage, when they are not available locally.

More details are available in the *Network capabilities* section.

6.1.4 Examples

1. The operator specs describe the action to be performed by **cct**. So the following script

```
echo 12 55 0 0 | cct +proj=utm +zone=32 +ellps=GRS80
```

will transform the input geographic coordinates into UTM zone 32 coordinates. Hence, the command

```
echo 12 55 | cct -z0 -t0 +proj=utm +zone=32 +ellps=GRS80
```

Should give results comparable to the classic **proj** command

```
echo 12 55 | proj +proj=utm +zone=32 +ellps=GRS80
```

2. Convert geographical input to UTM zone 32 on the GRS80 ellipsoid:

```
cct +proj=utm +ellps=GRS80 +zone=32
```

3. Roundtrip accuracy check for the case above:

```
cct +proj=pipeline +proj=utm +ellps=GRS80 +zone=32 +step +step +inv
```

4. As (2) but specify input columns for longitude, latitude, height and time:

```
cct -c 5,2,1,4 +proj=utm +ellps=GRS80 +zone=32
```

5. As (2) but specify fixed height and time, hence needing only 2 cols in input:

```
cct -t 0 -z 0 +proj=utm +ellps=GRS80 +zone=32
```

6. Auxiliary data following the coordinate input is forward to the output stream:

```
$ echo 12 56 100 2018.0 auxiliary data | cct +proj=merc
1335833.8895   7522963.2411      100.0000     2018.0000 auxiliary data
```

7. Coordinate operation referenced through its code

```
$ echo 3541657.3778 948984.2343 5201383.5231 2020.5 | cct EPSG:8366
3541657.9112    948983.7503  5201383.2482     2020.5000
```

8. Coordinate operation referenced through its name

```
$ echo 3541657.3778 948984.2343 5201383.5231 2020.5 | cct "ITRF2014 to ETRF2014 (1)"
3541657.9112    948983.7503  5201383.2482     2020.5000
```

6.1.5 Background

cct also refers to Carl Christian Tscherning (1942–2014), professor of Geodesy at the University of Copenhagen, mentor and advisor for a generation of Danish geodesists, colleague and collaborator for two generations of global geodesists, Secretary General for the International Association of Geodesy, IAG (1995–2007), fellow of the American Geophysical Union (1991), recipient of the IAG Levallois Medal (2007), the European Geosciences Union Vening Meinesz Medal (2008), and of numerous other honours.

cct, or Christian, as he was known to most of us, was recognized for his good mood, his sharp wit, his tireless work, and his great commitment to the development of geodesy – both through his scientific contributions, comprising more than 250 publications, and by his mentoring and teaching of the next generations of geodesists.

As Christian was an avid Fortran programmer, and a keen Unix connoisseur, he would have enjoyed to know that his initials would be used to name a modest Unix style transformation filter, hinting at the tireless aspect of his personality, which was certainly one of the reasons he accomplished so much, and meant so much to so many people.

Hence, in honour of *cct* (the geodesist) this is **cct** (the program).

6.2 cs2cs

6.2.1 Synopsis

cs2cs [**-eEfIlrstvwW** [args]]
[[–area <name_or_code>] | [–bbox <west_long,south_lat,east_long,north_lat>]]
[–authority <name>] [–no-ballpark] [–accuracy <accuracy>]
([+*opt[=arg]* ...] [+to +*opt[=arg]* ...] | {source_crs} {target_crs})
file ...

where {source_crs} or {target_crs} is one of the possibilities accepted by `proj_create()`, provided it expresses a CRS

- a proj-string,
- a WKT string,
- an object code (like "EPSG:4326", "urn:ogc:def:crs:EPSG::4326", "urn:ogc:def:coordinateOperation:EPSG::1671"),
- an Object name. e.g "WGS 84", "WGS 84 / UTM zone 31N". In that case as uniqueness is not guaranteed, heuristics are applied to determine the appropriate best match.
- a OGC URN combining references for compound coordinate reference systems (e.g "urn:ogc:def:crs,crs:EPSG::2393,crs:EPSG::5717" or custom abbreviated syntax "EPSG:2393+5717"),
- a OGC URN combining references for references for projected or derived CRSs e.g. for Projected 3D CRS "UTM zone 31N / WGS 84 (3D)": "urn:ogc:def:crs,crs:EPSG::4979,cs:PROJ::ENh,coordinateOperation:EPSG::16031" (*added in 6.2*)
- a OGC URN combining references for concatenated operations (e.g. "urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618")
- a PROJJSON string. The jsonschema is at https://proj.org/schemas/v0.2/projjson.schema.json (*added in 6.2*)
- a compound CRS made from two object names separated with " + ". e.g. "WGS 84 + EGM96 height" (*added in 7.1*)

New in version 6.0.0.

Note: before 7.0.1, it was needed to add +to between {source_crs} and {target_crs} when adding a filename

6.2.2 Description

`cs2cs` performs transformation between the source and destination cartographic coordinate reference system on a set of input points. The coordinate reference system transformation can include translation between projected and geographic coordinates as well as the application of datum shifts.

The following control parameters can appear in any order:

-I

Method to specify inverse translation, convert from *+to* coordinate system to the primary coordinate system defined.

-t<a>

Where *a* specifies a character employed as the first character to denote a control line to be passed through without processing. This option applicable to ASCII input only. (# is the default value).

-d <n>

New in version 5.2.0.

Specify the number of decimals in the output.

-e `<string>`

Where *string* is an arbitrary string to be output if an error is detected during data transformations. The default value is a three character string: `*\t*`.

-E

Causes the input coordinates to be copied to the output line prior to printing the converted values.

-l`<[=id]>`

List projection identifiers that can be selected with *+proj*. `cs2cs -l=id` gives expanded description of projection *id*, e.g. `cs2cs -l=merc`.

-lp

List of all projection id that can be used with the *+proj* parameter. Equivalent to `cs2cs -l`.

-lP

Expanded description of all projections that can be used with the *+proj* parameter.

-le

List of all ellipsoids that can be selected with the *+ellps* parameters.

-lu

List of all distance units that can be selected with the *+units* parameter.

-r

This options reverses the order of the first two expected inputs from that specified by the CRS to the opposite order. The third coordinate, typically height, remains third.

-s

This options reverses the order of the first two expected outputs from that specified by the CRS to the opposite order. The third coordinate, typically height, remains third.

-f <format>

Where *format* is a printf format string to control the form of the output values. For inverse projections, the output will be in degrees when this option is employed. If a format is specified for inverse projection the output data will be in decimal degrees. The default format is `"%.2f"` for forward projection and DMS for inverse.

-w<n>

Where *n* is the number of significant fractional digits to employ for seconds output (when the option is not specified, `-w3` is assumed).

-W<n>

Where *n* is the number of significant fractional digits to employ for seconds output. When `-W` is employed the fields will be constant width with leading zeroes.

-v

Causes a listing of cartographic control parameters tested for and used by the program to be printed prior to input data.

--area <name_or_code>

New in version 8.0.0.

Specify an area of interest to restrict the results when researching coordinate operations between 2 CRS. The area of interest can be specified either as a name (e.g "Denmark - onshore") or a AUTHORITY:CODE (EPSG:3237)

This option is mutually exclusive with *--bbox*.

--bbox <west_long,south_lat,east_long,north_lat>

New in version 8.0.0.

Specify an area of interest to restrict the results when researching coordinate operations between 2 CRS. The area of interest is specified as a bounding box with geographic coordinates, expressed in degrees in a unspecified geographic CRS. *west_long* and *east_long* should be in the [-180,180] range, and *south_lat* and *north_lat* in the [-90,90]. *west_long* is generally lower than *east_long*, except in the case where the area of interest crosses the antimeridian.

--no-ballpark

New in version 8.0.0.

Disallow any coordinate operation that is, or contains, a *Ballpark transformation*

--accuracy <accuracy>

New in version 8.0.0.

Sets the minimum desired accuracy for candidate coordinate operations.

--authority <name>

New in version 8.0.0.

This option can be used to restrict the authority of coordinate operations looked up in the database. When not specified, coordinate operations from any authority will be searched, with the restrictions set in the `authority_to_authority_preference` database table related to the authority of the source/target CRS themselves. If authority is set to `any`, then coordinate operations from any authority will be searched If authority is a non-empty string different of `any`, then coordinate operations will be searched only in that authority namespace (e.g `EPSG`).

This option is mutually exclusive with *--bbox*.

The **cs2cs** program requires two coordinate reference system (CRS) definitions. The first (or primary is defined based on all projection parameters not appearing after the *+to* argument. All projection parameters appearing after the *+to* argument are considered the definition of the second CRS. If there is no second CRS defined, a geographic CRS based on the datum and ellipsoid of the source CRS is assumed. Note that the source and destination CRS can both of same or different nature (geographic, projected, compound CRS), or one of each and may have the same or different datums.

When using a WKT definition or a AUTHORITY:CODE, the axis order of the CRS will be enforced. So for example if using EPSG:4326, the first value expected (or returned) will be a latitude.

Internally, **cs2cs** uses the `proj_create_crs_to_crs()` function to compute the appropriate coordinate operation, so implementation details of this function directly impact the results returned by the program.

The environment parameter `PROJ_LIB` establishes the directory for resource files (database, datum shift grids, etc.)

One or more files (processed in left to right order) specify the source of data to be transformed. A `-` will specify the location of processing standard input. If no files are specified, the input is assumed to be from stdin. For input data the two data values must be in the first two white space separated fields and when both input and output are ASCII all trailing portions of the input line are appended to the output line.

Input geographic data (longitude and latitude) must be in DMS or decimal degrees format and input cartesian data must be in units consistent with the ellipsoid major axis or sphere radius units. Output geographic coordinates will normally be in DMS format (use `-f %.12f` for decimal degrees with 12 decimal places), while projected (cartesian) coordinates will be in linear (meter, feet) units.

6.2.2.1 Use of remote grids

New in version 7.0.0.

If the `PROJ_NETWORK` environment variable is set to `ON`, **cs2cs** will attempt to use remote grids stored on CDN (Content Delivery Network) storage, when they are not available locally.

More details are available in the *Network capabilities* section.

6.2.3 Examples

6.2.3.1 Using PROJ strings

The following script

```
cs2cs +proj=latlong +datum=NAD83 +to +proj=utm +zone=10 +datum=NAD27 -r <<EOF
45d15'33.1" 111.5W
45d15.551666667N -111d30
+45.25919444444 111d30'000w
EOF
```

will transform the input NAD83 geographic coordinates into NAD27 coordinates in the UTM projection with zone 10 selected. The geographic values of this example are equivalent and meant as examples of various forms of DMS input. The x-y output data will appear as three lines of:

```
1402293.44  5076292.68 0.00
```

6.2.3.2 Using EPSG CRS codes

Transforming from WGS 84 latitude/longitude (in that order) to UTM Zone 31N/WGS 84

```
cs2cs EPSG:4326 EPSG:32631 <<EOF
45N 2E
EOF
```

outputs

```
421184.70   4983436.77 0.00
```

6.2.3.3 Using EPSG CRS names

Transforming from WGS 84 latitude/longitude (in that order) with EGM96 height to UTM Zone 31N/WGS 84 with WGS84 ellipsoidal height

```
echo 45 2 0 | cs2cs "WGS 84 + EGM96 height" "WGS 84 / UTM zone 31N"
```

outputs

```
421184.70   4983436.77 50.69
```

6.3 geod

6.3.1 Synopsis

geod +*ellps*=<*ellipse*> [**-afFIlptwW** [args]] [+*opt[=arg]* ...] file ...

invgeod +*ellps*=<*ellipse*> [**-afFIlptwW** [args]] [+*opt[=arg]* ...] file ...

6.3.2 Description

geod (direct) and **invgeod** (inverse) perform geodesic (Great Circle) computations for determining latitude, longitude and back azimuth of a terminus point given a initial point latitude, longitude, azimuth and distance (direct) or the forward and back azimuths and distance between an initial and terminus point latitudes and longitudes (inverse). The results are accurate to round off for $|f| < 1/50$, where f is flattening.

invgeod may not be available on all platforms; in this case use *geod -I* instead.

The following command-line options can appear in any order:

-I

Specifies that the inverse geodesic computation is to be performed. May be used with execution of **geod** as an alternative to **invgeod** execution.

-a

Latitude and longitudes of the initial and terminal points, forward and back azimuths and distance are output.

-t<a>

Where *a* specifies a character employed as the first character to denote a control line to be passed through without processing.

`-le`

Gives a listing of all the ellipsoids that may be selected with the *+ellps=* option.

`-lu`

Gives a listing of all the units that may be selected with the *+units=* option. (Default units are meters.)

`-f <format>`

Where *format* is a printf format string to control the output form of the geographic coordinate values. The default mode is DMS.

`-F <format>`

Where *format* is a printf format string to control the output form of the distance value. The default mode is `"%.3f"`.

`-w<n>`

Where *n* is the number of significant fractional digits to employ for seconds output (when the option is not specified, `-w3` is assumed).

`-W<n>`

Where *n* is the number of significant fractional digits to employ for seconds output. When `-W` is employed the fields will be constant width with leading zeroes.

`-p`

This option causes the azimuthal values to be output as unsigned DMS numbers between 0 and 360 degrees. Also note `-f`.

The *+opt* command-line options are associated with geodetic parameters for specifying the ellipsoidal or sphere to use. controls. The options are processed in left to right order from the command line. Reentry of an option is ignored with the first occurrence assumed to be the desired value.

One or more files (processed in left to right order) specify the source of data to be transformed. A `-` will specify the location of processing standard input. If no files are specified, the input is assumed to be from stdin.

For direct determinations input data must be in latitude, longitude, azimuth and distance order and output will be latitude, longitude and back azimuth of the terminus point. Latitude, longitude of the initial and terminus point are input for the inverse mode and respective forward and back azimuth from the initial and terminus points are output along with the distance between the points.

Input geographic coordinates (latitude and longitude) and azimuthal data must be in decimal degrees or DMS format and input distance data must be in units consistent with the ellipsoid major axis or sphere radius units. The latitude must lie in the range [-90d,90d]. Output geographic coordinates will be in DMS (if the `-f` switch is not employed) to 0.001" with trailing, zero-valued minute-second fields deleted. Output distance data will be in the same units as the ellipsoid or sphere radius.

The Earth's ellipsoidal figure may be selected in the same manner as program **proj** by using *+ellps=*, *+a=*, *+es=*, etc.

geod may also be used to determine intermediate points along either a geodesic line between two points or along an arc of specified distance from a geographic point. In both cases an initial point must be specified with *+lat_1=lat* and *+lon_1=lon* parameters and either a terminus point *+lat_2=lat* and *+lon_2=lon* or a distance and azimuth from the initial point with *+S=distance* and *+A=azimuth* must be specified.

If points along a geodesic are to be determined then either *+n_S=integer* specifying the number of intermediate points and/or *+del_S=distance* specifying the incremental distance between points must be specified.

To determine points along an arc equidistant from the initial point both *+del_A=angle* and *+n_A=integer* must be specified which determine the respective angular increments and number of points to be determined.

6.3.3 Examples

The following script determines the geodesic azimuths and distance in U.S. statute miles from Boston, MA, to Portland, OR:

```
geod +ellps=clrk66 <<EOF -I +units=us-mi
42d15'N 71d07'W 45d31'N 123d41'W
EOF
```

which gives the results:

```
-66d31'50.141" 75d39'13.083" 2587.504
```

where the first two values are the azimuth from Boston to Portland, the back azimuth from Portland to Boston followed by the distance.

An example of forward geodesic use is to use the Boston location and determine Portland's location by azimuth and distance:

```
geod +ellps=clrk66 <<EOF +units=us-mi
42d15'N 71d07'W -66d31'50.141" 2587.504
EOF
```

which gives:

```
45d31'0.003"N 123d40'59.985"W 75d39'13.094"
```

Note: Lack of precision in the distance value compromises the precision of the Portland location.

6.3.4 Further reading

1. GeographicLib.
2. C. F. F. Karney, Algorithms for Geodesics, J. Geodesy **87**(1), 43–55 (2013); addenda.
3. A geodesic bibliography.

6.4 gie

6.4.1 Synopsis

gie [**-hovql** [args]] file[s]

6.4.2 Description

gie, the Geospatial Integrity Investigation Environment, is a regression testing environment for the PROJ transformation library. Its primary design goal is to be able to perform regression testing of code that are a part of PROJ, while not requiring any other kind of tooling than the same C compiler already employed for compiling the library.

-h, --help

Print usage information

-o <file>**, --output** <file>

Specify output file name

-v, --verbose

Verbose: Provide non-essential informational output. Repeat *-v* for more verbosity (e.g. -vv)

-q, --quiet

Quiet: Opposite of verbose. In quiet mode not even errors are reported. Only interaction is through the return code (0 on success, non-zero indicates number of FAILED tests)

-l, --list

List the PROJ internal system error codes

--version

Print version number

Tests for **gie** are defined in simple text files. Usually having the extension `.gie`. Test for **gie** are written in the purpose-build command language for gie. The basic functionality of the gie command language is implemented through just 3 command verbs: `operation`, which defines the PROJ operation to test, `accept`, which defines the input coordinate to read, and `expect`, which defines the result to expect.

A sample test file for **gie** that uses the three above basic commands looks like:

```
<gie>

--------------------------------------------
Test output of the UTM projection
--------------------------------------------
operation  +proj=utm  +zone=32  +ellps=GRS80
--------------------------------------------
accept     12  55
expect     691_875.632_14   6_098_907.825_05

</gie>
```

Parsing of a **gie** file starts at `<gie>` and ends when `</gie>` is reached. Anything before `<gie>` and after `</gie>` is not considered. Test cases are created by defining an *operation* which *accept* an input coordinate and *expect* an output coordinate.

Because **gie** tests are wrapped in the `<gie>`/`</gie>` tags it is also possible to add test cases to custom made *init files*. The tests will be ignore by PROJ when reading the init file with *+init* and **gie** ignores anything not wrapped in `<gie>`/`</gie>`.

gie tests are defined by a set of commands like *operation*, *accept* and *expect* in the example above. Together the commands make out the **gie** command language. Any line in a **gie** file that does not start with a command is ignored. In the example above it is seen how this can be used to add comments and styling to **gie** test files in order to make them more readable as well as documenting what the purpose of the various tests are.

Below the *gie command language* is explained in details.

6.4.3 Examples

1. Run all tests in a file with all debug information turned on

```
gie -vvvv corner-cases.gie
```

2. Run all tests in several files

```
gie foo bar
```

6.4.4 gie command language

operation <+args>

Define a PROJ operation to test. Example:

```
operation proj=utm zone=32 ellps=GRS80
# test 4D function
accept    12 55 0 0
expect    691875.63214  6098907.82501  0  0

# test 2D function
accept    12 56
expect    687071.4391   6210141.3267
```

accept <x y [z [t]]>

Define the input coordinate to read. Takes test coordinate. The coordinate can be defined by either 2, 3 or 4 values, where the first two values are the x- and y-components, the 3rd is the z-component and the 4th is the time component. The number of components in the coordinate determines which version of the operation is tested (2D, 3D or 4D). Many coordinates can be accepted for one *operation*. For each *accept* an accompanying *expect* is needed.

Note that **gie** accepts the underscore (_) as a thousands separator. It is not required (in fact, it is entirely ignored by the input routine), but it significantly improves the readability of the very long strings of numbers typically required in projected coordinates.

See *operation* for an example.

expect <x y [z [t]]> | <error code>

Define the expected coordinate that will be returned from accepted coordinate passed though an operation. The expected coordinate can be defined by either 2, 3 or 4 components, similarly to *accept*. Many coordinates can be expected for one *operation*. For each *expect* an accompanying *accept* is needed.

See *operation* for an example.

In addition to expecting a coordinate it is also possible to expect a PROJ error code in case an operation can't be created. This is useful when testing that errors are caught and handled correctly. Below is an example of that tests that the pipeline operator fails correctly when a non-invertible pipeline is constructed.

```
operation   proj=pipeline step
            proj=urm5 n=0.5 inv
expect      failure pjd_err_malformed_pipeline
```

See *gie --list* for a list of error codes that can be expected.

tolerance <tolerance>

The *tolerance* command controls how much accepted coordinates can deviate from the expected coordinate. This is handy to test that an operation meets a certain numerical tolerance threshold. Some operations are expected to be accurate within millimeters where others might only be accurate within a few meters. *tolerance* should

```
operation       proj=merc
# test coordinate as returned by ```echo 12 55 | proj +proj=merc``
tolerance       1 cm
accept          12 55
expect          1335833.89 7326837.72

# test that the same coordinate with a 50 m false easting as determined
# by ``echo 12 55 |proj +proj=merc +x_0=50`` is still within a 100 m
# tolerance of the unaltered coordinate from proj=merc
tolerance       100 m
accept          12 55
expect          1335883.89  7326837.72
```

The default tolerance is 0.5 mm. See *proj -lu* for a list of possible units.

roundtrip <n> <tolerance>

Do a roundtrip test of an operation. *roundtrip* needs a *operation* and a *accept* command to function. The accepted coordinate is passed to the operation first in it's forward mode, then the output from the forward operation is passed back to the inverse operation. This procedure is done `n` times. If the resulting coordinate is within the set tolerance of the initial coordinate, the test is passed.

Example with the default 100 iterations and the default tolerance:

```
operation       proj=merc
accept          12 55
roundtrip
```

Example with count and default tolerance:

```
operation       proj=merc
accept          12 55
roundtrip       10000
```

Example with count and tolerance:

```
operation       proj=merc
accept          12 55
roundtrip       10000 5 mm
```

direction <direction>

The *direction* command specifies in which direction an operation is performed. This can either be `forward` or `inverse`. An example of this is seen below where it is tested that a symmetrical transformation pipeline returns the same results in both directions.

```
operation proj=pipeline zone=32 step
          proj=utm  ellps=GRS80 step
          proj=utm  ellps=GRS80 inv
tolerance 0.1 mm
```

(continues on next page)

(continued from previous page)

```
accept 12 55 0 0
expect 12 55 0 0

# Now the inverse direction (still same result: the pipeline is symmetrical)

direction inverse
expect 12 55 0 0
```

The default direction is “forward”.

ignore <error code>

This is especially useful in test cases that rely on a grid that is not guaranteed to be available. Below is an example of that situation.

```
operation proj=hgridshift +grids=nzgd2kgrid0005.gsb ellps=GRS80
tolerance 1 mm
ignore    pjd_err_failed_to_load_grid
accept    172.999892181021551 -45.001620431954613
expect    173                 -45
```

See `gie --list` for a list of error codes that can be ignored.

require_grid <grid_name>

Checks the availability of the grid <grid_name>. If it is not found, then all `accept`/`expect` pairs until the next `operation` will be skipped. `require_grid` can be repeated several times to specify several grids whose presence is required.

echo <text>

Add user defined text to the output stream. See the example below.

```
<gie>
echo ** Mercator projection tests **
operation +proj=merc
accept  0   0
expect  0   0
</gie>
```

which returns

```
-------------------------------------------------------------------------------
Reading file 'test.gie'
** Mercator projection test **
-------------------------------------------------------------------------------
total:  1 tests succeeded,  0 tests skipped,  0 tests failed.
-------------------------------------------------------------------------------
```

skip

Skip any test after the first occurrence of `skip`. In the example below only the first test will be performed. The second test is skipped. This feature is mostly relevant for debugging when writing new test cases.

```
<gie>
operation proj=merc
```

(continues on next page)

(continued from previous page)

```
accept  0   0
expect  0   0
skip
accept  0   1
expect  0   110579.9
</gie>
```

6.4.5 Strict mode

New in version 7.1.

A stricter variant of normal gie syntax can be used by wrapping gie commands between `<gie-strict>` and `</gie-strict>`. In strict mode, comment lines must start with a sharp character. Unknown commands will be considered as an error. A command can still be split on several lines, but intermediate lines must end with the space character followed by backslash to mark the continuation.

```
<gie-strict>
# This is a comment. The following line with multiple repeated characters too
-------------------------------------------------
# A command on several lines must use " \" continuation
operation proj=hgridshift +grids=nzgd2kgrid0005.gsb \
          ellps=GRS80
tolerance 1 mm
ignore    pjd_err_failed_to_load_grid
accept    172.999892181021551 -45.001620431954613
expect    173                 -45
</gie-strict>
```

6.4.6 Background

More importantly than being an acronym for "Geospatial Integrity Investigation Environment", gie were also the initials, user id, and USGS email address of Gerald Ian Evenden (1935–2016), the geospatial visionary, who, already in the 1980s, started what was to become the PROJ of today.

Gerald's clear vision was that map projections are *just special functions*. Some of them rather complex, most of them of two variables, but all of them *just special functions*, and not particularly more special than the `sin()`, `cos()`, `tan()`, and `hypot()` already available in the C standard library.

And hence, according to Gerald, *they should not be particularly much harder to use*, for a programmer, than the `sin()`'s, `tan()`'s and `hypot()`'s so readily available.

Gerald's ingenuity also showed in the implementation of the vision, where he devised a comprehensive, yet simple, system of key-value pairs for parameterising a map projection, and the highly flexible `PJ` struct, storing run-time compiled versions of those key-value pairs, hence making a map projection function call, `pj_fwd(PJ, point)`, as easy as a traditional function call like `hypot(x,y)`.

While today, we may have more formally well defined metadata systems (most prominent the OGC WKT2 representation), nothing comes close being as easily readable ("human compatible") as Gerald's key-value system. This system in particular, and the PROJ system in general, was Gerald's great gift to anyone using and/or communicating about geodata.

It is only reasonable to name a program, keeping an eye on the integrity of the PROJ system, in honour of Gerald.

So in honour, and hopefully also in the spirit, of Gerald Ian Evenden (1935–2016), this is the Geospatial Integrity Investigation Environment.

6.5 proj

6.5.1 Synopsis

proj [**-beEfiIlmorsStTvVwW**] [args]] [+*opt[=arg]* ...] file ...

invproj [**-beEfiIlmorsStTvVwW**] [args]] [+*opt[=arg]* ...] file ...

6.5.2 Description

`proj` and `invproj` perform respective forward and inverse conversion of cartographic data to or from cartesian data with a wide range of selectable projection functions.

`invproj` may not be available on all platforms; in this case use *proj -I* instead.

The following control parameters can appear in any order

`-b`

Special option for binary coordinate data input and output through standard input and standard output. Data is assumed to be in system type double floating point words. This option is to be used when `proj` is a child process and allows bypassing formatting operations.

`-d` <n>

New in version 5.2.0: Specify the number of decimals in the output.

`-i`

Selects binary input only (see *-b*).

`-I`

Alternate method to specify inverse projection. Redundant when used with `invproj`.

`-o`

Selects binary output only (see *-b*).

`-t<a>`

Where *a* specifies a character employed as the first character to denote a control line to be passed through without processing. This option applicable to ASCII input only. (# is the default value).

`-e <string>`

Where *string* is an arbitrary string to be output if an error is detected during data transformations. The default value is a three character string: `*\t*`. Note that if the *-b*, *-i* or *-o* options are employed, an error is returned as HUGE_VAL value for both return values.

`-E`

Causes the input coordinates to be copied to the output line prior to printing the converted values.

`-l<[=id]>`

List projection identifiers that can be selected with +*proj*. `proj -l=id` gives expanded description of projection *id*, e.g. `proj -l=merc`.

`-lp`

List of all projection id that can be used with the *+proj* parameter. Equivalent to `proj -l`.

`-lP`

Expanded description of all projections that can be used with the *+proj* parameter.

`-le`

List of all ellipsoids that can be selected with the *+ellps* parameters.

`-lu`

List of all distance units that can be selected with the *+units* parameter.

`-r`

This options reverses the order of the expected input from longitude-latitude or x-y to latitude-longitude or y-x.

`-s`

This options reverses the order of the output from x-y or longitude-latitude to y-x or latitude-longitude.

`-S`

Causes estimation of meridional and parallel scale factors, area scale factor and angular distortion, and maximum and minimum scale factors to be listed between <> for each input point. For conformal projections meridional and parallel scales factors will be equal and angular distortion zero. Equal area projections will have an area factor of 1.

`-m <mult>`

The cartesian data may be scaled by the *mult* parameter. When processing data in a forward projection mode the cartesian output values are multiplied by *mult* otherwise the input cartesian values are divided by *mult* before inverse projection. If the first two characters of *mult* are 1/ or 1: then the reciprocal value of *mult* is employed.

`-f <format>`

Where *format* is a printf format string to control the form of the output values. For inverse projections, the output will be in degrees when this option is employed. The default format is `"%.2f"` for forward projection and DMS for inverse.

`-w<n>`

Where *n* is the number of significant fractional digits to employ for seconds output (when the option is not specified, `-w3` is assumed).

`-W<n>`

Where *n* is the number of significant fractional digits to employ for seconds output. When `-W` is employed the fields will be constant width with leading zeroes.

`-v`

Causes a listing of cartographic control parameters tested for and used by the program to be printed prior to input data.

`-V`

This option causes an expanded annotated listing of the characteristics of the projected point. `-v` is implied with this option.

The *+opt* run-line arguments are associated with cartographic parameters. Additional projection control parameters may be contained in two auxiliary control files: the first is optionally referenced with the *+init=file:id* and the second is always processed after the name of the projection has been established from either the run-line or the contents of +init file. The environment parameter `PROJ_LIB` establishes the default directory for a file reference without an absolute path. This is also used for supporting files like datum shift files.

One or more files (processed in left to right order) specify the source of data to be converted. A `-` will specify the location of processing standard input. If no files are specified, the input is assumed to be from stdin. For ASCII input data the two data values must be in the first two white space separated fields and when both input and output are ASCII all trailing portions of the input line are appended to the output line.

Input geographic data (longitude and latitude) must be in DMS or decimal degrees format and input cartesian data must be in units consistent with the ellipsoid major axis or sphere radius units. Output geographic coordinates will be in DMS (if the `-w` switch is not employed) and precise to 0.001" with trailing, zero-valued minute-second fields deleted.

6.5.3 Example

The following script

```
proj +proj=utm +lon_0=112w +ellps=clrk66 -r <<EOF
45d15'33.1" 111.5W
45d15.551666667N -111d30
+45.25919444444 111d30'000w
EOF
```

will perform UTM forward projection with a standard UTM central meridian nearest longitude 112W. The geographic values of this example are equivalent and meant as examples of various forms of DMS input. The x-y output data will appear as three lines of:

```
460769.27     5011648.45
```

6.6 projinfo

6.6.1 Synopsis

projinfo
[-o formats] [-k crs|operation|datum|ensemble|ellipsoid] [–summary] [-q]
[[–area name_or_code] | [–bbox west_long,south_lat,east_long,north_lat]]
[–spatial-test contains|intersects]
[–crs-extent-use none|both|intersection|smallest]
[–grid-check none|discard_missing|sort|known_available]
[–pivot-crs always|if_no_direct_transformation|never|{auth:code[,auth:code]*}]
[–show-superseded] [–hide-ballpark] [–accuracy {accuracy}]
[–allow-ellipsoidal-height-as-vertical-crs]
[–boundcrs-to-wgs84]
[–main-db-path path] [–aux-db-path path]*
[–identify] [–3d]
[–c-ify] [–single-line]
–searchpaths | –remote-data | {object_definition} |
{object_reference} | (-s {srs_def} -t {srs_def})

where {object_definition} or {srs_def} is one of the possibilities accepted by `proj_create()`

- a proj-string,
- a WKT string,

- an object code (like "EPSG:4326", "urn:ogc:def:crs:EPSG::4326", "urn:ogc:def:coordinateOperation:EPSG::1671"),
- an Object name. e.g "WGS 84", "WGS 84 / UTM zone 31N". In that case as uniqueness is not guaranteed, heuristics are applied to determine the appropriate best match.
- a OGC URN combining references for compound coordinate reference systems (e.g "urn:ogc:def:crs,crs:EPSG::2393,crs:EPSG::5717" or custom abbreviated syntax "EPSG:2393+5717"),
- a OGC URN combining references for references for projected or derived CRSs e.g. for Projected 3D CRS "UTM zone 31N / WGS 84 (3D)": "urn:ogc:def:crs,crs:EPSG::4979,cs:PROJ::ENh,coordinateOperation:EPSG::16031" (*added in 6.2*)
- a OGC URN combining references for concatenated operations (e.g. "urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618")
- a PROJJSON string. The jsonschema is at https://proj.org/schemas/v0.2/projjson.schema.json (*added in 6.2*)
- a compound CRS made from two object names separated with " + ". e.g. "WGS 84 + EGM96 height" (*added in 7.1*)

{object_reference} is a filename preceded by the '@' character. The file referenced by the {object_reference} must contain a valid {object_definition}.

6.6.2 Description

projinfo is a program that can query information on a geodetic object, coordinate reference system (CRS) or coordinate operation, when the `-s` and `-t` options are specified, and display it under different formats (PROJ string, WKT string or PROJJSON string).

It can also be used to query coordinate operations available between two CRS.

The program is named with some reference to the GDAL **gdalsrsinfo** that offers partly similar services.

The following control parameters can appear in any order:

-o `formats`

formats is a comma separated combination of: `all`, `default`, `PROJ`, `WKT_ALL`, `WKT2:2015`, `WKT2:2019`, `WKT1:GDAL`, `WKT1:ESRI`, `PROJJSON`.

Except `all` and `default`, other formats can be preceded by `-` to disable them.

Note: WKT2_2019 was previously called WKT2_2018.

Note: Before PROJ 6.3.0, WKT1:GDAL was implicitly calling –boundcrs-to-wgs84. This is no longer the case.

-k `crs|operation|datum|ensemble|ellipsoid`

When used to query a single object with a AUTHORITY:CODE, determines the (k)ind of the object in case there are CRS, coordinate operations or ellipsoids with the same CODE. The default is crs.

--summary

When listing coordinate operations available between 2 CRS, return the result in a summary format, mentioning only the name of the coordinate operation, its accuracy and its area of use.

Note: only used for coordinate operation computation

-q

Turn on quiet mode. Quiet mode is only available for queries on single objects, and only one output format is selected. In that mode, only the PROJ, WKT or PROJJSON string is displayed, without other introduction output. The output is then potentially compatible of being piped in other utilities.

--area `name_or_code`

Specify an area of interest to restrict the results when researching coordinate operations between 2 CRS. The area of interest can be specified either as a name (e.g "Denmark - onshore") or a AUTHORITY:CODE (EPSG:3237) This option is exclusive of *--bbox*.

Note: only used for coordinate operation computation

--bbox `west_long,south_lat,east_long,north_lat`

Specify an area of interest to restrict the results when researching coordinate operations between 2 CRS. The area of interest is specified as a bounding box with geographic coordinates, expressed in degrees in a unspecified geographic CRS. *west_long* and *east_long* should be in the [-180,180] range, and *south_lat* and *north_lat* in the [-90,90]. *west_long* is generally lower than *east_long*, except in the case where the area of interest crosses the antimeridian.

Note: only used for coordinate operation computation

--spatial-test `contains|intersects`

Specify how the area of use of coordinate operations found in the database are compared to the area of use specified explicitly with *--area* or *--bbox*, or derived implicitly from the area of use of the source and target CRS. By default, **projinfo** will only keep coordinate operations whose are of use is strictly within the area of interest (`contains` strategy). If using the `intersects` strategy, the spatial test is relaxed, and any coordinate operation whose area of use at least partly intersects the area of interest is listed.

Note: only used for coordinate operation computation

--crs-extent-use `none|both|intersection|smallest`

Specify which area of interest to consider when no explicit one is specified with *--area* or *--bbox* options. By default (`smallest` strategy), the area of use of the source or target CRS will be looked, and the one that is the smallest one in terms of area will be used as the area of interest. If using `none`, no area of interest is used. If using `both`, only coordinate operations that relate (contain or intersect depending of the *--spatial-test* strategy) to the area of use of both CRS are selected. If using `intersection`, the area of interest is the intersection of the bounding box of the area of use of the source and target CRS

Note: only used for coordinate operation computation

--grid-check `none|discard_missing|sort|known_available`

Specify how the presence or absence of a horizontal or vertical shift grid required for a coordinate operation affects the results returned when researching coordinate operations between 2 CRS. The default strategy is `sort` (if *PROJ_NETWORK* is not defined). In that case, all candidate operations are returned, but the actual availability of the grids is used to determine the sorting order. That is, if a coordinate operation involves using a grid that is not available in the PROJ resource directories (determined by the *PROJ_LIB* environment variable, it will be listed in the bottom of the results. The `none` strategy completely disables the checks of presence of grids and this returns the results as if all the grids where available. The `discard_missing` strategy discards results that involve grids not present in the PROJ resource directories. The `known_available` strategy discards results that involve grids not present in the PROJ resource directories and that are not known of the CDN. This is the default strategy is *PROJ_NETWORK* is set to `ON`.

Note: only used for coordinate operation computation

--pivot-crs `always|if_no_direct_transformation|never|{auth:code[,auth:code]*}`

Determine if intermediate (pivot) CRS can be used when researching coordinate operation between 2 CRS. A typical example is the WGS84 pivot. By default, **projinfo** will consider any potential pivot if there is no direct transformation (`if_no_direct_transformation`). If using the `never` strategy, only direct transformations between the source and target CRS will be used. If using the `always` strategy, intermediate CRS will be considered even if there are direct transformations. It is also possible to restrict the pivot CRS to consider by specifying one or several CRS by their AUTHORITY:CODE.

Note: only used for coordinate operation computation

--show-superseded

When enabled, coordinate operations that are superseded by others will be listed. Note that supersession is not equivalent to deprecation: superseded operations are still considered valid although they have a better equivalent, whereas deprecated operations have been determined to be erroneous and are not considered at all.

Note: only used for coordinate operation computation

--hide-ballpark

New in version 7.1.

Hides any coordinate operation that is, or contains, a *Ballpark transformation*

Note: only used for coordinate operation computation

--accuracy `{accuracy}`

New in version 8.0.

Sets the minimum desired accuracy for returned coordinate operations.

Note: only used for coordinate operation computation

--allow-ellipsoidal-height-as-vertical-crs

New in version 8.0.

Allows exporting a geographic or projected 3D CRS as a compound CRS whose vertical CRS represents the ellipsoidal height.

Note: only used for CRS, and with WKT1:GDAL output format

--boundcrs-to-wgs84

When specified, this option researches a coordinate operation from the base geographic CRS of the single CRS, source or target CRS to the WGS84 geographic CRS, and if found, wraps those CRS into a BoundCRS object. This is mostly to be used for early-binding approaches.

--main-db-path `path`

Specify the name and path of the database to be used by **projinfo**. The default is `proj.db` in the PROJ resource directories.

--aux-db-path `path`

Specify the name and path of auxiliary databases, that are to be combined with the main database. Those auxiliary databases must have a table structure that is identical to the main database, but can be partly filled and their entries can refer to entries of the main database. The option may be repeated to specify several auxiliary databases.

--identify

When used with an object definition, this queries the PROJ database to find known objects, typically CRS, that are close or identical to the object. Each candidate object is associated with an approximate likelihood percentage. This is useful when used with a WKT string that lacks a EPSG identifier, such as ESRI WKT1. This might also be used with PROJ strings. For example, *+proj=utm +zone=31 +datum=WGS84 +type=crs* will be identified with a likelihood of 70% to EPSG:32631

--3d

New in version 6.3.

"Promote" the CRS(s) to their 3D version. In the context of researching available coordinate transformations, explicitly specifying this option is not necessary, because when one of the source or target CRS has a vertical component but not the other one, the one that has no vertical component is automatically promoted to a 3D version, where its vertical axis is the ellipsoidal height in metres, using the ellipsoid of the base geodetic CRS.

--c-ify

For developers only. Modify the string output of the utility so that it is easy to put those strings in C/C++ code

--single-line

Output PROJ, WKT or PROJJSON strings on a single line, instead of multiple indented lines by default.

--searchpaths

New in version 7.0.

Output the directories into which PROJ resources will be looked for (if not using C API such as `proj_context_set_search_paths()` that will override them.

--remote-data

New in version 7.0.

Display information regarding if *Network capabilities* is enabled, and the related URL.

6.6.3 Examples

1. Query the CRS object corresponding to EPSG:4326

```
projinfo EPSG:4326
```

Output:

```
PROJ.4 string:
+proj=longlat +datum=WGS84 +no_defs +type=crs

WKT2:2019 string:
GEOGCRS["WGS 84",
    DATUM["World Geodetic System 1984",
        ELLIPSOID["WGS 84",6378137,298.257223563,
            LENGTHUNIT["metre",1]]],
    PRIMEM["Greenwich",0,
        ANGLEUNIT["degree",0.0174532925199433]],
    CS[ellipsoidal,2],
        AXIS["geodetic latitude (Lat)",north,
            ORDER[1],
            ANGLEUNIT["degree",0.0174532925199433]],
        AXIS["geodetic longitude (Lon)",east,
            ORDER[2],
            ANGLEUNIT["degree",0.0174532925199433]],
    USAGE[
        SCOPE["unknown"],
        AREA["World"],
        BBOX[-90,-180,90,180]],
    ID["EPSG",4326]]
```

2. List the coordinate operations between NAD27 (designed with its CRS name) and NAD83 (designed with its EPSG code 4269) within an area of interest

```
projinfo -s NAD27 -t EPSG:4269 --area "USA - Missouri"
```

Output:

```
DERIVED_FROM(EPSG):1241, NAD27 to NAD83 (1), 0.15 m, USA - CONUS including EEZ

PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1 +step +proj=unitconvert \
+xy_in=deg +xy_out=rad +step +proj=hgridshift +grids=conus \
+step +proj=unitconvert +xy_in=rad +xy_out=deg +step +proj=axisswap +order=2,1

WKT2:2019 string:
COORDINATEOPERATION["NAD27 to NAD83 (1)",
    SOURCECRS[
        GEOGCRS["NAD27",
            DATUM["North American Datum 1927",
                ELLIPSOID["Clarke 1866",6378206.4,294.978698213898,
                    LENGTHUNIT["metre",1]]],
            PRIMEM["Greenwich",0,
                ANGLEUNIT["degree",0.0174532925199433]],
            CS[ellipsoidal,2],
                AXIS["geodetic latitude (Lat)",north,
                    ORDER[1],
                    ANGLEUNIT["degree",0.0174532925199433]],
                AXIS["geodetic longitude (Lon)",east,
                    ORDER[2],
                    ANGLEUNIT["degree",0.0174532925199433]]]],
```

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```
    TARGETCRS[
        GEOGCRS["NAD83",
            DATUM["North American Datum 1983",
                ELLIPSOID["GRS 1980",6378137,298.257222101,
                    LENGTHUNIT["metre",1]]],
            PRIMEM["Greenwich",0,
                ANGLEUNIT["degree",0.0174532925199433]],
            CS[ellipsoidal,2],
                AXIS["geodetic latitude (Lat)",north,
                    ORDER[1],
                    ANGLEUNIT["degree",0.0174532925199433]],
                AXIS["geodetic longitude (Lon)",east,
                    ORDER[2],
                    ANGLEUNIT["degree",0.0174532925199433]]]],
    METHOD["CTABLE2"],
    PARAMETERFILE["Latitude and longitude difference file","conus"],
    OPERATIONACCURACY[0.15],
    USAGE[
        SCOPE["unknown"],
        AREA["USA - CONUS including EEZ"],
        BBOX[23.81,-129.17,49.38,-65.69]],
    ID["DERIVED_FROM(EPSG)",1241]]
```

3. Export an object as a PROJJSON string

```
projinfo GDA94 -o PROJJSON -q
```

Output:

```
{
    "type": "GeographicCRS",
    "name": "GDA94",
    "datum": {
        "type": "GeodeticReferenceFrame",
        "name": "Geocentric Datum of Australia 1994",
        "ellipsoid": {
            "name": "GRS 1980",
            "semi_major_axis": 6378137,
            "inverse_flattening": 298.257222101
        }
    },
    "coordinate_system": {
        "subtype": "ellipsoidal",
        "axis": [
        {
            "name": "Geodetic latitude",
            "abbreviation": "Lat",
            "direction": "north",
            "unit": "degree"
        },
        {
            "name": "Geodetic longitude",
```

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```
            "abbreviation": "Lon",
            "direction": "east",
            "unit": "degree"
        }
        ]
    },
    "area": "Australia - GDA",
    "bbox": {
        "south_latitude": -60.56,
        "west_longitude": 93.41,
        "north_latitude": -8.47,
        "east_longitude": 173.35
    },
    "id": {
        "authority": "EPSG",
        "code": 4283
    }
}
```

4. Exporting the SQL statements to insert a new CRS in an auxiliary database.

```
# Get the SQL statements for a custom CRS
projinfo "+proj=merc +lat_ts=5 +datum=WGS84 +type=crs +title=my_crs" --output-id HOBU:MY_
↪CRS -o SQL -q > my_crs.sql
cat my_crs.sql

# Initialize an auxiliary database with the schema of the reference database
echo ".schema" | sqlite3 /path/to/proj.db | sqlite3 aux.db

# Append the content of the definition of HOBU:MY_CRS
sqlite3 aux.db < my_crs.db

# Check that everything works OK
projinfo --aux-db-path aux.db HOBU:MY_CRS
```

or more simply:

```
# Create an auxiliary database with the definition of a custom CRS.
projinfo "+proj=merc +lat_ts=5 +datum=WGS84 +type=crs +title=my_crs" --output-id HOBU:MY_
↪CRS --dump-db-structure | sqlite3 aux.db

# Check that everything works OK
projinfo --aux-db-path aux.db HOBU:MY_CRS
```

Output:

```
INSERT INTO geodetic_crs VALUES('HOBU','GEODETIC_CRS_MY_CRS','unknown','','geographic 2D
↪','EPSG','6424','EPSG','6326',NULL,0);
INSERT INTO usage VALUES('HOBU','USAGE_GEODETIC_CRS_MY_CRS','geodetic_crs','HOBU',
↪'GEODETIC_CRS_MY_CRS','PROJ','EXTENT_UNKNOWN','PROJ','SCOPE_UNKNOWN');
INSERT INTO conversion VALUES('HOBU','CONVERSION_MY_CRS','unknown','','EPSG','9805',
↪'Mercator (variant B)','EPSG','8823','Latitude of 1st standard parallel',5,'EPSG','9122
↪','EPSG','8802','Longitude of natural origin',0,'EPSG','9122','EPSG','8806','False␣
```

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```
↪easting',0,'EPSG','9001','EPSG','8807','False northing',0,'EPSG','9001',NULL,NULL,NULL,
↪NULL,NULL,NULL,NULL,NULL,NULL,NULL,NULL,NULL,NULL,NULL,NULL,NULL,NULL,NULL,0);
INSERT INTO usage VALUES('HOBU','USAGE_CONVERSION_MY_CRS','conversion','HOBU',
↪'CONVERSION_MY_CRS','PROJ','EXTENT_UNKNOWN','PROJ','SCOPE_UNKNOWN');
INSERT INTO projected_crs VALUES('HOBU','MY_CRS','my_crs','','EPSG','4400','HOBU',
↪'GEODETIC_CRS_MY_CRS','HOBU','CONVERSION_MY_CRS',NULL,0);
INSERT INTO usage VALUES('HOBU','USAGE_PROJECTED_CRS_MY_CRS','projected_crs','HOBU','MY_
↪CRS','PROJ','EXTENT_UNKNOWN','PROJ','SCOPE_UNKNOWN');
```

```
PROJ.4 string:
+proj=merc +lat_ts=5 +lon_0=0 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs +type=crs

WKT2:2019 string:
PROJCRS["my_crs",
    BASEGEOGCRS["unknown",
        ENSEMBLE["World Geodetic System 1984 ensemble",
            MEMBER["World Geodetic System 1984 (Transit)"],
            MEMBER["World Geodetic System 1984 (G730)"],
            MEMBER["World Geodetic System 1984 (G873)"],
            MEMBER["World Geodetic System 1984 (G1150)"],
            MEMBER["World Geodetic System 1984 (G1674)"],
            MEMBER["World Geodetic System 1984 (G1762)"],
            ELLIPSOID["WGS 84",6378137,298.257223563,
                LENGTHUNIT["metre",1]],
            ENSEMBLEACCURACY[2.0]],
        PRIMEM["Greenwich",0,
            ANGLEUNIT["degree",0.0174532925199433]],
        ID["HOBU","GEODETIC_CRS_MY_CRS"]],
    CONVERSION["unknown",
        METHOD["Mercator (variant B)",
            ID["EPSG",9805]],
        PARAMETER["Latitude of 1st standard parallel",5,
            ANGLEUNIT["degree",0.0174532925199433],
            ID["EPSG",8823]],
        PARAMETER["Longitude of natural origin",0,
            ANGLEUNIT["degree",0.0174532925199433],
            ID["EPSG",8802]],
        PARAMETER["False easting",0,
            LENGTHUNIT["metre",1],
            ID["EPSG",8806]],
        PARAMETER["False northing",0,
            LENGTHUNIT["metre",1],
            ID["EPSG",8807]]],
    CS[Cartesian,2],
        AXIS["(E)",east,
            ORDER[1],
            LENGTHUNIT["metre",1]],
        AXIS["(N)",north,
            ORDER[2],
            LENGTHUNIT["metre",1]],
    ID["HOBU","MY_CRS"]]
```

5. Get the WKT representation of EPSG:25832 in the WKT1:GDAL output format and on a single line

```
projinfo -o WKT1:GDAL --single-line EPSG:25832
```

Output:

```
WKT1:GDAL string:
PROJCS["ETRS89 / UTM zone 32N",GEOGCS["ETRS89",DATUM["European_Terrestrial_Reference_
↪System_1989",SPHEROID["GRS 1980",6378137,298.257222101,AUTHORITY["EPSG","7019"]],
↪AUTHORITY["EPSG","6258"]],PRIMEM["Greenwich",0,AUTHORITY["EPSG","8901"]],UNIT["degree",
↪0.0174532925199433,AUTHORITY["EPSG","9122"]],AUTHORITY["EPSG","4258"]],PROJECTION[
↪"Transverse_Mercator"],PARAMETER["latitude_of_origin",0],PARAMETER["central_meridian",
↪9],PARAMETER["scale_factor",0.9996],PARAMETER["false_easting",500000],PARAMETER["false_
↪northing",0],UNIT["metre",1,AUTHORITY["EPSG","9001"]],AXIS["Easting",EAST],AXIS[
↪"Northing",NORTH],AUTHORITY["EPSG","25832"]]
```

6.7 projsync

6.7.1 Synopsis

projsync
[–endpoint URL]
[–local-geojson-file FILENAME]
([–user-writable-directory] | [–system-directory] | [–target-dir DIRNAME])
[–bbox west_long,south_lat,east_long,north_lat]
[–spatial-test contains|intersects]
[–source-id ID] [–area-of-use NAME]
[–file NAME]
[–all] [–exclude-world-coverage]
[–quiet] [–dry-run] [–list-files]

6.7.2 Description

projsync is a program that downloads remote resource files into a local directory. This is an alternative to downloading a proj-data-X.Y.Z archive file, or using the on-demand *networking capabilities* of PROJ.

The following control parameters can appear in any order:

--endpoint URL
Defines the URL where to download the master `files.geojson` file and then the resource files. Defaults to the value set in *proj.ini*

--local-geojson-file FILENAME
Defines the filename for the master GeoJSON files that references resources. Defaults to `${endpoint}/files.geojson`

--user-writable-directory
Specifies that resource files must be downloaded in the *user writable directory*. This is the default.

`--system-directory`
: Specifies that resource files must be downloaded in the ${installation_prefix}/share/proj directory. The user launching projsync should make sure it has writing rights in that directory.

`--target-dir` `DIRNAME`
: Directory into which resource files must be downloaded.

`--bbox` `west_long,south_lat,east_long,north_lat`
: Specify an area of interest to restrict the resources to download. The area of interest is specified as a bounding box with geographic coordinates, expressed in degrees in a unspecified geographic CRS. *west_long* and *east_long* should be in the [-180,180] range, and *south_lat* and *north_lat* in the [-90,90]. *west_long* is generally lower than *east_long*, except in the case where the area of interest crosses the antimeridian.

`--spatial-test` `contains|intersects`
: Specify how the extent of the resource files are compared to the area of use specified explicitly with *`--bbox`*. By default, any resource files whose extent intersects the value specified by *`--bbox`* will be selected. If using the `contains` strategy, only resource files whose extent is contained in the value specified by *`--bbox`* will be selected.

`--source-id` `ID`
: Restrict resource files to be downloaded to those whose source_id property contains the ID value. Specifying ? as ID will list all possible values.

`--area-of-use` `NAME`
: Restrict resource files to be downloaded to those whose area_of_use property contains the NAME value. Specifying ? as NAME will list all possible values.

`--file` `NAME`
: Restrict resource files to be downloaded to those whose name property contains the NAME value. Specifying ? as NAME will list all possible values.

`--all`
: Ask to download all files.

`--exclude-world-coverage`
: Exclude files which have world coverage.

`-q` `/ --quiet`
: Quiet mode

`--dry-run`
: Simulate the behavior of the tool without downloading resource files.

`--list-files`
: List file names, with the source_id and area_of_use properties.

At least one of *`--list-files`*, *`--file`*, *`--source-id`*, *`--area-of-use`*, *`--bbox`* or *`--all`* must be specified.

Options *`--file`*, *`--source-id`*, *`--area-of-use`* and *`--bbox`* are combined with a AND logic.

6.7.3 Examples

1. Download all resource files

```
projsync --all
```

2. Download resource files covering specified point and attributing to an agency

```
projsync --source-id fr_ign --bbox 2,49,2,49
```

CHAPTER

SEVEN

COORDINATE OPERATIONS

Coordinate operations in PROJ are divided into three groups: Projections, conversions and transformations. Projections are purely cartographic mappings of the sphere onto the plane. Technically projections are conversions (according to ISO standards), though in PROJ projections are distinguished from conversions. Conversions are coordinate operations that do not exert a change in reference frame. Operations that do exert a change in reference frame are called transformations.

7.1 Projections

Projections are coordinate operations that are technically conversions but since projections are so fundamental to PROJ we differentiate them from conversions.

Projections map the spherical 3D space to a flat 2D space.

7.1.1 Adams Hemisphere in a Square

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	adams_hemi
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.1.1 Parameters

Note: All parameters are optional.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

Fig. 1: proj-string: `+proj=adams_hemi`

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.2 Adams World in a Square I

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	adams_ws1
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.2.1 Parameters

Note: All parameters are optional.

+lon_0=<value>
Longitude of projection center.

Defaults to 0.0.

+R=<value>
Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.3 Adams World in a Square II

Classification	Miscellaneous
Available forms	Forward and inverse, spherical
Defined area	Global
Alias	adams_ws2
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

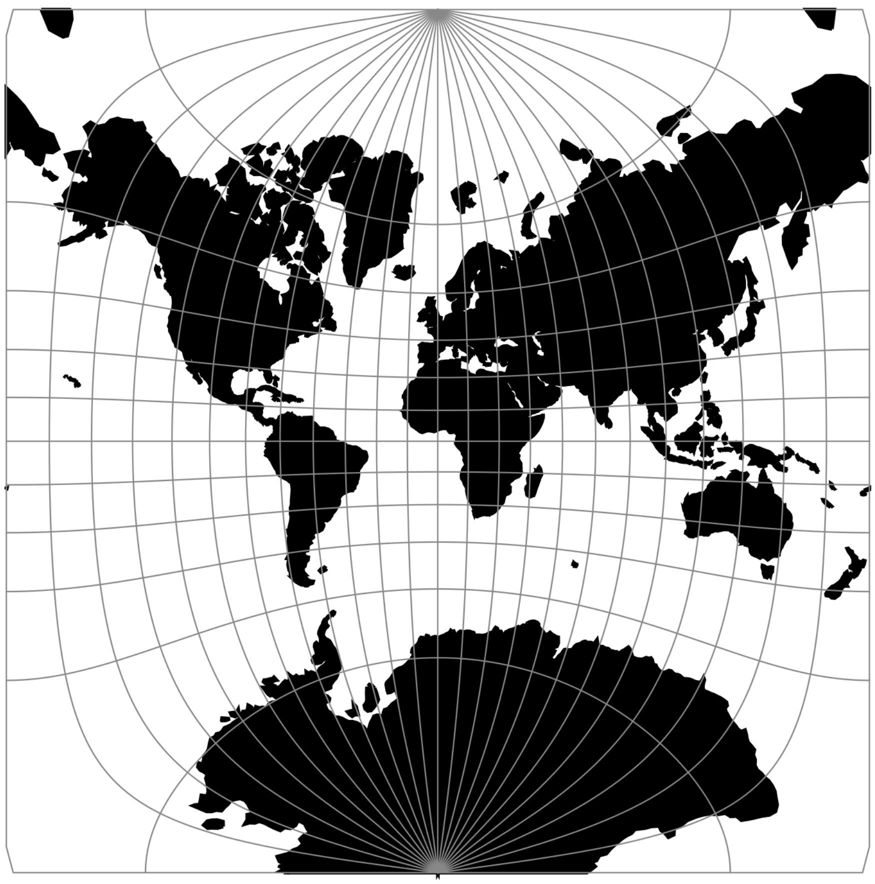


Fig. 2: proj-string: `+proj=adams_ws1`

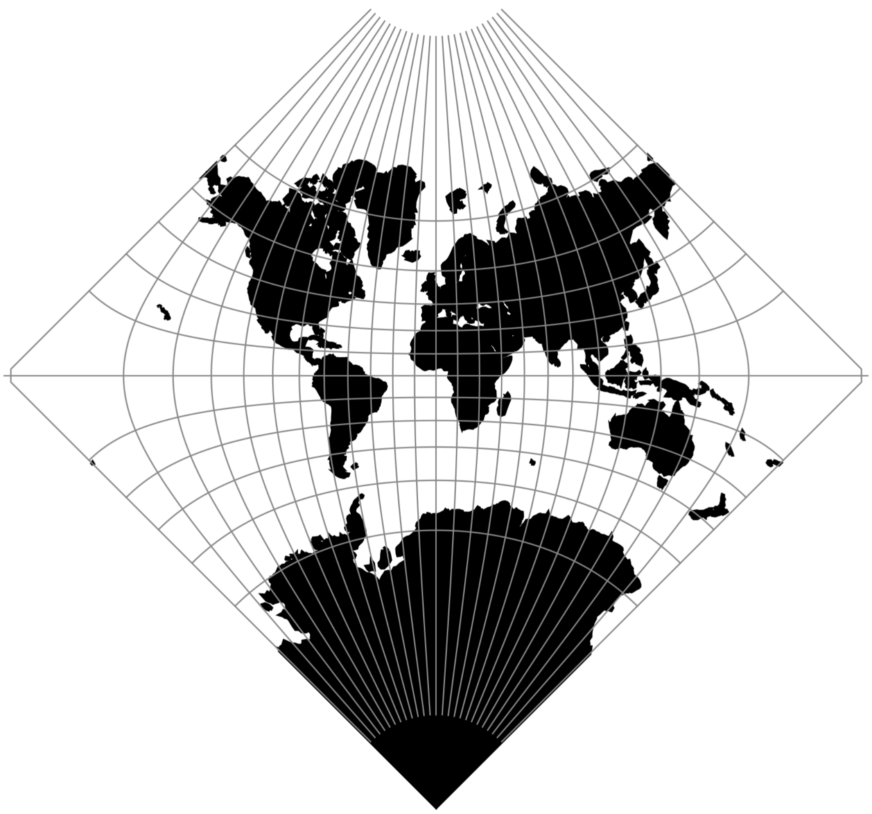


Fig. 3: proj-string: +proj=adams_ws2

7.1.3.1 Parameters

Note: All parameters are optional.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.4 Albers Equal Area

Classification	Conic
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	aea
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.4.1 Options

Required

`+lat_1=<value>`

First standard parallel.

Defaults to 0.0.

`+lat_2=<value>`

Second standard parallel.

Defaults to 0.0.

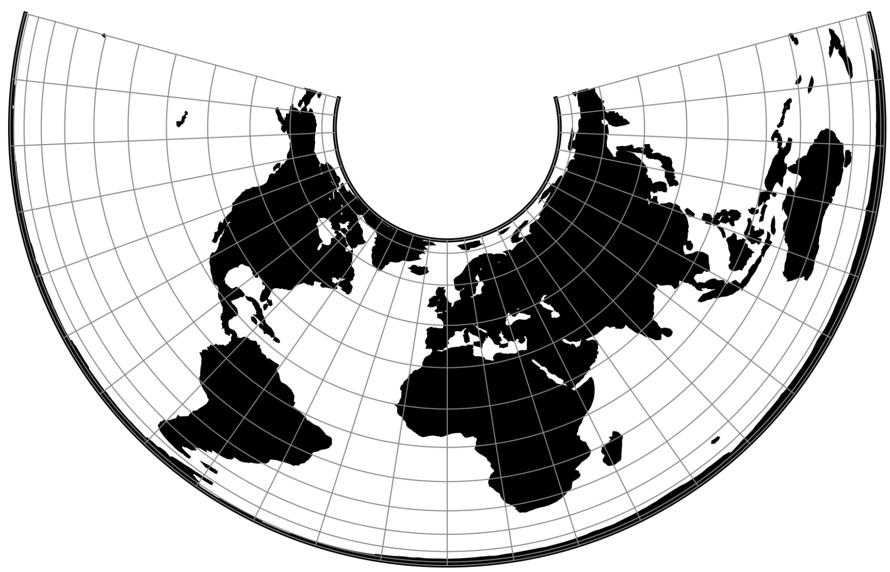


Fig. 4: proj-string: `+proj=aea +lat_1=29.5 +lat_2=42.5`

Optional

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.5 Azimuthal Equidistant

Classification	Azimuthal
Available forms	Forward and inverse, spherical and ellipsoidal
Alias	aeqd
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 5: proj-string: `+proj=aeqd`

7.1.5.1 Options

Note: All options are optional for the Azimuthal Equidistant projection.

+guam

Use Guam ellipsoidal formulas. Only accurate near the Island of Guam ($\lambda \approx 144.5°$, $\phi \approx 13.5°$)

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

7.1.6 Airy

The Airy projection is an azimuthal minimum error projection for the region within the small or great circle defined by an angular distance, ϕ_b, from the tangency point of the plane (λ_0, ϕ_0).

Classification	Azimuthal
Available forms	Forward spherical projection
Defined area	Global
Alias	airy
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 6: proj-string: `+proj=airy`

7.1.6.1 Options

+lat_b

Angular distance from tangency point of the plane (λ_0, ϕ_0) where the error is kept at minimum.

Defaults to 90° (suitable for hemispherical maps).

+no_cut

Do not cut at hemisphere limit

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

7.1.7 Aitoff

Classification	Miscellaneous
Available forms	Forward and inverse spherical projection
Defined area	Global
Alias	aitoff
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.7.1 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

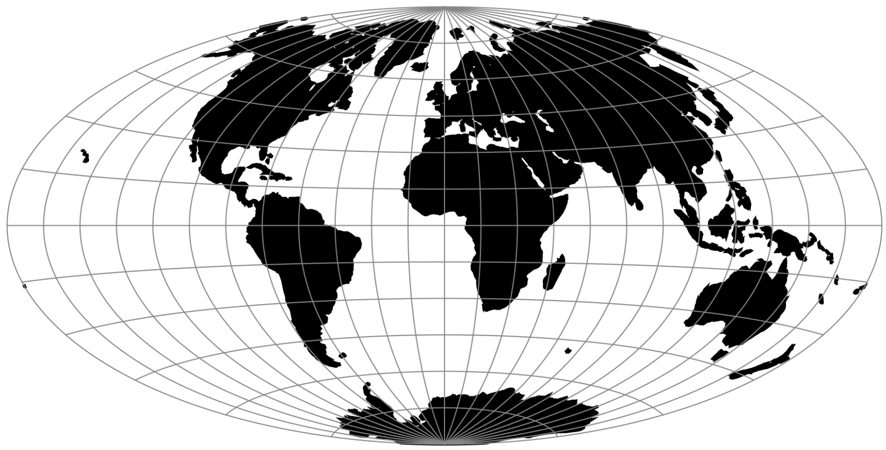


Fig. 7: proj-string: `+proj=aitoff`

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.8 Modified Stereographic of Alaska

Classification	Modified azimuthal
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Alaska
Alsk	alsk
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

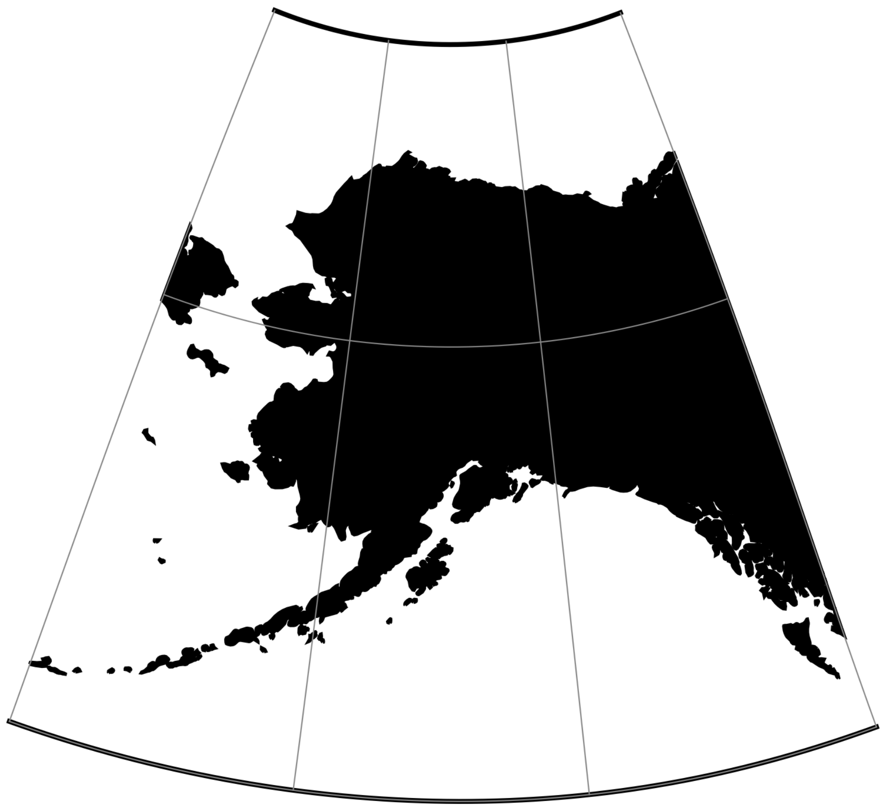


Fig. 8: proj-string: `+proj=alsk`

7.1.8.1 Options

Note: All options are optional for the projection.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

`+ellps=<value>`

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

7.1.9 Apian Globular I

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	apian
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

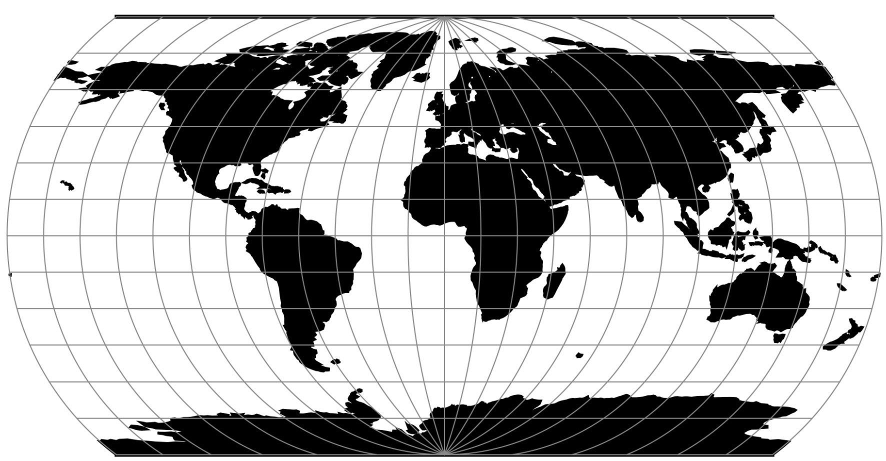


Fig. 9: proj-string: `+proj=apian`

7.1.9.1 Options

Note: All options are optional for the Apian Globular projection.

+lat_0=<value>
    Latitude of projection center.

    Defaults to 0.0.

+lon_0=<value>
    Longitude of projection center.

    Defaults to 0.0.

+R=<value>
    Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>
    False easting.

    Defaults to 0.0.

+y_0=<value>
    False northing.

    Defaults to 0.0.

7.1.10 August Epicycloidal

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	august
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.10.1 Parameters

Note: All options are optional for the August Epicycloidal projection.

+lon_0=<value>
    Longitude of projection center.

    Defaults to 0.0.

+R=<value>
    Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

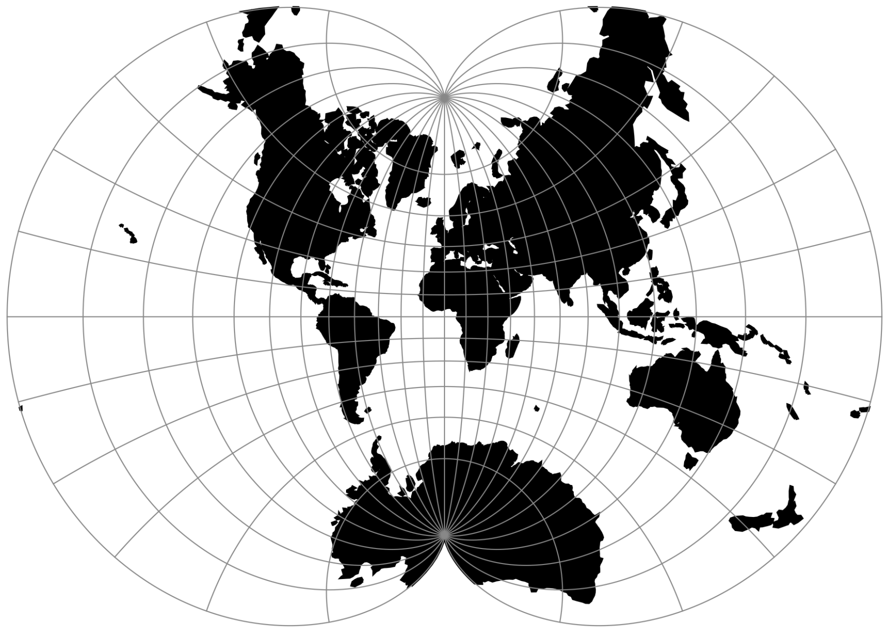


Fig. 10: proj-string: `+proj=august`

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.11 Bacon Globular

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	bacon
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

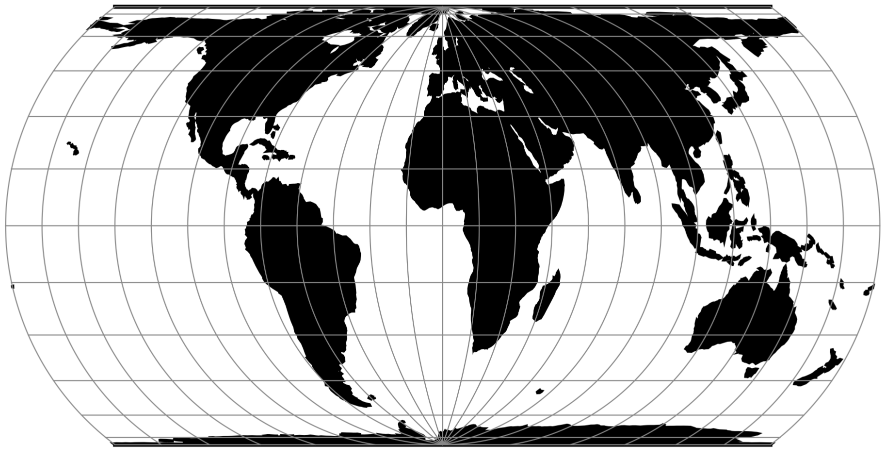


Fig. 11: proj-string: `+proj=bacon`

7.1.11.1 Parameters

Note: All parameters are optional for the Bacon Globular projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.12 Bertin 1953

New in version 6.0.0.

Classification	Miscellaneous
Available forms	Forward, spherical projection
Defined area	Global
Alias	bertin1953
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

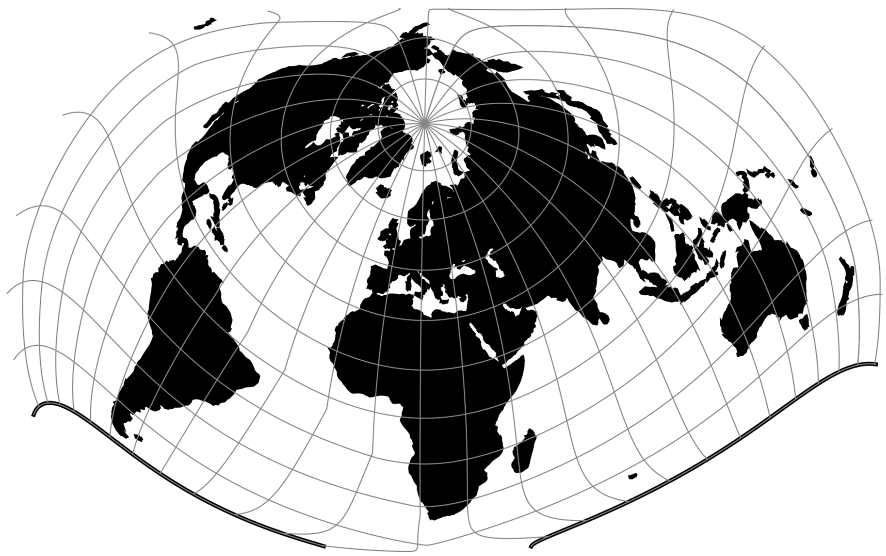


Fig. 12: proj-string: `+proj=bertin1953`

The Bertin 1953 projection is intended for making world maps. Created by Jacques Bertin in 1953, this projection was the go-to choice of the French cartographic school when they wished to represent phenomena on a global scale. The projection was formulated in 2017 by Philippe Rivière for visionscarto.net.

7.1.12.1 Usage

The Bertin 1953 projection has no special options. Its rotation parameters are fixed. Here is an example of a forward projection with scale 1:

$ echo 122 47 | src/proj +proj=bertin1953 +R=1 0.72 0.73

7.1.12.2 Parameters

Note: All parameters for the projection are optional.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.12.3 Further reading

1. Philippe Rivière (2017). *Bertin Projection (1953) <https://visionscarto.net/bertin-projection-1953>*, Visionscarto.net.

7.1.13 Bipolar conic of western hemisphere

Classification	Miscellaneous
Available forms	Forward and inverse spherical projection
Defined area	Global
Alias	bipc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 13: proj-string: `+proj=bipc +ns`

7.1.13.1 Parameters

Note: All options are optional for the Bipolar Conic projection.

+ns

Return non-skewed cartesian coordinates.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.14 Boggs Eumorphic

Classification	Pseudocylindrical
Available forms	Forward spherical projection
Defined area	Global
Alias	boggs
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.14.1 Parameters

Note: All options are optional for the Boggs Eumorphic projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

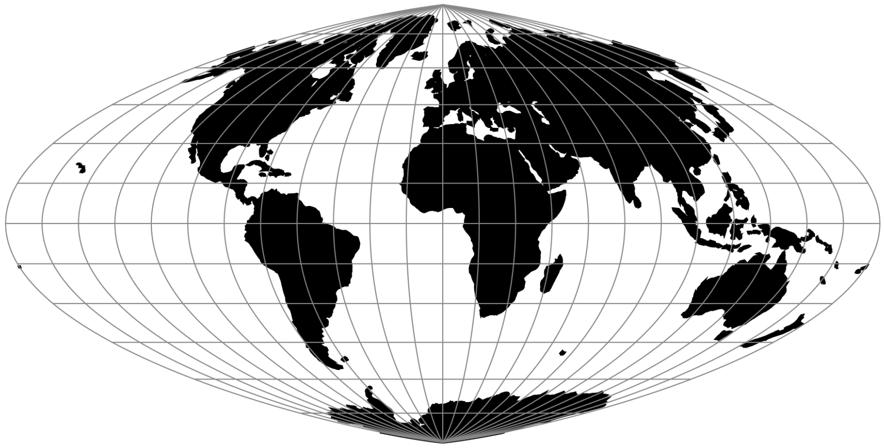


Fig. 14: proj-string: `+proj=boggs`

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.15 Bonne (Werner lat_1=90)

Classification	Miscellaneous
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	bonne
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.15.1 Parameters

Required

+lat_1=<value>

First standard parallel.

Defaults to 0.0.

Fig. 15: proj-string: `+proj=bonne +lat_1=10`

Optional

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

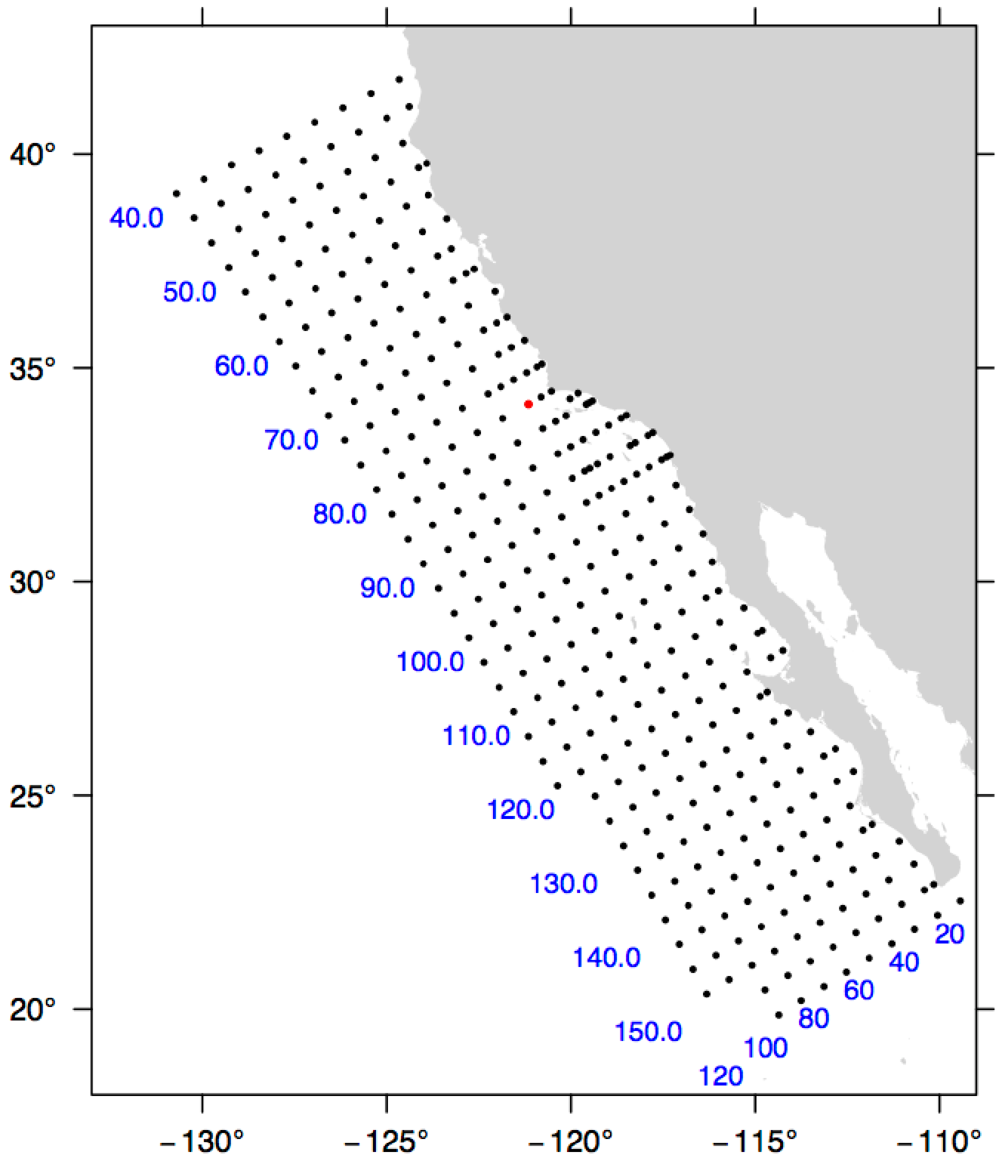
False northing.

Defaults to 0.0.

7.1.16 Cal Coop Ocean Fish Invest Lines/Stations

The CalCOFI pseudo-projection is the line and station coordinate system of the California Cooperative Oceanic Fisheries Investigations program, known as CalCOFI, for sampling offshore of the west coast of the U.S. and Mexico.

Classification	Conformal cylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Only valid for the west coast of USA and Mexico
Alias	calcofi
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates



The coordinate system is based on the Mercator projection with units rotated -30 degrees from the meridian so that they are oriented with the coastline of the Southern California Bight and Baja California. Lines increase from Northwest to Southeast. A unit of line is 12 nautical miles. Stations increase from inshore to offshore. A unit of station is equal to 4 nautical miles. The rotation point is located at line 80, station 60, or 34.15 degrees N, -121.15 degrees W, and is depicted by the red dot in the figure. By convention, the ellipsoid of Clarke 1866 is used to calculate CalCOFI coordinates.

The CalCOFI program is a joint research effort by the U.S. National Oceanic and Atmospheric Administration, University of California Scripps Oceanographic Institute, and California Department of Fish and Game. Surveys have been conducted for the CalCOFI program since 1951, creating one of the oldest and most scientifically valuable joint oceanographic and fisheries data sets in the world. The CalCOFI line and station coordinate system is now used by several other programs including the Investigaciones Mexicanas de la Corriente de California (IMECOCAL) program offshore of Baja California. The figure depicts some commonly sampled locations from line 40 to line 156.7 and offshore to station 120. Blue numbers indicate line (bottom) or station (left) numbers along the grid. Note that lines spaced at approximate 3-1/3 intervals are commonly sampled, e.g., lines 43.3 and 46.7.

7.1.16.1 Usage

A typical forward CalCOFI projection would be from lon/lat coordinates on the Clark 1866 ellipsoid. For example:

```
proj +proj=calcofi +ellps=clrk66 -E <<EOF
-121.15 34.15
EOF
```

Output of the above command:

```
-121.15 34.15   80.00   60.00
```

The reverse projection from line/station coordinates to lon/lat would be entered as:

```
proj +proj=calcofi +ellps=clrk66 -I -E -f "%.2f" <<EOF
80.0 60.0
EOF
```

Output of the above command:

```
80.0 60.0   -121.15 34.15
```

7.1.16.2 Options

Note: All options are optional for the CalCOFI projection.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

7.1.16.3 Mathematical definition

The algorithm used to make conversions is described in [EberHewitt1979] with a few corrections reported in [Weber-Moore2013].

7.1.16.4 Further reading

1. General information about the CalCOFI program
2. The Investigaciones Mexicanas de la Corriente de California

7.1.17 Cassini (Cassini-Soldner)

Although the Cassini projection has been largely replaced by the Transverse Mercator, it is still in limited use outside the United States and was one of the major topographic mapping projections until the early 20th century.

Classification	Transverse and oblique cylindrical
Available forms	Forward and inverse, Spherical and ellipsoidal
Defined area	Global, but best used near the central meridian with long, narrow areas
Alias	cass
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.17.1 Usage

There has been little usage of the spherical version of the Cassini, but the ellipsoidal Cassini-Soldner version was adopted by the Ordnance Survey for the official survey of Great Britain during the second half of the 19th century [Steers1970]. Many of these maps were prepared at a scale of 1:2,500. The Cassini-Soldner was also used for the detailed mapping of many German states during the same period.

Example using EPSG 30200 (Trinidad 1903, units in clarke's links):

```
$ echo 0.17453293 -1.08210414 | proj +proj=cass +lat_0=10.44166666666667 +lon_0=-61.
↪33333333333334 +x_0=86501.46392051999 +y_0=65379.0134283 +a=6378293.645208759␣
↪+b=6356617.987679838 +to_meter=0.201166195164
66644.94    82536.22
```

Example using EPSG 3068 (Soldner Berlin):

```
$ echo 13.5 52.4 | proj +proj=cass +lat_0=52.41864827777778 +lon_0=13.62720366666667 +x_
↪0=40000 +y_0=10000 +ellps=bessel +units=m
31343.05    7932.76
```

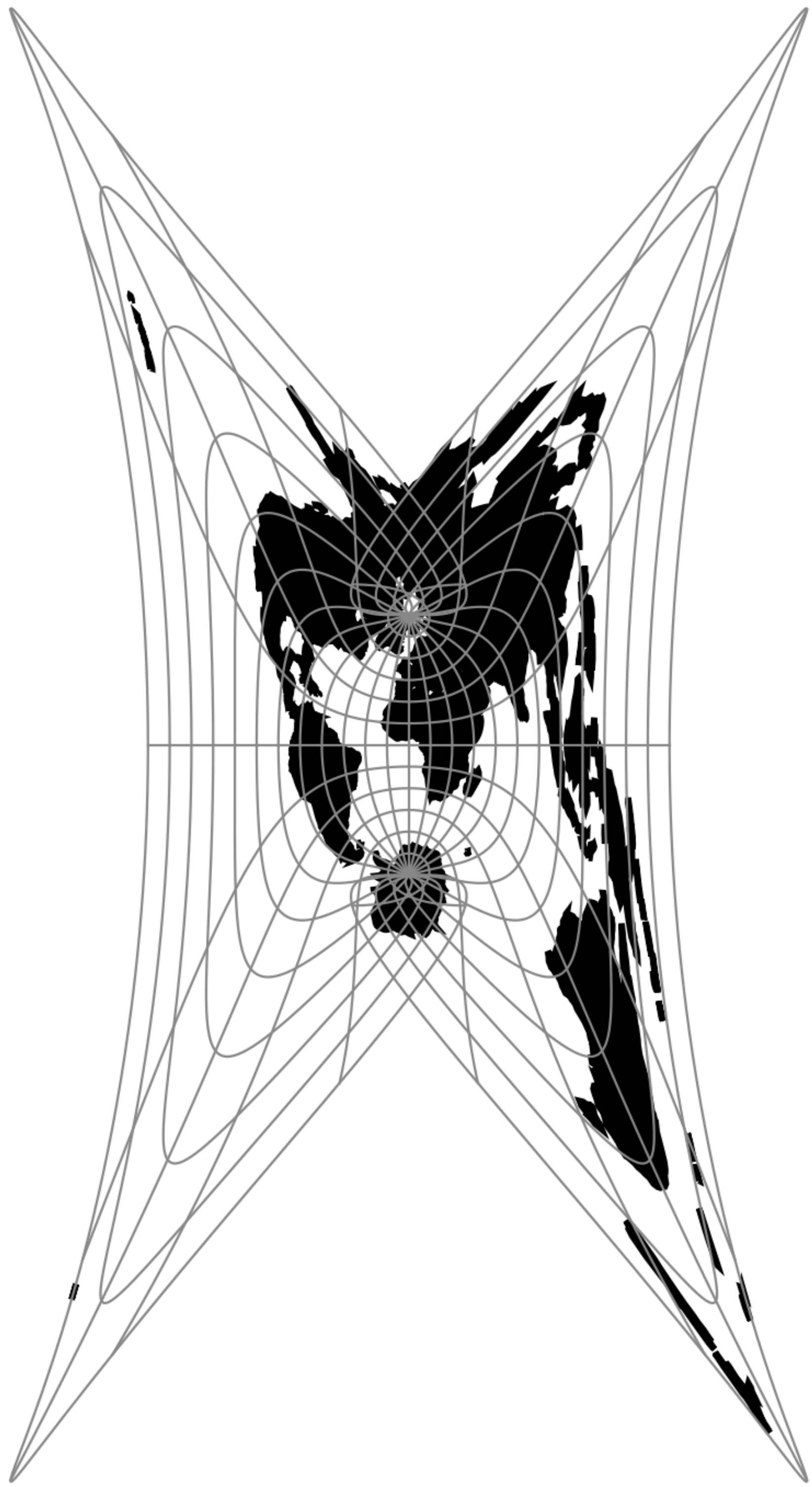


Fig. 16: proj-string: `+proj=cass`

7.1.17.2 Options

Note: All options are optional for the Cassini projection.

`+lat_0=<value>`

Latitude of projection center.

Defaults to 0.0.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

`+ellps=<value>`

See *proj -le* for a list of available ellipsoids.

Defaults to "GRS80".

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

7.1.17.3 Mathematical definition

The formulas describing the Cassini projection are taken from [Snyder1987].

ϕ_0 is the latitude of origin that match the center of the map (default to 0). It can be set with `+lat_0`.

Spherical form

Forward projection

$$x = \arcsin(\cos(\phi)\sin(\lambda))$$

$$y = \arctan 2(\tan(\phi), \cos(\lambda)) - \phi_0$$

Inverse projection

$$\phi = \arcsin(\sin(y + \phi_0)\cos(x))$$

$$\lambda = \arctan 2(\tan(x), \cos(y + \phi_0))$$

Ellipsoidal form

Forward projection

$$N = (1 - e^2 \sin^2(\phi))^{-1/2}$$

$$T = \tan^2(\phi)$$

$$A = \lambda \cos(\phi)$$

$$C = \frac{e^2}{1 - e^2} cos^2(\phi)$$

$$x = N(A - T\frac{A^3}{6} - (8 - T + 8C)T\frac{A^5}{120})$$

$$y = M(\phi) - M(\phi_0) + N\tan(\phi)(\frac{A^2}{2} + (5 - T + 6C)\frac{A^4}{24})$$

and M() is the meridional distance function.

Inverse projection

$$\phi' = M^{-1}(M(\phi_0) + y)$$

if $\phi' = \frac{\pi}{2}$ then $\phi = \phi'$ and $\lambda = 0$

otherwise evaluate T and N above using ϕ' and

$$R = (1 - e^2)(1 - e^2 sin^2 \phi')^{-3/2}$$

$$D = x/N$$

$$\phi = \phi' - \tan\phi' \frac{N}{R}(\frac{D^2}{2} - (1 + 3T)\frac{D^4}{24})$$

$$\lambda = \frac{(D - T\frac{D^3}{3} + (1 + 3T)T\frac{D^5}{15})}{\cos\phi'}$$

7.1.17.4 Further reading

1. Wikipedia
2. EPSG, POSC literature pertaining to Coordinate Conversions and Transformations including Formulas

7.1.18 Central Cylindrical

Classification	Cylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	cc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.18.1 Parameters

Note: All parameters are optional for the Central Cylindrical projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.19 Central Conic

New in version 5.0.0.

This is central (centrographic) projection on cone tangent at :option:`lat_1` latitude, identical with `conic()` projection from `mapproj` R package.

Classification	Conic
Available forms	Forward and inverse, spherical projection
Defined area	Global, but best used near the standard parallel
Alias	ccon
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

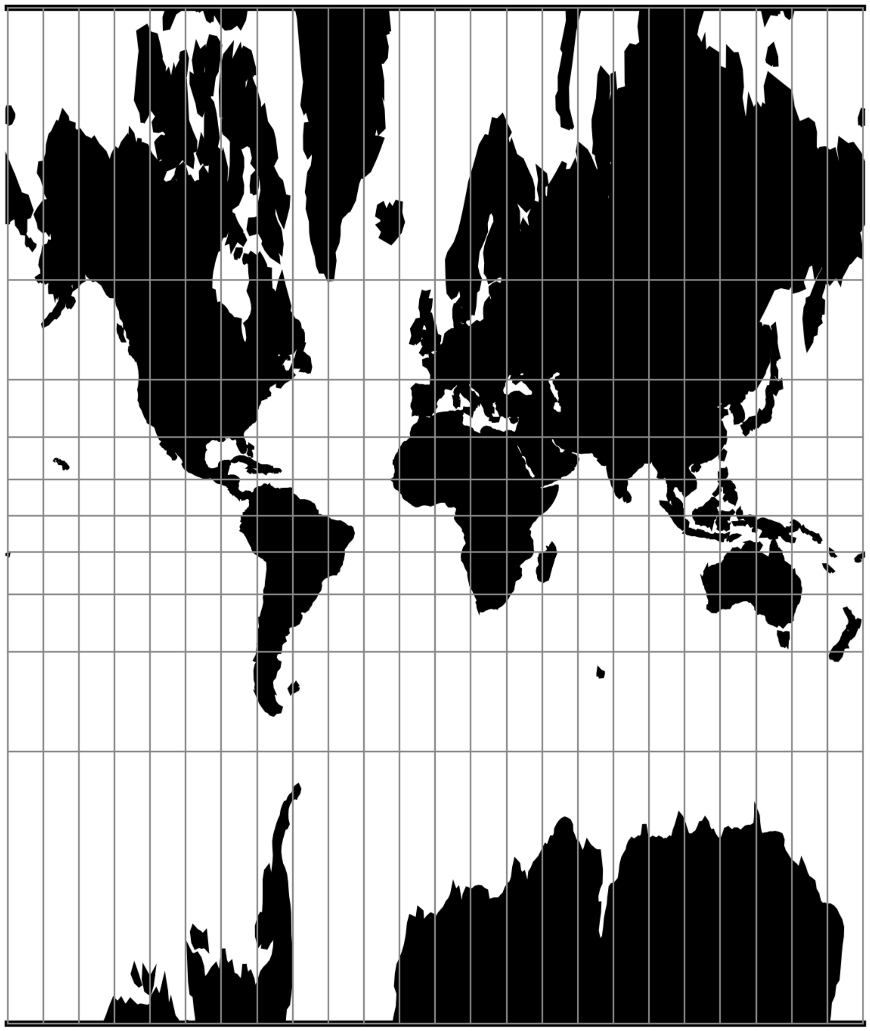


Fig. 17: proj-string: `+proj=cc`

Fig. 18: proj-string: `+proj=ccon +lat_1=52 +lon_0=19`

7.1.19.1 Usage

This simple projection is rarely used, as it is not equidistant, equal-area, nor conformal.

An example of usage (and the main reason to implement this projection in proj4) is the ATPOL geobotanical grid of Poland, developed in Institute of Botany, Jagiellonian University, Krakow, Poland in 1970s [Zajac1978]. The grid was originally handwritten on paper maps and further copied by hand. The projection (together with strange Earth radius) was chosen by its creators as the compromise fit to existing maps during first software development in DOS era. Many years later it is still de facto standard grid in Polish geobotanical research.

The ATPOL coordinates can be achieved with with the following parameters:

```
+proj=ccon +lat_1=52 +lon_0=19 +axis=esu +a=6390000 +x_0=330000 +y_0=-350000
```

For more information see [Komsta2016] and [Verey2017].

7.1.19.2 Parameters

Required

`+lat_1`=<value>

Standard parallel of projection.

Optional

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.19.3 Mathematical definition

Forward projection

$$r = \cot\phi_0 - \tan(\phi - \phi_0)$$

$$x = r\sin(\lambda\sin\phi_0)$$

$$y = \cot\phi_0 - r\cos(\lambda\sin\phi_0)$$

Inverse projection

$$y = \cot\phi_0 - y$$

$$\phi = \phi_0 - \tan^{-1}(\sqrt{x^2+y^2} - \cot\phi_0)$$

$$\lambda = \frac{\tan^{-1}\sqrt{x^2+y^2}}{\sin\phi_0}$$

7.1.19.4 Reference values

For ATPOL to WGS84 test, run the following script:

```
#!/bin/bash
cat << EOF | src/cs2cs -v -f "%E" +proj=ccon +lat_1=52 +lat_0=52 +lon_0=19 +axis=esu
↪+a=6390000 +x_0=330000 +y_0=-350000 +to +proj=longlat
0 0
0 700000
700000 0
```

(continues on next page)

(continued from previous page)

```
700000 700000
330000 350000
EOF
```

It should result with

```
1.384023E+01 5.503040E+01 0.000000E+00
1.451445E+01 4.877385E+01 0.000000E+00
2.478271E+01 5.500352E+01 0.000000E+00
2.402761E+01 4.875048E+01 0.000000E+00
1.900000E+01 5.200000E+01 0.000000E+00
```

Analogous script can be run for reverse test:

```
cat << EOF  | src/cs2cs -v -f "%E" +proj=longlat +to +proj=ccon +lat_1=52 +lat_0=52 +lon_
↪0=19 +axis=esu +a=6390000 +x_0=330000 +y_0=-350000
24 55
15 49
24 49
19 52
EOF
```

and it should give the following results:

```
6.500315E+05 4.106162E+03 0.000000E+00
3.707419E+04 6.768262E+05 0.000000E+00
6.960534E+05 6.722946E+05 0.000000E+00
3.300000E+05 3.500000E+05 0.000000E+00
```

7.1.20 Equal Area Cylindrical

Classification	Cylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	cea
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.20.1 Parameters

Note: All parameters are optional for the Equal Area Cylindrical projection.

`+lat_ts`=<value>

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over `+k_0` if both options are used together.

Defaults to 0.0.

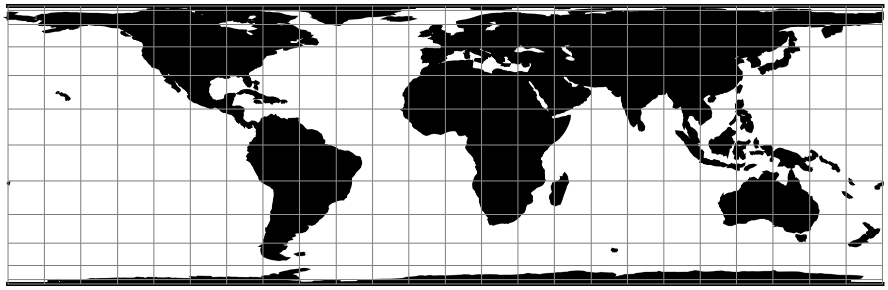


Fig. 19: proj-string: +proj=cea

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+ellps=<value>

See proj -le for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+k_0=<value>

Scale factor. Determines scale factor used in the projection.

Defaults to 1.0.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

Note: lat_ts and k_0 are mutually exclusive. If lat_ts is specified, it is equivalent to setting k_0 to $\frac{\cos\phi_{ts}}{\sqrt{1-e^2\sin^2\phi_{ts}}}$

7.1.21 Chamberlin Trimetric

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	chamb
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

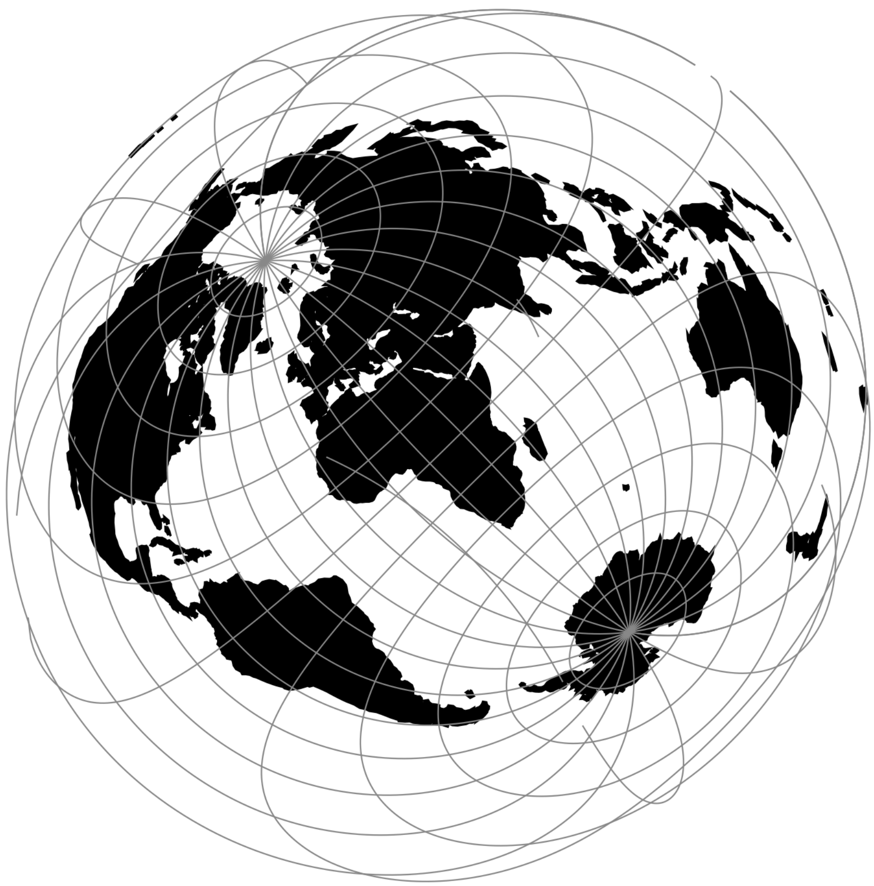


Fig. 20: proj-string: `+proj=chamb +lat_1=10 +lon_1=30 +lon_2=40`

7.1.21.1 Parameters

Required

Note: Control points should be oriented clockwise.

+lat_1=<value>
Latitude of the first control point.

+lon_1=<value>
Longitude of the first control point.

+lat_2=<value>
Latitude of the second control point.

+lon_2=<value>
Longitude of the second control point.

+lat_3=<value>
Latitude of the third control point.

+lon_3=<value>
Longitude of the third control point.

Optional

+lon_0=<value>
Longitude of projection center.

Defaults to 0.0.

+R=<value>
Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.22 Collignon

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	collg
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

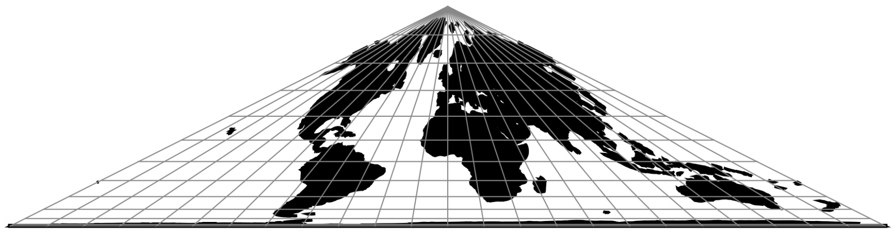


Fig. 21: proj-string: `+proj=collg`

7.1.22.1 Parameters

Note: All parameters are optional for the Collignon projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.23 Colombia Urban

New in version 7.2.

Classification	Miscellaneous
Available forms	Forward and inverse ellipsoidal projection
Alias	col_urban
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

From [IOGP2018]:

> The capital cites of each department in Colombia use an urban projection for large scale topographic mapping of the urban areas. It is based on a plane through the origin at an average height for the area, eliminating the need for corrections to engineering survey observations.

proj-string: `+proj=col_urban`

7.1.23.1 Parameters

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

+h_0=<value>

Projection plane origin height (in metre)

Defaults to 0.0.

7.1.24 Compact Miller

The Compact Miller projection is a cylindrical map projection with a height-to-width ratio of 0.6:1.

See [Jenny2015]

Classification	Cylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	comill
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.24.1 Parameters

Note: All parameters are optional for projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

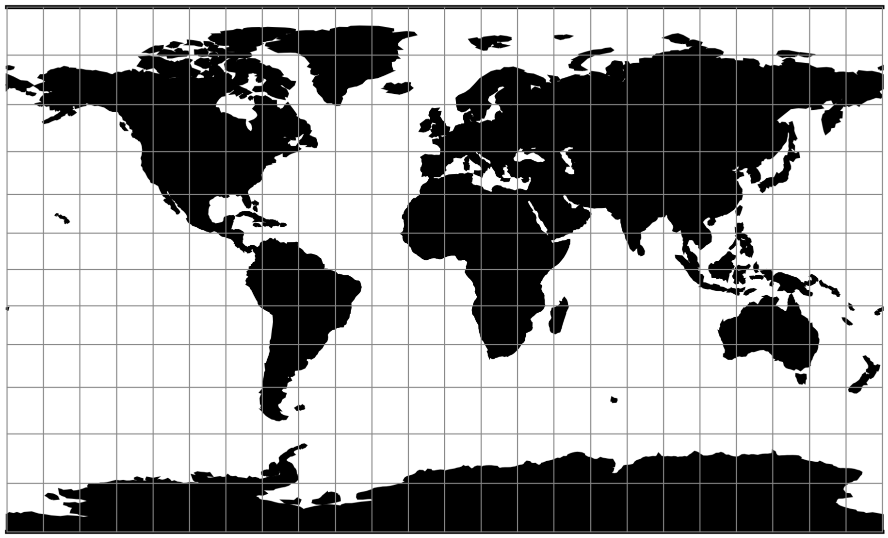


Fig. 22: proj-string: +proj=comill

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.25 Craster Parabolic (Putnins P4)

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	crast
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

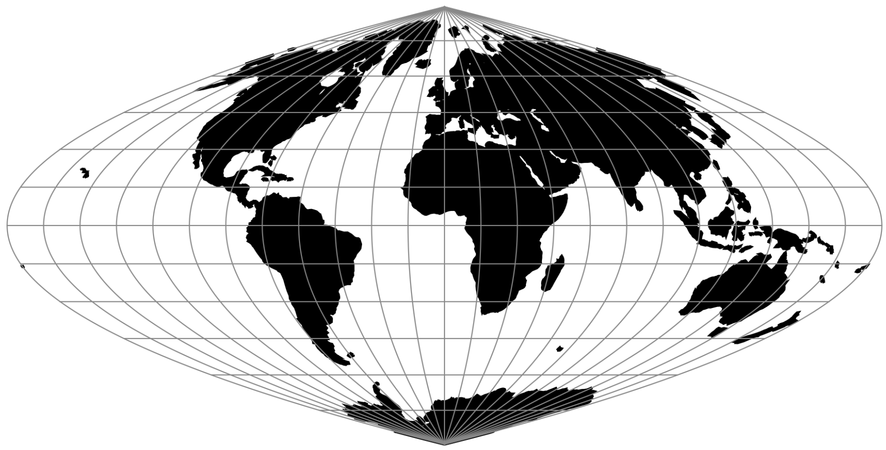


Fig. 23: proj-string: `+proj=crast`

7.1.25.1 Parameters

Note: All parameters are optional for the Craster Parabolic projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.26 Denoyer Semi-Elliptical

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	denoy
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

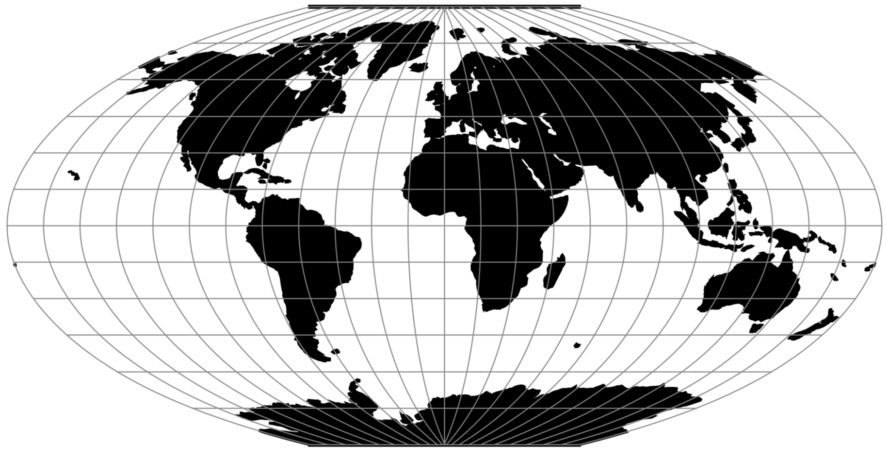


Fig. 24: proj-string: `+proj=denoy`

7.1.26.1 Parameters

Note: All parameters are optional for the Denoyer Semi-Elliptical projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.27 Eckert I

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	eck1
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

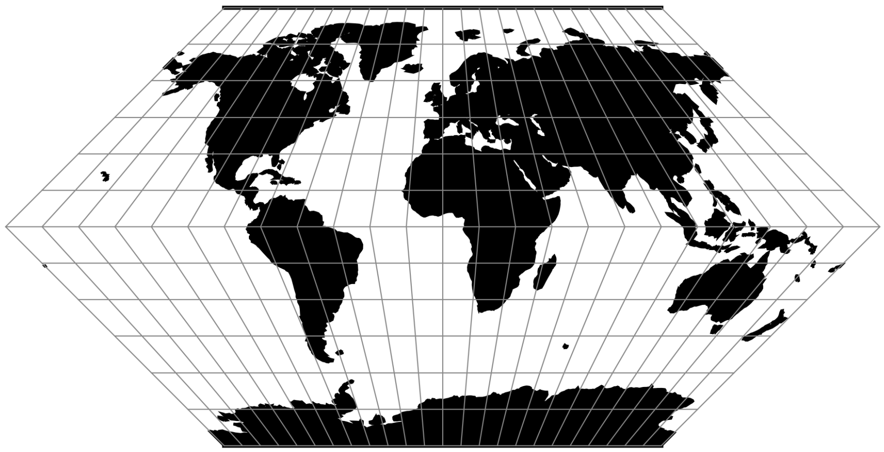


Fig. 25: proj-string: `+proj=eck1`

$$x = 2\sqrt{2/3\pi}\lambda(1 - |\phi|/\pi)$$
$$y = 2\sqrt{2/3\pi}\phi$$

7.1.27.1 Parameters

Note: All parameters are optional for the Eckert I projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.28 Eckert II

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	eck2
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

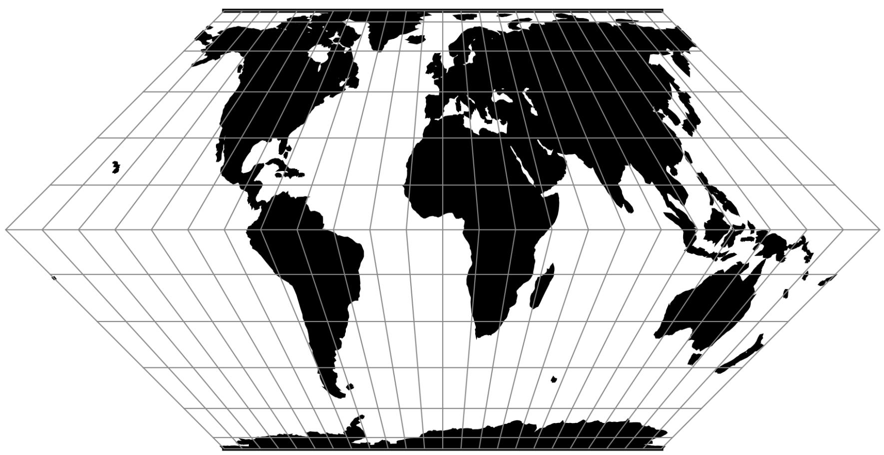


Fig. 26: proj-string: `+proj=eck2`

7.1.28.1 Parameters

Note: All parameters are optional for the Eckert II projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.29 Eckert III

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	eck3
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

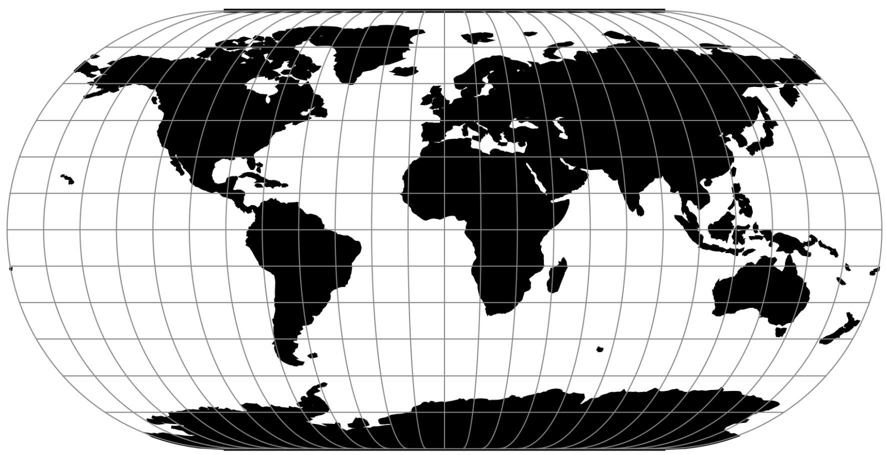


Fig. 27: proj-string: `+proj=eck3`

7.1.29.1 Parameters

Note: All parameters are optional for the Eckert III projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.30 Eckert IV

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	eck4
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

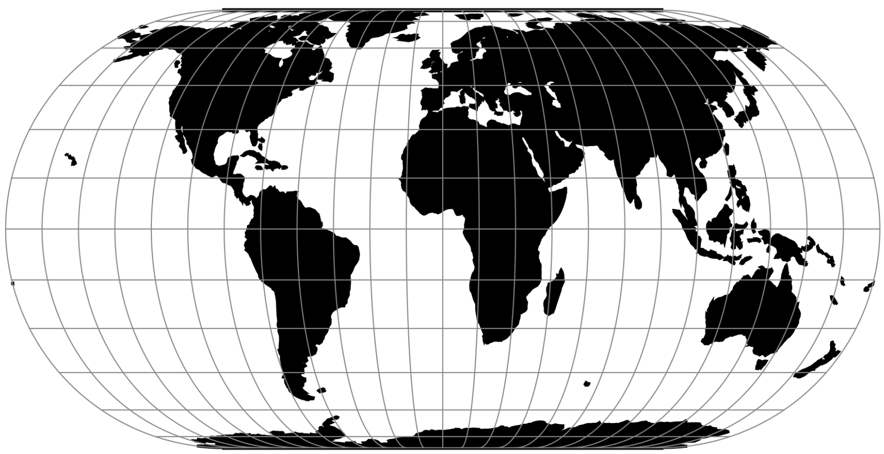


Fig. 28: proj-string: `+proj=eck4`

$$x = \lambda(1 + cos\phi)/\sqrt{2+\pi}$$

$$y = 2\phi/\sqrt{2+\pi}$$

7.1.30.1 Parameters

Note: All parameters are optional for the Eckert IV projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.31 Eckert V

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	eck5
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

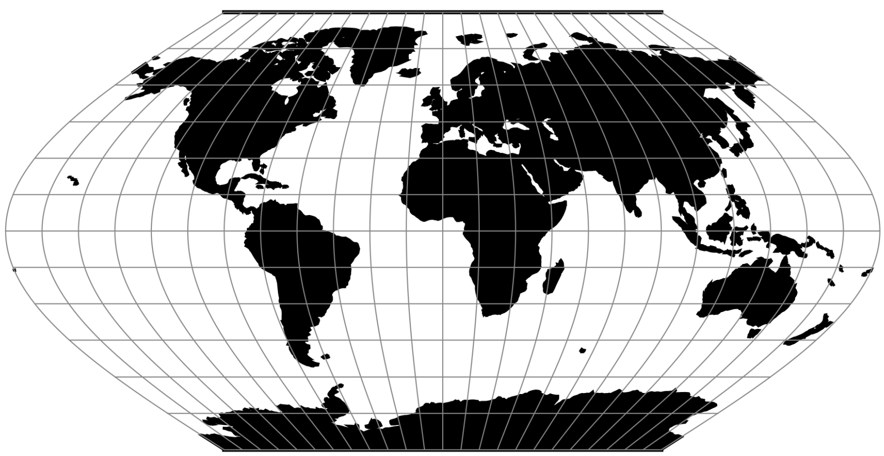


Fig. 29: proj-string: `+proj=eck5`

7.1.31.1 Parameters

Note: All parameters are optional for the Eckert V projection.

+lon_0=<value>
Longitude of projection center.

Defaults to 0.0.

+R=<value>
Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.32 Eckert VI

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	eck6
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

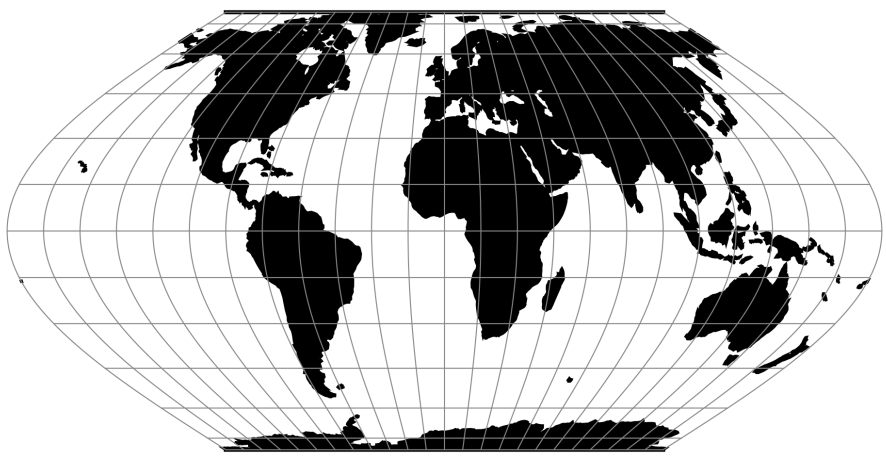


Fig. 30: proj-string: `+proj=eck6`

7.1.32.1 Parameters

Note: All parameters are optional for the Eckert VI projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.33 Equidistant Cylindrical (Plate Carrée)

The simplest of all projections. Standard parallels (0° when omitted) may be specified that determine latitude of true scale (k=h=1).

Classification	Conformal cylindrical
Available forms	Forward and inverse
Defined area	Global, but best used near the equator
Alias	eqc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

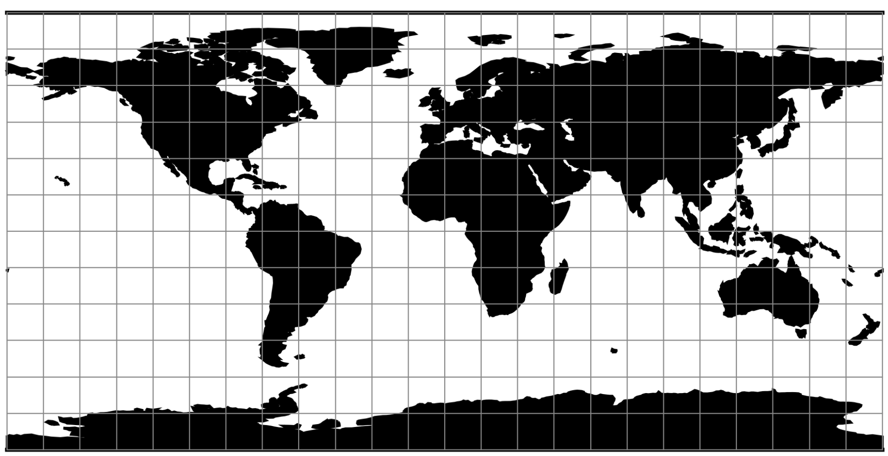


Fig. 31: proj-string: `+proj=eqc`

7.1.33.1 Usage

Because of the distortions introduced by this projection, it has little use in navigation or cadastral mapping and finds its main use in thematic mapping. In particular, the plate carrée has become a standard for global raster datasets, such as Celestia and NASA World Wind, because of the particularly simple relationship between the position of an image pixel on the map and its corresponding geographic location on Earth.

The following table gives special cases of the cylindrical equidistant projection.

Projection Name	(lat ts=) ϕ_0
Plain/Plane Chart	0°
Simple Cylindrical	0°
Plate Carrée	0°
Ronald Miller—minimum overall scale distortion	37°30′
E.Grafarend and A.Niermann	42°
Ronald Miller—minimum continental scale distortion	43°30′
Gall Isographic	45°
Ronald Miller Equirectangular	50°30′
E.Grafarend and A.Niermann minimum linear distortion	61°7′

Example using EPSG 32662 (WGS84 Plate Carrée):

```
$ echo 2 47 | proj +proj=eqc +lat_ts=0 +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +ellps=WGS84␣
↪+units=m
222638.98       5232016.07
```

Example using Plate Carrée projection with true scale at latitude 30° and central meridian 90°W:

```
$ echo -88 30 | proj +proj=eqc +lat_ts=30 +lon_0=90w
192811.01       3339584.72
```

7.1.33.2 Parameters

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+lat_ts=<value>

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over `+k_0` if both options are used together.

Defaults to 0.0.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

7.1.33.3 Mathematical definition

The formulas describing the Equidistant Cylindrical projection are all taken from [Snyder1987].

ϕ_{ts} is the latitude of true scale, that mean the standard parallels where the scale of the projection is true. It can be set with `+lat_ts`.

ϕ_0 is the latitude of origin that match the center of the map. It can be set with `+lat_0`.

Forward projection

$$x = \lambda \cos \phi_{ts}$$

$$y = \phi - \phi_0$$

Inverse projection

$$\lambda = x / cos \phi_{ts}$$

$$\phi = y + \phi_0$$

7.1.33.4 Further reading

1. Wikipedia
2. Wolfram Mathworld

7.1.34 Equidistant Conic

Classification	Conic
Available forms	Forward and inverse, ellipsoidal
Defined area	Global
Alias	eqdc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.34.1 Parameters

Required

+lat_1=<value>

First standard parallel.

Defaults to 0.0.

Fig. 32: proj-string: `+proj=eqdc +lat_1=55 +lat_2=60`

+lat_2=<value>

Second standard parallel.

Defaults to 0.0.

Optional

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.35 Equal Earth

New in version 5.2.0.

Classification	Pseudo cylindrical
Available forms	Forward and inverse, spherical and ellipsoidal projection
Defined area	Global
Alias	eqearth
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

The Equal Earth projection is intended for making world maps. Equal Earth is a projection inspired by the Robinson projection, but unlike the Robinson projection retains the relative size of areas. The projection was designed in 2018 by Bojan Savric, Tom Patterson and Bernhard Jenny [Savric2018].

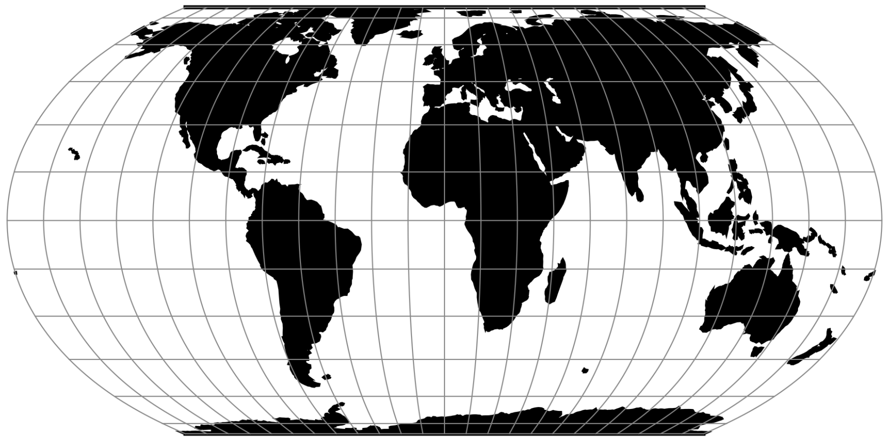


Fig. 33: proj-string: `+proj=eqearth`

7.1.35.1 Usage

The Equal Earth projection has no special options. Here is an example of an forward projection on a sphere with a radius of 1 m:

```
$ echo 122 47 | src/proj +proj=eqearth +R=1
1.55    0.89
```

7.1.35.2 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.35.3 Further reading

1. Bojan Savric, Tom Patterson & Bernhard Jenny (2018). The Equal Earth map projection, International Journal of Geographical Information Science

7.1.36 Euler

Classification	Miscellaneous
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	euler
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 34: proj-string: `+proj=euler +lat_1=67 +lat_2=75`

7.1.36.1 Parameters

Required

`+lat_1=<value>`

First standard parallel.

Defaults to 0.0.

`+lat_2=<value>`

Second standard parallel.

Defaults to 0.0.

Optional

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.37 Fahey

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	fahey
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

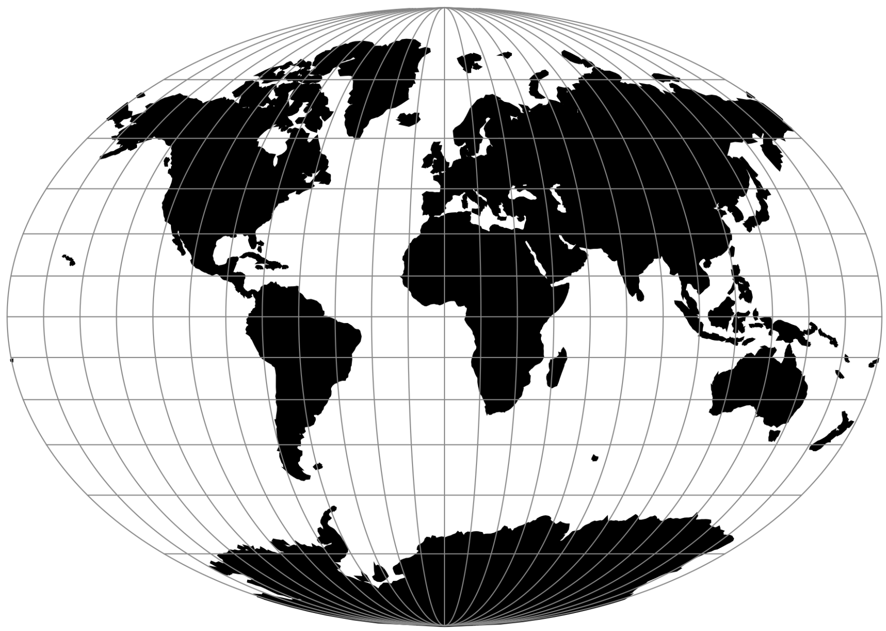


Fig. 35: proj-string: `+proj=fahey`

7.1.37.1 Parameters

Note: All parameters are optional for the Fahey projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.38 Foucault

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	fouc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

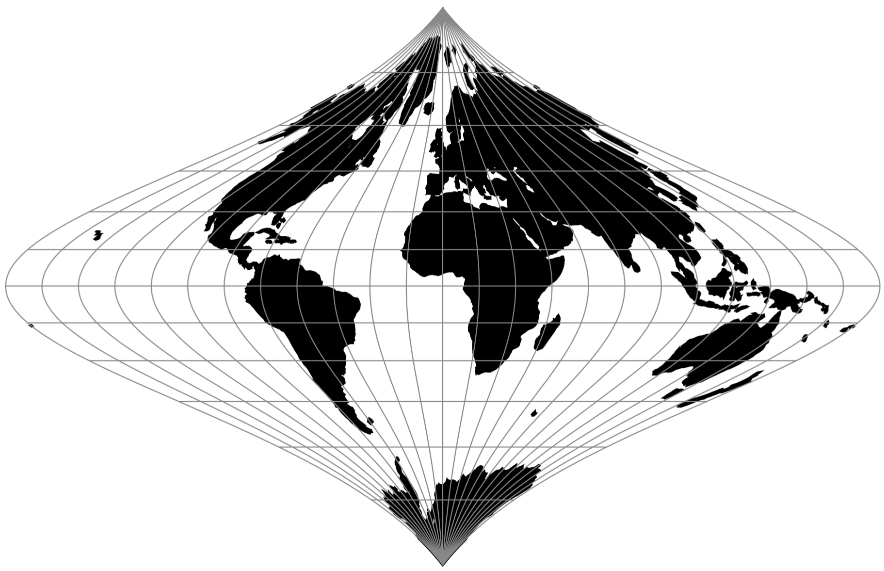


Fig. 36: proj-string: `+proj=fouc`

7.1.38.1 Parameters

Note: All parameters are optional for the Foucault projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.39 Foucaut Sinusoidal

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	fouc_s
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

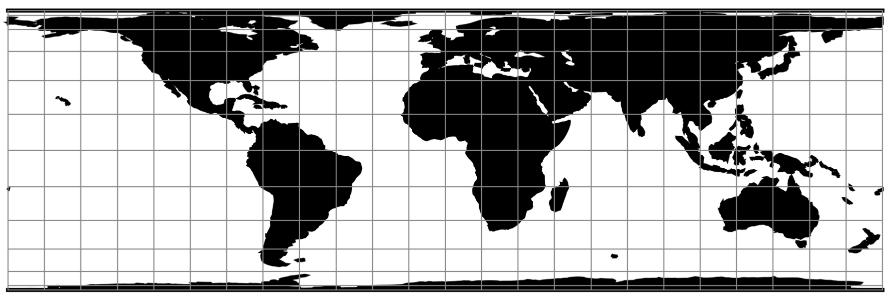


Fig. 37: proj-string: `+proj=fouc_s`

The *y*-axis is based upon a weighted mean of the cylindrical equal-area and the sinusoidal projections. Parameter $n = n$ is the weighting factor where $0 <= n <= 1$.

$$x = \lambda \cos\phi / (n + (1 - n)\ cos\phi)$$
$$y = n\phi + (1 - n) \sin\phi$$

For the inverse, the Newton-Raphson method can be used to determine ϕ from the equation for y above. As $n \to 0$ and $\phi \to \pi/2$, convergence is slow but for $n = 0$, $\phi = \sin^1 y$

7.1.39.1 Parameters

Note: All parameters are optional for the Foucaut Sinusoidal projection.

`+n=<value>`

Weighting factor. Value should be in the interval 0-1.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

+R=<value>
Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.40 Gall (Gall Stereographic)

The Gall stereographic projection, presented by James Gall in 1855, is a cylindrical projection. It is neither equal-area nor conformal but instead tries to balance the distortion inherent in any projection.

Classification	Transverse and oblique cylindrical
Available forms	Forward and inverse, Spherical
Defined area	Global
Alias	gall
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

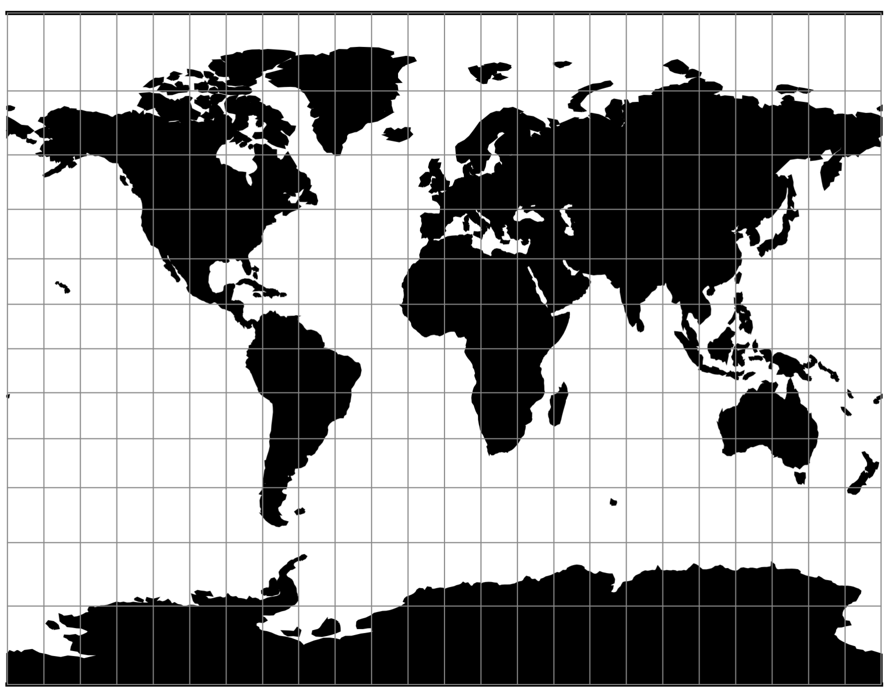


Fig. 38: proj-string: +proj=gall

7.1.40.1 Usage

The need for a world map which avoids some of the scale exaggeration of the Mercator projection has led to some commonly used cylindrical modifications, as well as to other modifications which are not cylindrical. The earliest common cylindrical example was developed by James Gall of Edinburgh about 1855 (Gall, 1885, p. 119-123). His meridians are equally spaced, but the parallels are spaced at increasing intervals away from the Equator. The parallels of latitude are actually projected onto a cylinder wrapped about the sphere, but cutting it at lats. 45° N. and S., the point of perspective being a point on the Equator opposite the meridian being projected. It is used in several British atlases, but seldom in the United States. The Gall projection is neither conformal nor equal-area, but has a blend of various features. Unlike the Mercator, the Gall shows the poles as lines running across the top and bottom of the map.

Example using Gall Stereographic

```
$ echo 9 51 | proj +proj=gall +lon_0=0 +x_0=0 +y_0=0 +ellps=WGS84 +units=m
708432.90   5193386.36
```

Example using Gall Stereographic (Central meridian 90°W)

```
$ echo 9 51 | proj +proj=gall +lon_0=90w +x_0=0 +y_0=0 +ellps=WGS84 +units=m
7792761.91  5193386.36
```

7.1.40.2 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

7.1.40.3 Mathematical definition

The formulas describing the Gall Stereographic are all taken from [Snyder1993].

Spherical form

Forward projection

$$x = \frac{\lambda}{\sqrt{2}}$$

$$y = (1 + \frac{\sqrt{2}}{2}) \tan(\phi/2)$$

Inverse projection

$$\phi = 2 \arctan(\frac{y}{1 + \frac{\sqrt{2}}{2}})$$

$$\lambda = \sqrt{2}x$$

7.1.40.4 Further reading

1. Wikipedia
2. Cartographic Projection Procedures for the UNIX Environment-A User's Manual

7.1.41 Geostationary Satellite View

The geos projection pictures how a geostationary satellite scans the earth at regular scanning angle intervals.

Classification	Azimuthal
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	geos
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 39: proj-string: `+proj=geos +h=35785831.0 +lon_0=-60 +sweep=y`

7.1.41.1 Usage

In order to project using the geos projection you can do the following:

```
proj +proj=geos +h=35785831.0
```

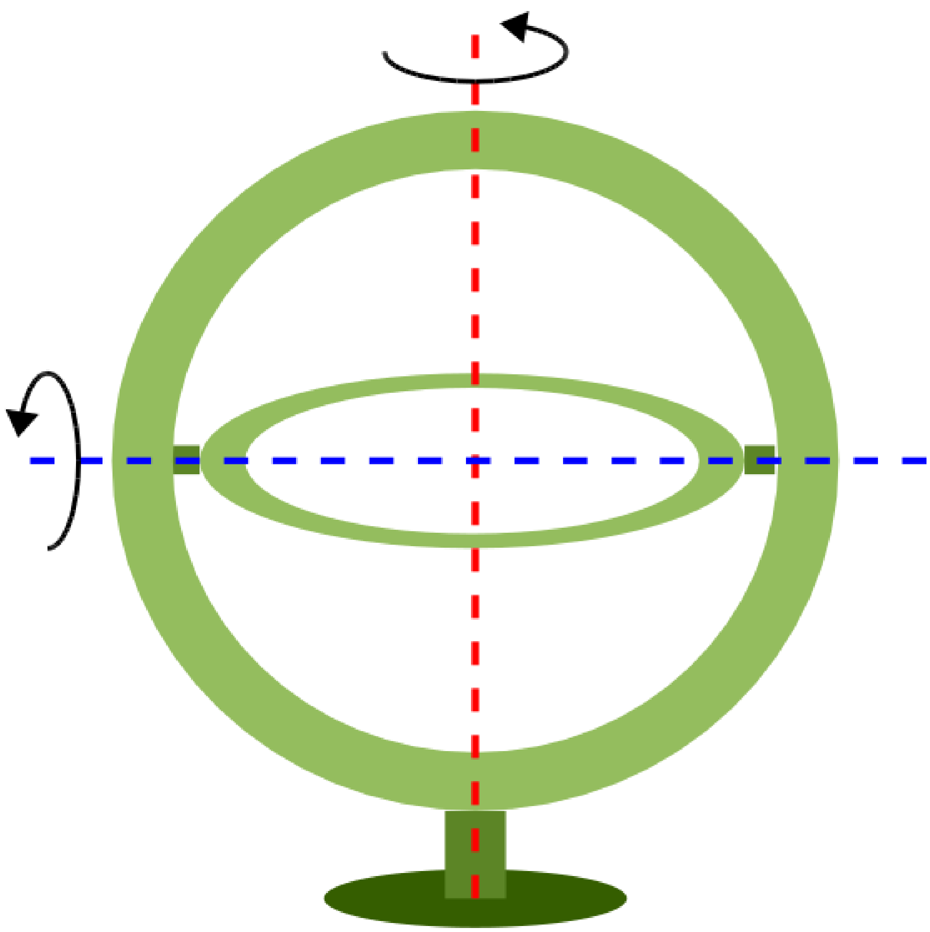
The required argument h is the viewing point (satellite position) height above the earth.

The projection coordinate relate to the scanning angle by the following simple relation:

```
scanning_angle (radians) = projection_coordinate / h
```

Note on sweep angle

The viewing instrument on-board geostationary satellites described by this projection have a two-axis gimbal viewing geometry. This means that the different scanning positions are obtained by rotating the gimbal along a N/S axis (or y) and a E/W axis (or x).



In the image above, the outer-gimbal axis, or sweep-angle axis, is the N/S axis (y) while the inner-gimbal axis, or fixed-angle axis, is the E/W axis (x).

This example represents the scanning geometry of the Meteosat series satellite. However, the GOES satellite series use the opposite scanning geometry, with the E/W axis (`x`) as the sweep-angle axis, and the N/S (`y`) as the fixed-angle axis.

The sweep argument is used to tell PROJ which on which axis the outer-gimbal is rotating. The possible values are x or y, y being the default. Thus, the scanning geometry of the Meteosat series satellite should take sweep as y, and GOES should take sweep as x.

7.1.41.2 Parameters

Required

+h=<value>
Height of the view point above the Earth and must be in the same units as the radius of the sphere or semimajor axis of the ellipsoid.

Optional

+sweep=<axis>
Sweep angle axis of the viewing instrument. Valid options are *"x"* and *"y"*.

Defaults to "y".

+lon_0=<value>
Longitude of projection center.

Defaults to 0.0.

+R=<value>
Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+ellps=<value>
See *proj -le* for a list of available ellipsoids.

Defaults to "GRS80".

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.42 Ginsburg VIII (TsNIIGAiK)

Classification	Pseudocylindrical
Available forms	Forward spherical projection
Defined area	Global
Alias	gins8
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 40: proj-string: `+proj=gins8`

7.1.42.1 Parameters

Note: All parameters are optional for the Ginsburg VIII projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.43 General Sinusoidal Series

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	gn_sinu
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

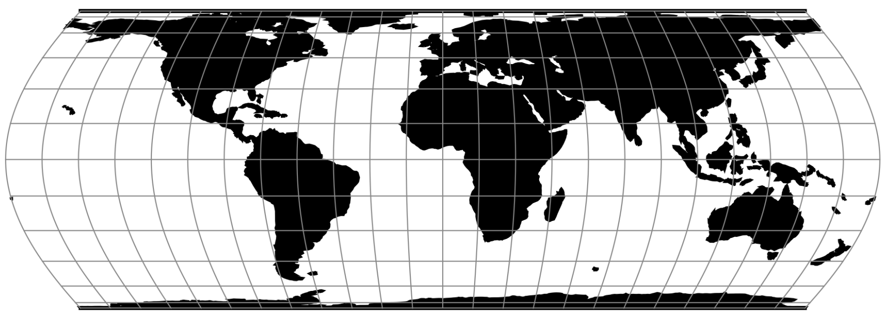


Fig. 41: proj-string: `+proj=gn_sinu +m=2 +n=3`

7.1.43.1 Parameters

Note: All parameters are optional for the General Sinusoidal Series projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.44 Gnomonic

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	gnom
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

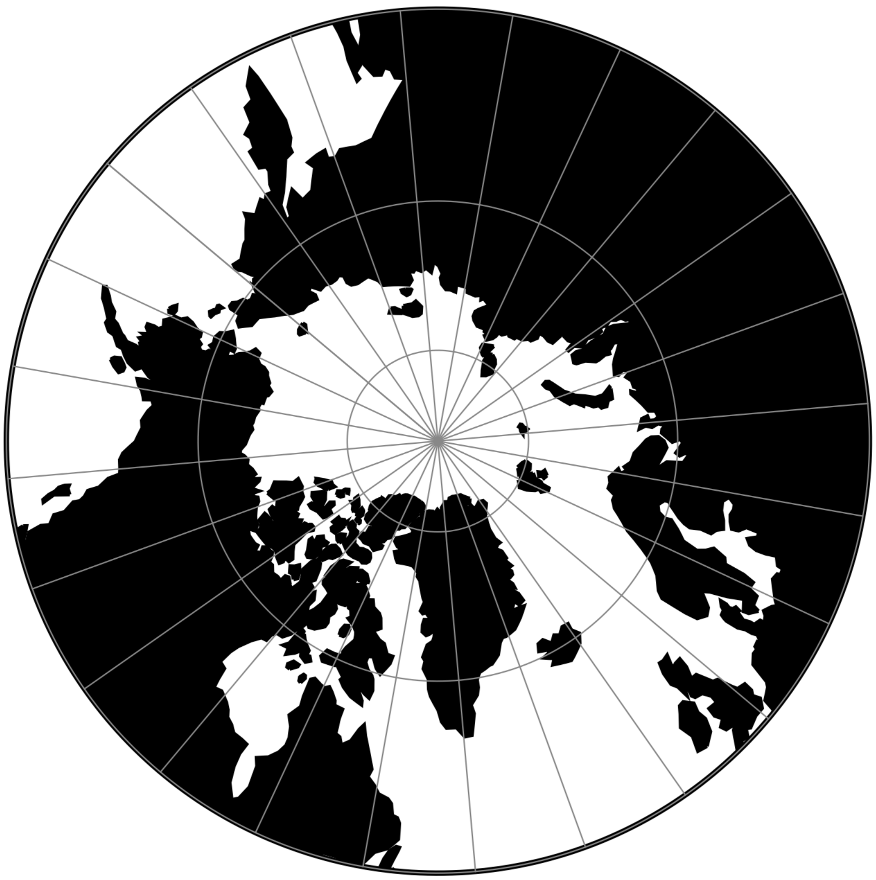


Fig. 42: proj-string: `+proj=gnom +lat_0=90 +lon_0=-50`

7.1.44.1 Parameters

Note: All parameters are optional for the Gnomonic projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.45 Goode Homolosine

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	goode
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

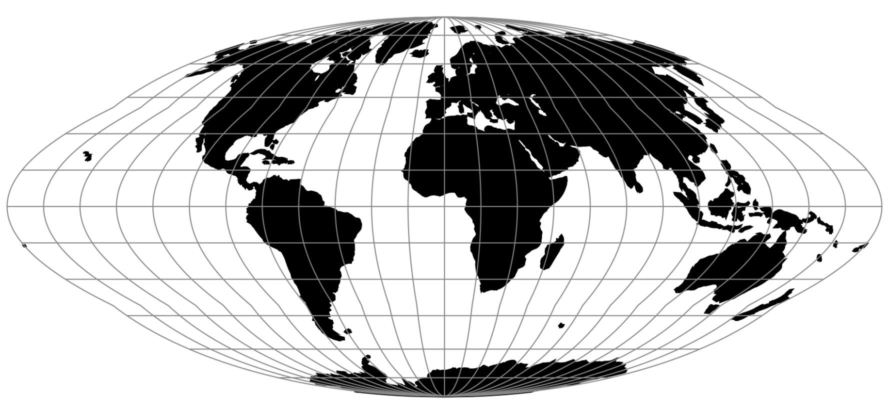


Fig. 43: proj-string: `+proj=goode`

7.1.45.1 Parameters

Note: All parameters are optional for the Goode Homolosine projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.46 Modified Stereographic of 48 U.S.

Classification	Azimuthal
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	The lower 48 states of the U.S.
Alias	gs48
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

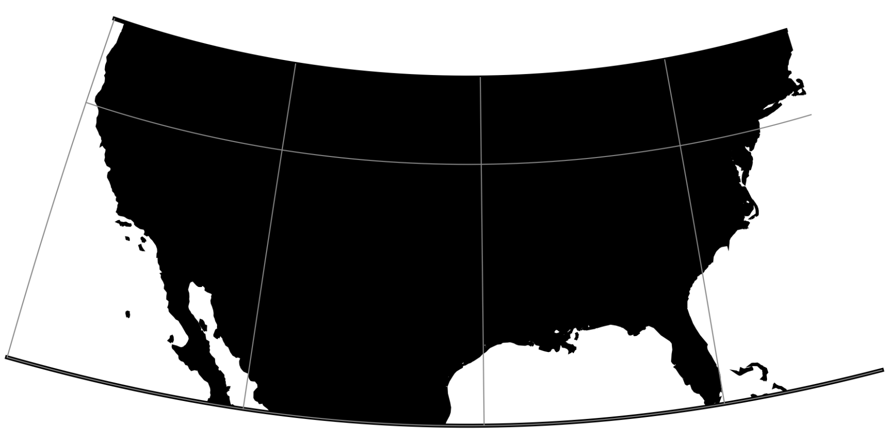


Fig. 44: proj-string: `+proj=gs48`

7.1.46.1 Parameters

Note: All parameters are optional for the projection.

+ellps=<value>

See *proj -le* for a list of available ellipsoids.

Defaults to "GRS80".

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.47 Modified Stereographic of 50 U.S.

Classification	Azimuthal
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	All 50 states of the U.S.
Alias	gs50
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 45: proj-string: `+proj=gs50`

7.1.47.1 Parameters

Note: All parameters are optional for the projection.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.48 Guyou

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	guyou
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.48.1 Parameters

Note: All parameters are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

Fig. 46: proj-string: `+proj=guyou`

7.1.49 Hammer & Eckert-Greifendorff

Classification	Azimuthal
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	hammer
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

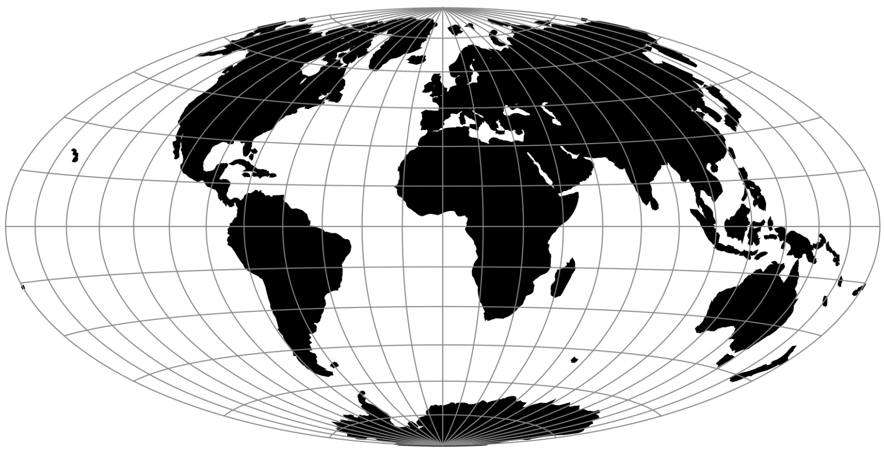


Fig. 47: proj-string: `+proj=hammer`

7.1.49.1 Parameters

Note: All parameters are optional for the projection.

`+W=<value>`

Set to 0.5 for the Hammer projection and 0.25 for the Eckert-Greifendorff projection. *+W* has to be larger than zero.

Defaults to 0.5.

`+M=<value>`

+M has to be larger than zero.

Defaults to 1.0.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.50 Hatano Asymmetrical Equal Area

Classification	*Pseudocylindrical Projection*
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	hatano
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

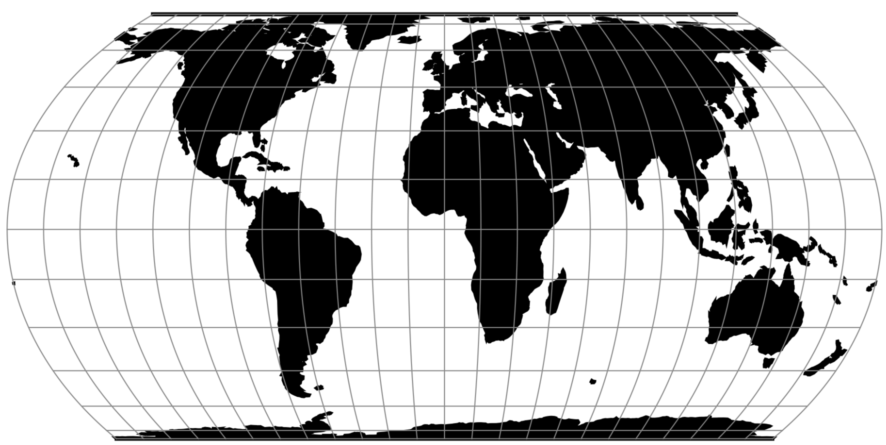


Fig. 48: proj-string: `+proj=hatano`

7.1.50.1 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

Mathematical Definition

Forward

$$x = 0.85\lambda \cos\theta$$
$$y = C_y \sin\theta$$
$$P(\theta) = 2\theta + \sin 2\theta - C_p \sin\phi$$
$$P'(\theta) = 2(1 + \cos 2\theta)$$
$$\theta_0 = 2\phi$$

Condition	C_y	C_p
For $\phi > 0$	1.75859	2.67595
For $\phi < 0$	1.93052	2.43763

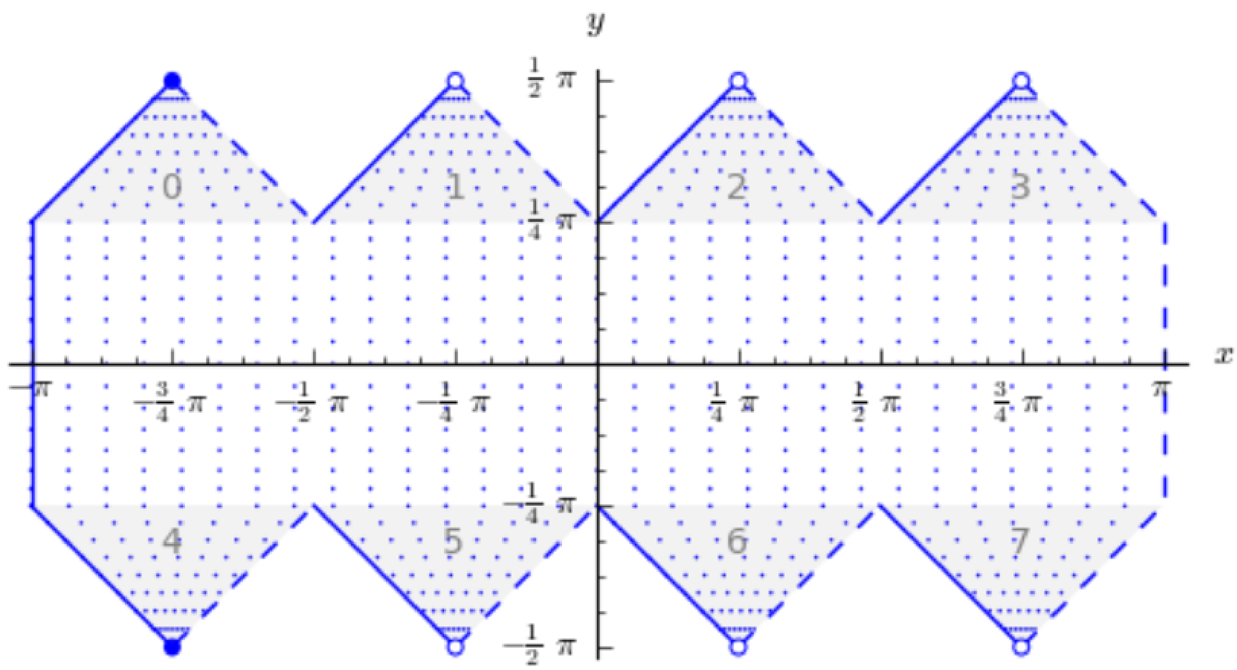
For $\phi = 0$, $y \leftarrow 0$, and $x \leftarrow 0.85\lambda$.

Further reading

1. Compare Map Projections
2. Mathworks

7.1.51 HEALPix

Classification	Miscellaneous
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	healpix
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates



The HEALPix projection is area preserving and can be used with a spherical and ellipsoidal model. It was initially developed for mapping cosmic background microwave radiation. The image below is the graphical representation of the mapping and consists of eight isomorphic triangular interrupted map graticules. The north and south contains four in which straight meridians converge polewards to a point and unequally spaced horizontal parallels. HEALPix provides a mapping in which points of equal latitude and equally spaced longitude are mapped to points of equal latitude and equally spaced longitude with the module of the polar interruptions.

7.1.51.1 Usage

To run a forward HEALPix projection on a unit sphere model, use the following command:

```
proj +proj=healpix +lon_0=0 +a=1 -E <<EOF
0 0
EOF
# output
0 0 0.00 0.00
```

7.1.51.2 Parameters

Note: All parameters for the projection are optional.

+rot_xy

New in version 6.3.0.

Rotation of the HEALPix map in degrees. A positive value results in a clockwise rotation around (x_0, y_0) in the cartesian / projected coordinate space.

Defaults to 0.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

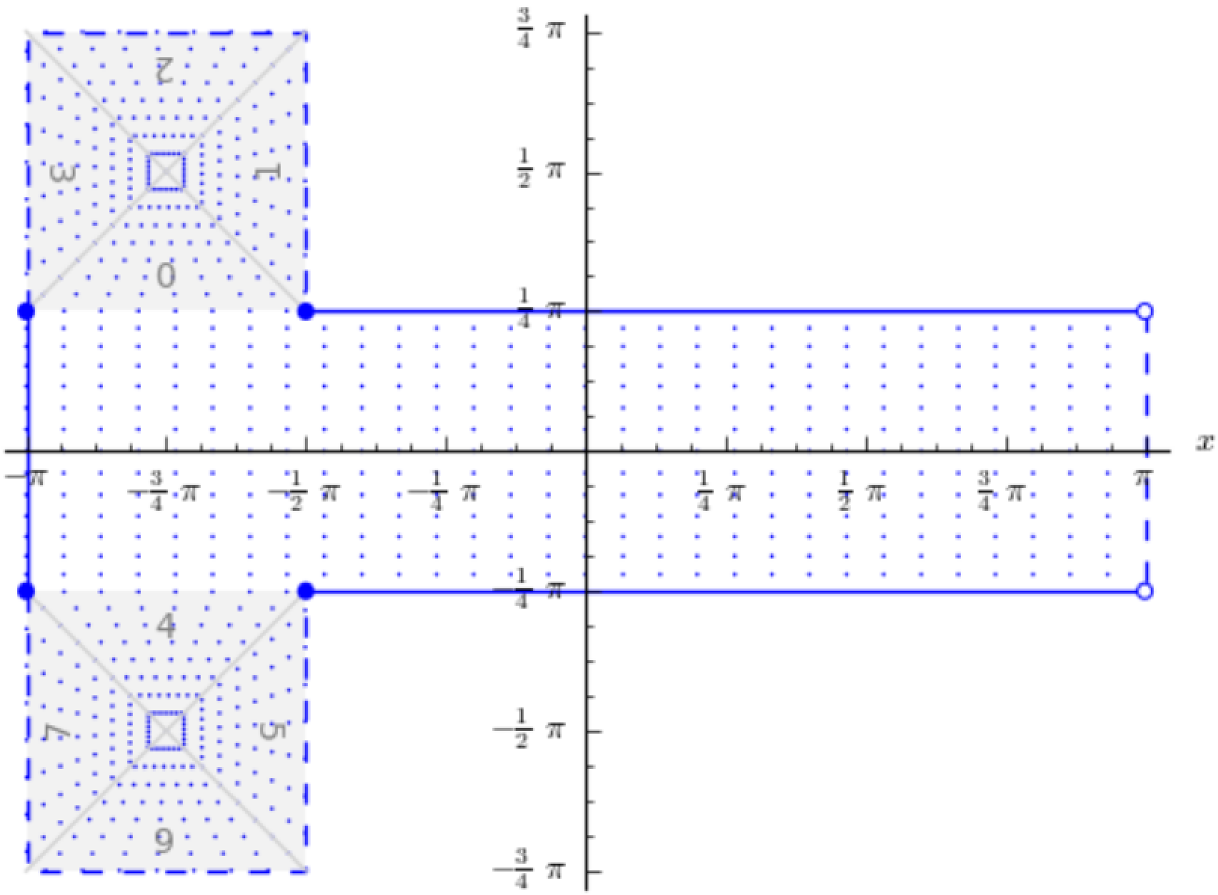
Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

7.1.51.3 Further reading

1. NASA
2. Wikipedia

7.1.52 rHEALPix

Classification	Miscellaneous
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	rhealpix
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates



rHEALPix is a projection based on the HEALPix projection. The implementation of rHEALPix uses the HEALPix projection. The rHEALPix combines the peaks of the HEALPix into a square. The square's position can be translated and rotated across the x-axis which is a novel approach for the rHEALPix projection. The initial intention of using rHEALPix in the Spatial Computation Engine Science Collaboration Environment (SCENZGrid).

7.1.52.1 Usage

To run a rHEALPix projection on a WGS84 ellipsoidal model, use the following command:

```
proj +proj=rhealpix -f '%.2f' +ellps=WGS84 +south_square=0 +north_square=2  -E << EOF
> 55 12
> EOF
55 12   6115727.86  1553840.13
```

7.1.52.2 Parameters

Note: All parameters for the projection are optional.

`+north_square`

Position of the north polar square. Valid inputs are 0–3.

Defaults to 0.0.

`+south_square`

Position of the south polar square. Valid inputs are 0–3.

Defaults to 0.0.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+ellps=<value>`

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.52.3 Further reading

1. NASA
2. Wikipedia

7.1.53 Interrupted Goode Homolosine

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	igh
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

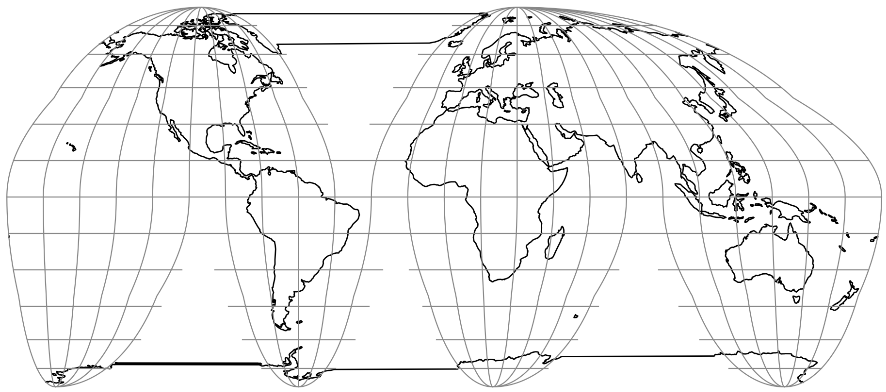


Fig. 49: proj-string: `+proj=igh`

7.1.53.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`
Longitude of projection center.

Defaults to 0.0.

`+R=<value>`
Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`
False easting.

Defaults to 0.0.

`+y_0=<value>`
False northing.

Defaults to 0.0.

7.1.54 Interrupted Goode Homolosine (Oceanic View)

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	igh_o
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

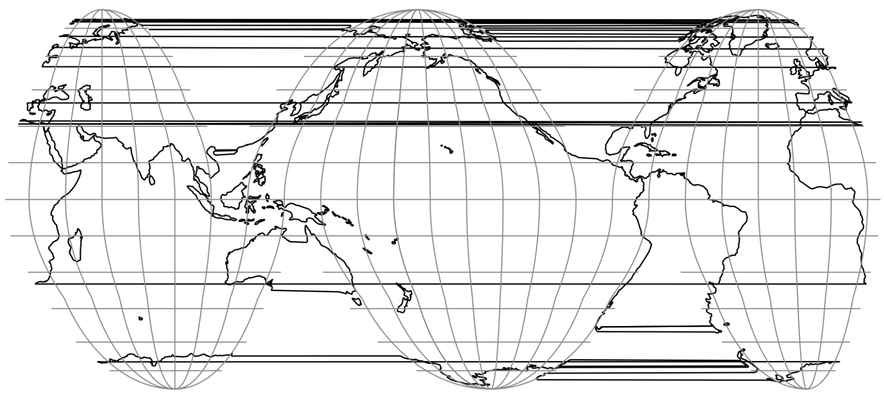


Fig. 50: proj-string: `+proj=igh_o +lon_0=-160`

7.1.54.1 Parameters

Note: All parameters are optional for the projection. A value of +lon_0=-160 is recommended.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.55 International Map of the World Polyconic

Classification	Pseudoconical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	imw_p
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

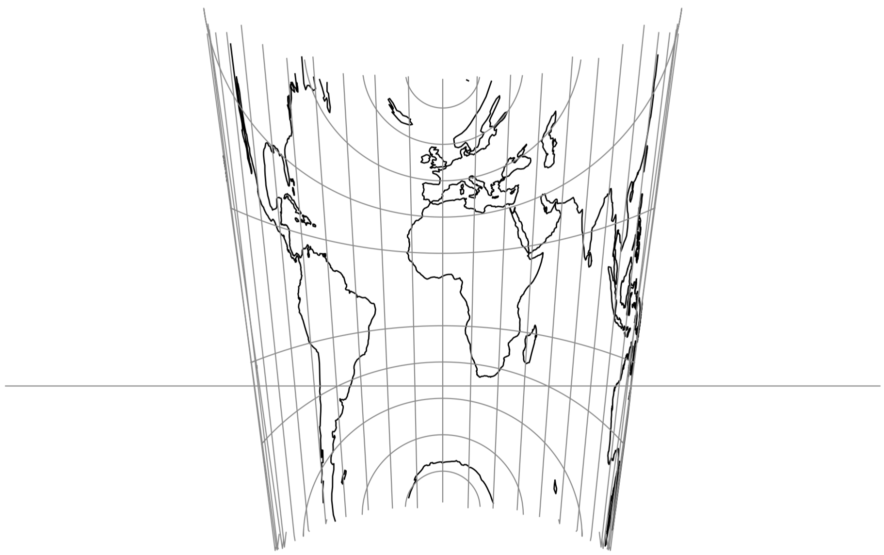


Fig. 51: proj-string: +proj=imw_p +lat_1=30 +lat_2=-40

7.1.55.1 Parameters

Required

+lat_1=<value>

First standard parallel.

Defaults to 0.0.

+lat_2=<value>

Second standard parallel.

Defaults to 0.0.

Optional

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.56 Icosahedral Snyder Equal Area

Snyder's Icosahedral Equal Area map projections on polyhedral globes for the dodecahedron and truncated icosahedron offer relatively low scale and angular distortion. The equations involved are relatively straight-forward, and for certain instructional tools and databases, the projections are useful for world maps. The interruptions remain a disadvantage, as with any low-error projection system applied to the entire globe [Snyder1992].

Classification	Polyhedral, equal area
Available forms	Forward, spherical
Defined area	Global
Alias	isea
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

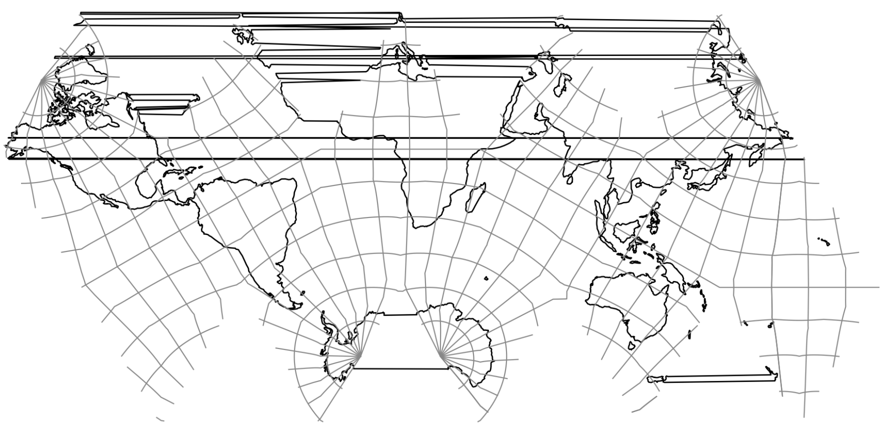


Fig. 52: proj-string: `+proj=isea`

7.1.56.1 Parameters

Note: All parameters are optional for the projection.

`+orient=<string>`

Can be set to either `isea` or `pole`. See Snyder's Figure 12 for pole orientation [Snyder1992].

Defaults to isea

`+azi=<value>`

Azimuth.

Defaults to 0.0

`+aperture=<value>`

Defaults to 3.0

`+resolution=<value>`

Defaults to 4.0

`+mode=<string>`

Can be either `plane`, `di`, `dd` or `hex`.

Defaults to plane

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+lat_0=<value>`

Latitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.57 Kavraisky V

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	kav5
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.57.1 Parameters

Note: All parameters are optional for the Kavraisky V projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

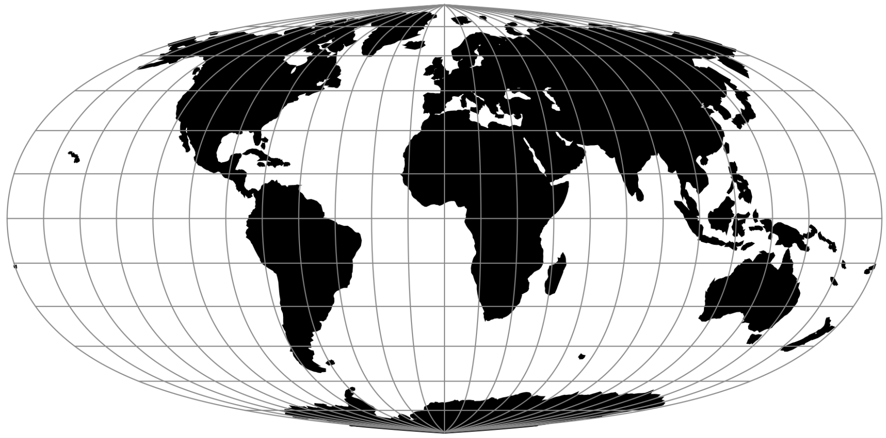


Fig. 53: proj-string: `+proj=kav5`

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.58 Kavraisky VII

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	kav7
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

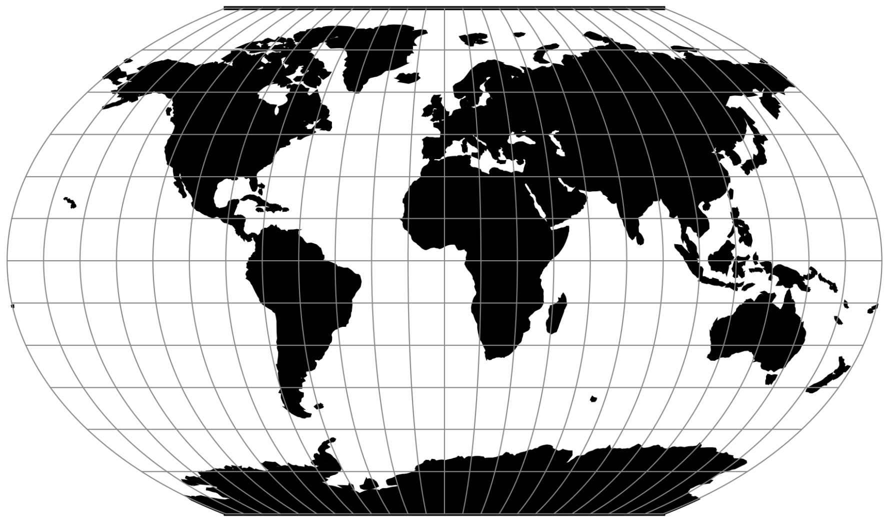


Fig. 54: proj-string: +proj=kav7

7.1.58.1 Parameters

Note: All parameters are optional for the Kavraisky VII projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.59 Krovak

Classification	Conical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global, but more accurate around Czechoslovakia
Alias	krovak
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 55: proj-string: `+proj=krovak`

7.1.59.1 Parameters

Note: All parameters are optional for the Krovak projection.

The latitude of pseudo standard parallel is hardcoded to 78.5° and the ellipsoid to Bessel.

+czech

Reverse the sign of the output coordinates, as is tradition in the Czech Republic.

+lon_0=<value>

Longitude of projection center.

Defaults to 24°50' (24.8333333333333)

+lat_0=<value>

Latitude of projection center.

Defaults to 49.5

+k_0=<value>

Scale factor. Determines scale factor used in the projection.

Defaults to 0.9999

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.60 Laborde

Classification	Cylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global, but more accurate around Madagascar
Alias	labrd
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.60.1 Parameters

Required

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

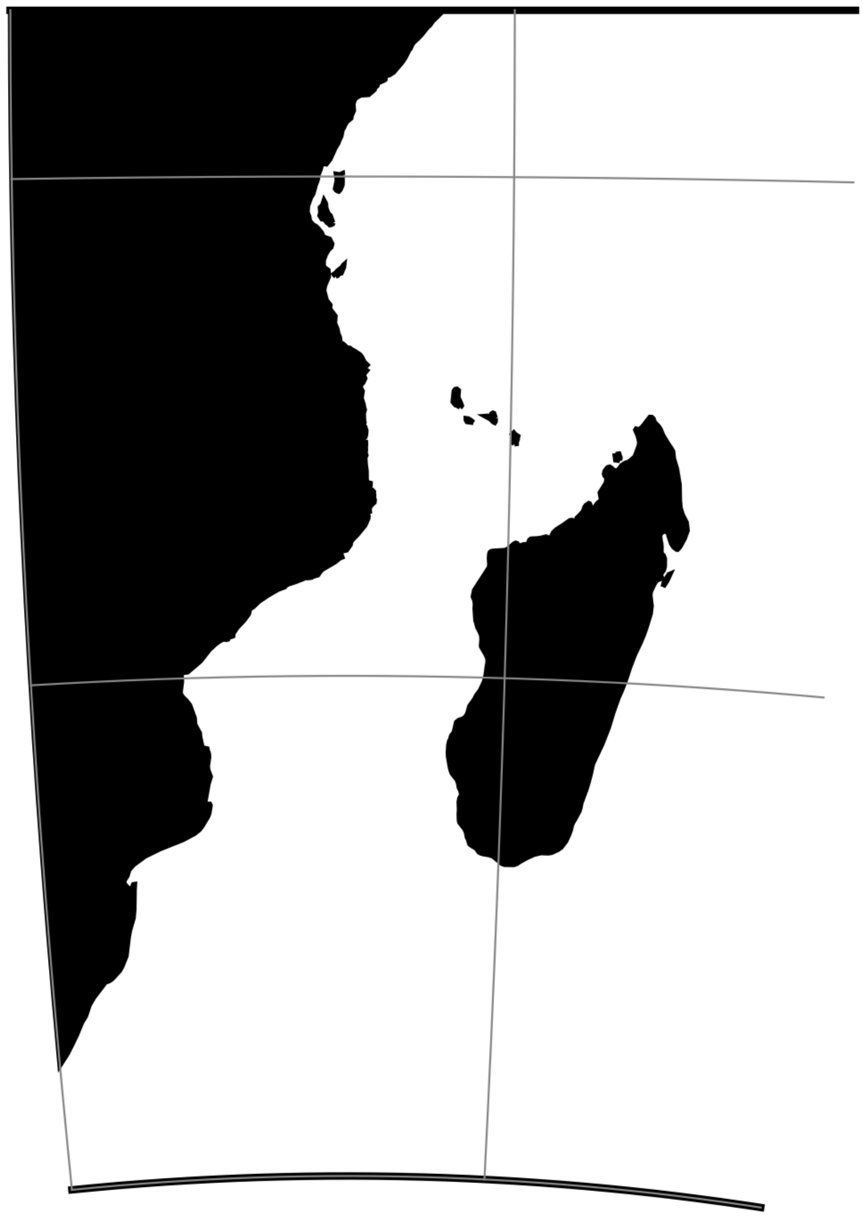


Fig. 56: proj-string: `+proj=labrd +lon_0=40 +lat_0=-10`

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

Optional

+azi=<value>

Azimuth of the central line.

Defaults to 0.0

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.61 Lambert Azimuthal Equal Area

Classification	Azimuthal
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	laea
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.61.1 Parameters

Note: All parameters are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

Fig. 57: proj-string: `+proj=laea`

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.62 Lagrange

Classification	Miscellaneous
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	lagrng
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.62.1 Parameters

Note: All parameters are optional for the projection.

+W=<value>

The factor `+W` is the ratio of the difference in longitude from the central meridian to the a circular meridian to 90. `+W` must be a positive value.

Defaults to 2.0

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+lat_1=<value>

First standard parallel.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

Fig. 58: proj-string: +proj=lagrng

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.63 Larrivee

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	larr
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 59: proj-string: `+proj=larr`

7.1.63.1 Parameters

Note: All parameters are optional for the Larrivee projection.

+lon_0=<value>
Longitude of projection center.

Defaults to 0.0.

+R=<value>
Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.64 Laskowski

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	lask
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.64.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
Longitude of projection center.

Defaults to 0.0.

+R=<value>
Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

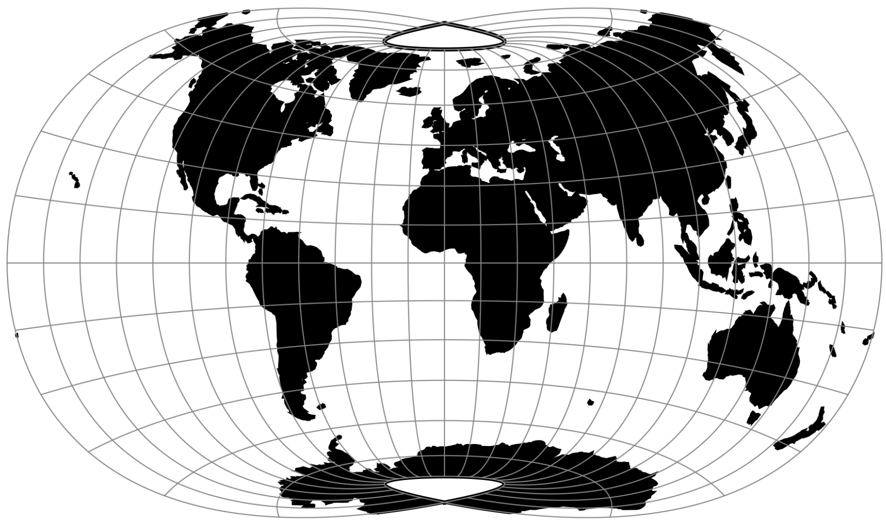


Fig. 60: proj-string: `+proj=lask`

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.65 Lambert Conformal Conic

A Lambert Conformal Conic projection (LCC) is a conic map projection used for aeronautical charts, portions of the State Plane Coordinate System, and many national and regional mapping systems. It is one of seven projections introduced by Johann Heinrich Lambert in 1772.

It has several different forms: with one and two standard parallels (referred to as 1SP and 2SP in EPSG guidance notes). Additionally we provide "2SP Michigan" form which is very similar to normal 2SP, but with a scaling factor on the ellipsoid (given as *k_0* parameter). It is implemented as per EPSG Guidance Note 7-2 (version 54, August 2018, page 25). It is used in a few systems in the EPSG database which justifies adding this otherwise non-standard projection.

Classification	Conformal conic
Available forms	Forward and inverse, spherical and ellipsoidal . One or two standard parallels (1SP and 2SP). "LCC 2SP Michigan" form can be used by setting `+k_0` parameter to specify ellipsoid scale.
Defined area	Best for regions predominantly east–west in extent and located in the middle north or south latitudes.
Alias	lcc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

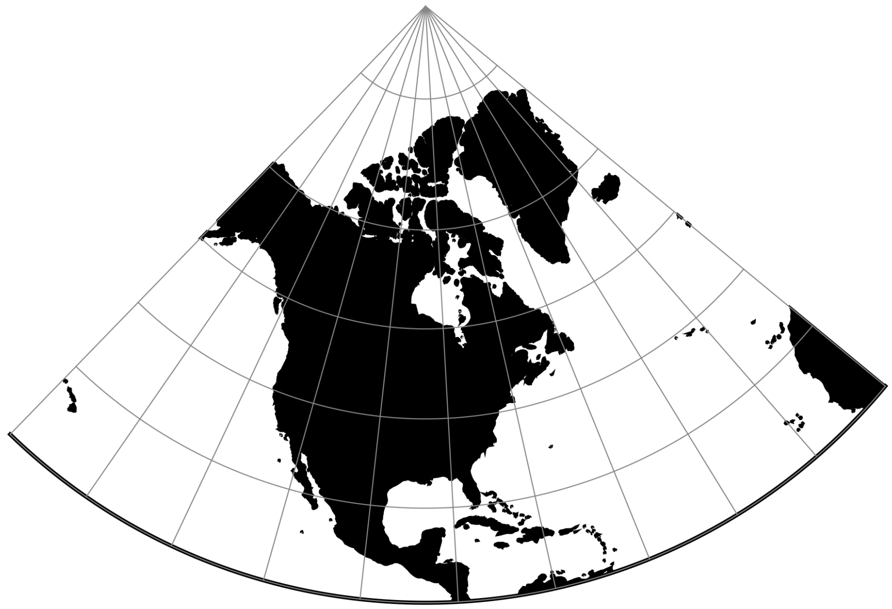


Fig. 61: proj-string: `+proj=lcc +lon_0=-90 +lat_1=33 +lat_2=45`

7.1.65.1 Parameters

Required

+lat_1=<value>

First standard parallel.

Defaults to 0.0.

Optional

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+lat_2=<value>

Second standard parallel.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>
Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

+k_0=<value>
This parameter can represent two different values depending on the form of the projection. In LCC 1SP it determines the scale factor at natural origin. In LCC 2SP Michigan it determines the ellipsoid scale factor.

Defaults to 1.0.

7.1.65.2 Further reading

1. Wikipedia
2. Wolfram Mathworld
3. John P. Snyder "Map projections: A working manual" (pp. 104-110)
4. ArcGIS documentation on "Lambert Conformal Conic"
5. EPSG Guidance Note 7-2 (version 54, August 2018, page 25)

7.1.66 Lambert Conformal Conic Alternative

Classification	Conical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	lcca
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.66.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
Longitude of projection center.

Defaults to 0.0.

Fig. 62: proj-string: `+proj=lcca +lat_0=35`

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.67 Lambert Equal Area Conic

Classification	Conical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	leac
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 63: proj-string: `+proj=leac`

7.1.67.1 Parameters

Note: All parameters are optional for the Lambert Equal Area Conic projection.

`+lat_1=<value>`

First standard parallel.

Defaults to 0.0.

`+south`

Sets the second standard parallel to 90°S. When the flag is off the second standard parallel is set to 90°N.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+ellps=<value>`

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>
Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.68 Lee Oblated Stereographic

Classification	Azimuthal
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	lee_os
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.68.1 Parameters

Note: All parameters are optional for the projection.

+ellps=<value>
See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.69 Loximuthal

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	loxim
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 64: proj-string: +proj=lee_os

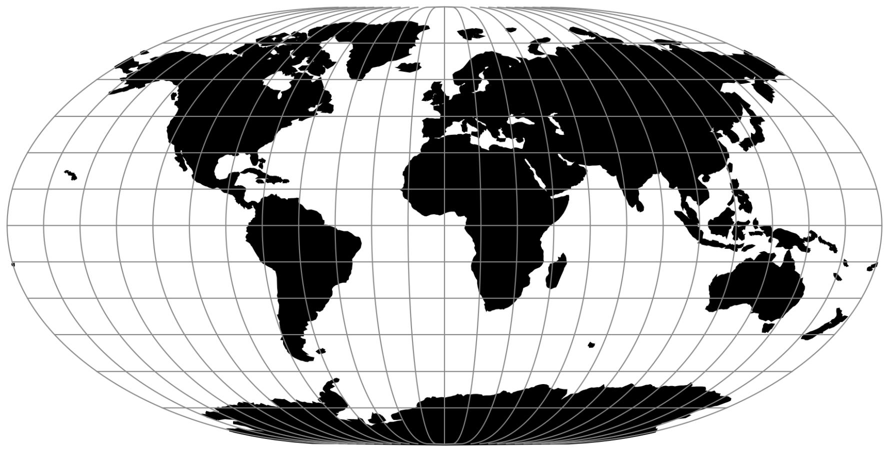


Fig. 65: proj-string: +proj=loxim

7.1.69.1 Parameters

Note: All parameters are optional for the Loximuthal projection.

+lat_1=<value>

First standard parallel.

Defaults to 0.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.70 Space oblique for LANDSAT

Classification	Cylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	lsat
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

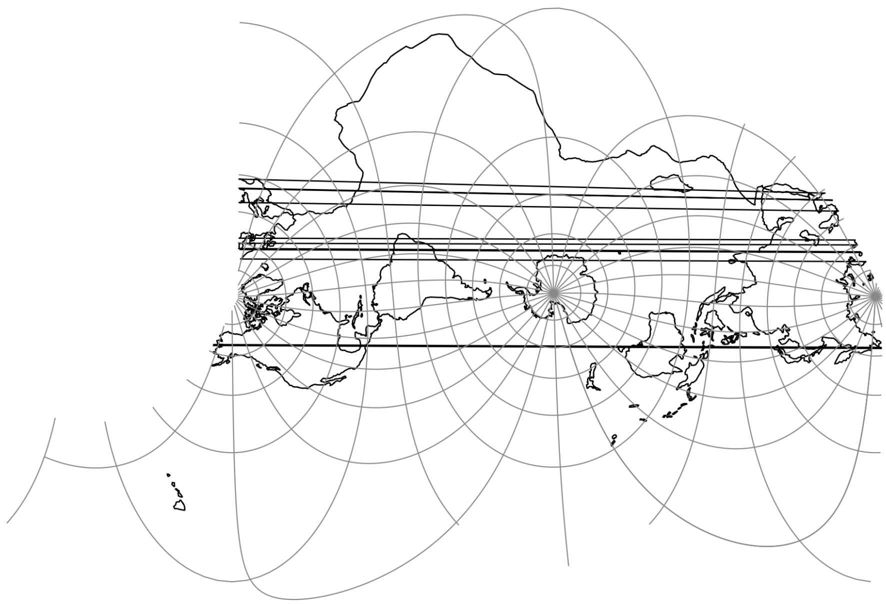


Fig. 66: proj-string: `+proj=lsat +ellps=GRS80 +lat_1=-60 +lat_2=60 +lsat=2 +path=2`

7.1.70.1 Parameters

Required

+lsat=<value>

Landsat satellite used for the projection. Value between 1 and 5.

+path=<value>

Selected path of satellite. Value between 1 and 253 when *+lsat* is set to 1,2 or 3, otherwise valid input is between 1 and 233.

Optional

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+ellps=<value>`

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.71 McBryde-Thomas Flat-Polar Sine (No. 1)

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	mbt_s
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

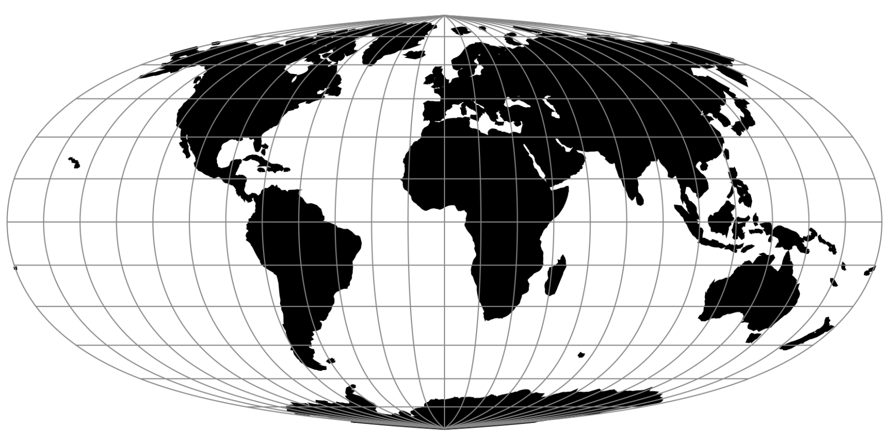


Fig. 67: proj-string: `+proj=mbt_s`

7.1.71.1 Parameters

Note: All parameters are optional for the McBryde-Thomas Flat-Polar Sine projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.72 McBryde-Thomas Flat-Pole Sine (No. 2)

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	mbt_fps
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

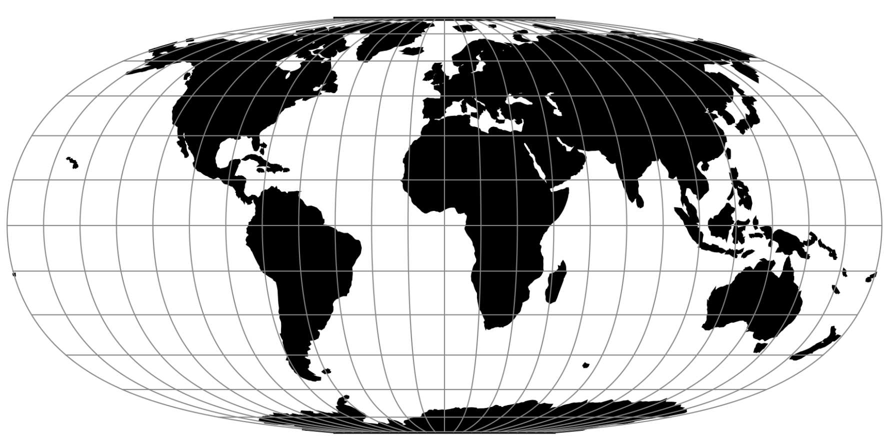


Fig. 68: proj-string: `+proj=mbt_fps`

7.1.72.1 Parameters

Note: All parameters are optional.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.73 McBride-Thomas Flat-Polar Parabolic

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	mbtfpp
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

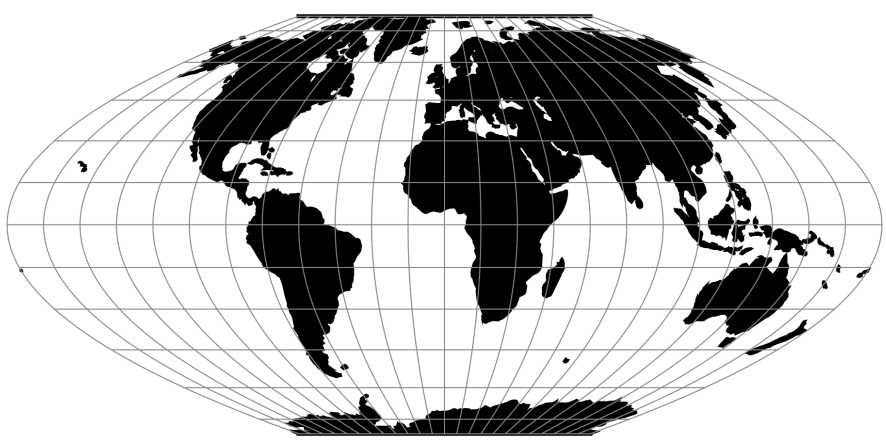


Fig. 69: proj-string: `+proj=mbtfpp`

7.1.73.1 Parameters

Note: All parameters are optional.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.74 McBryde-Thomas Flat-Polar Quartic

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	mbtfpq
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

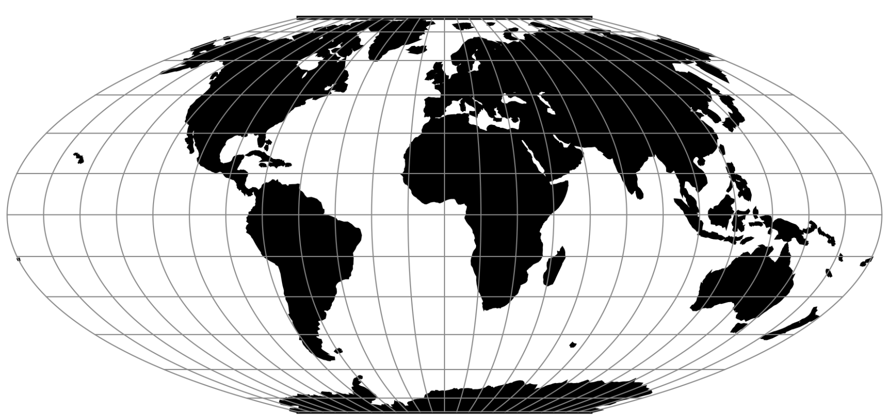


Fig. 70: proj-string: `+proj=mbtfpq`

7.1.74.1 Parameters

Note: All parameters are optional.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.75 McBryde-Thomas Flat-Polar Sinusoidal

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	mbtfps
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

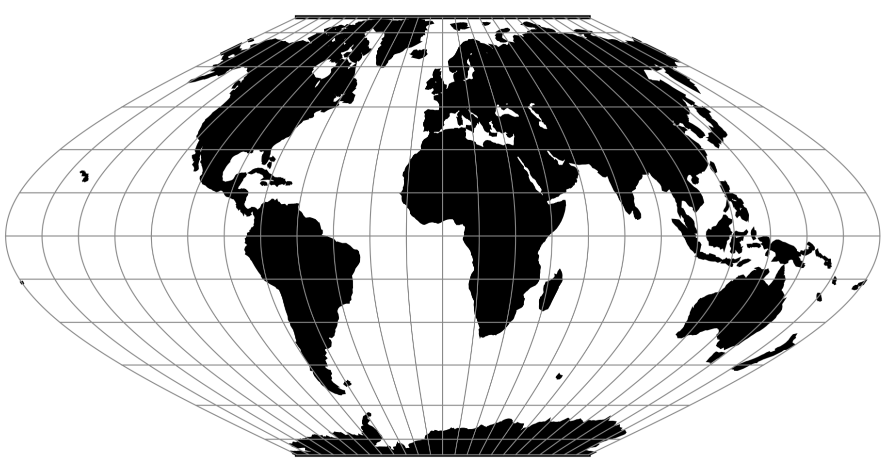


Fig. 71: proj-string: `+proj=mbtfps`

7.1.75.1 Parameters

Note: All parameters are optional for the McBryde-Thomas Flat-Polar Sinusoidal projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.76 Mercator

The Mercator projection is a cylindrical map projection that origins from the 16th century. It is widely recognized as the first regularly used map projection. It is a conformal projection in which the equator projects to a straight line at constant scale. The projection has the property that a rhumb line, a course of constant heading, projects to a straight line. This makes it suitable for navigational purposes.

Classification	Conformal cylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global, but best used near the equator
Alias	merc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.76.1 Usage

Applications should be limited to equatorial regions, but is frequently used for navigational charts with latitude of true scale (*+lat_ts*) specified within or near chart's boundaries. It is considered to be inappropriate for world maps because of the gross distortions in area; for example the projected area of Greenland is larger than that of South America, despite the fact that Greenland's area is $\frac{1}{8}$ that of South America [Snyder1987].

Example using latitude of true scale:

```
$ echo 56.35 12.32 | proj +proj=merc +lat_ts=56.5
3470306.37    759599.90
```

Example using scaling factor:

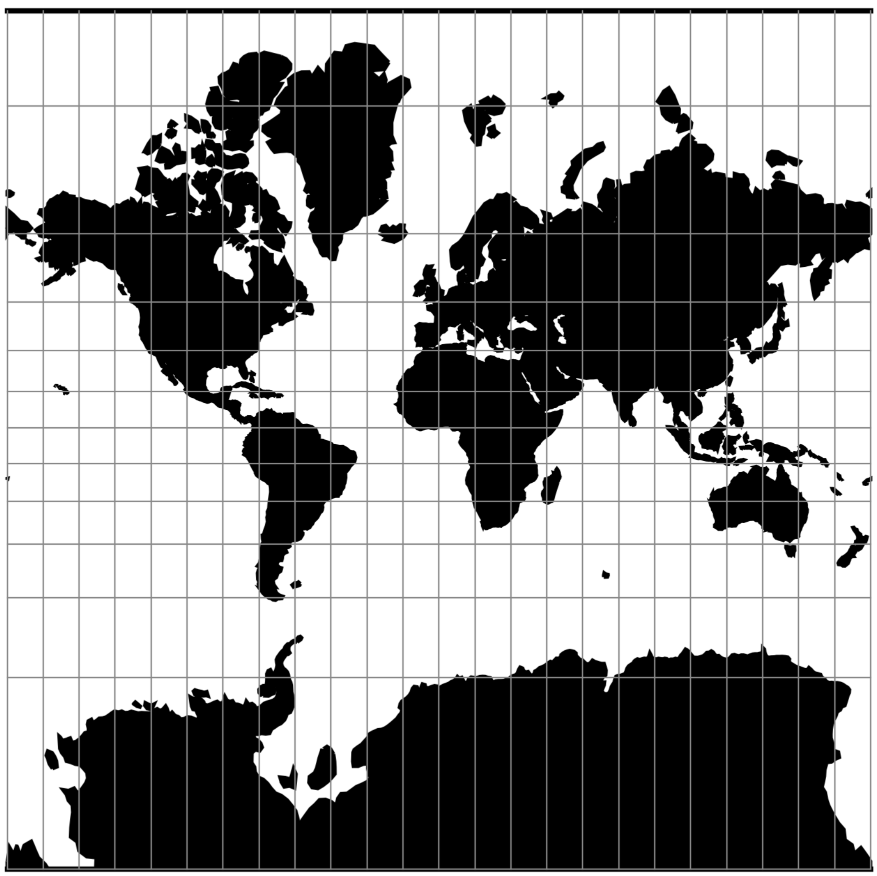


Fig. 72: proj-string: `+proj=merc`

```
echo 56.35 12.32 | proj +proj=merc +k_0=2
12545706.61     2746073.80
```

Note that *+lat_ts* and *+k_0* are mutually exclusive. If used together, *+lat_ts* takes precedence over *+k_0*.

7.1.76.2 Parameters

Note: All parameters for the projection are optional.

+lat_ts=<value>

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over +k_0 if both options are used together.

Defaults to 0.0.

+k_0=<value>

Scale factor. Determines scale factor used in the projection.

Defaults to 1.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

+ellps=<value>

See *proj -le* for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

7.1.76.3 Mathematical definition

Spherical form

For the spherical form of the projection we introduce the scaling factor:

$$k_0 = \cos \phi_{ts}$$

Forward projection

$$x = k_0 R\lambda; \qquad y = k_0 R\psi$$

$$\begin{aligned}\psi &= \ln\tan\left(\frac{\pi}{4} + \frac{\phi}{2}\right)\\ &= \sinh^{-1}\tan\phi\end{aligned}$$

The quantity ψ is the isometric latitude.

Inverse projection

$$\lambda = \frac{x}{k_0 R}; \qquad \psi = \frac{y}{k_0 R}$$

$$\begin{aligned}\phi &= \frac{\pi}{2} - 2\tan^{-1}\exp(-\psi)\\ &= \tan^{-1}\sinh\psi\end{aligned}$$

Ellipsoidal form

For the ellipsoidal form of the projection we introduce the scaling factor:

$$k_0 = m(\phi_{ts})$$

where

$$m(\phi) = \frac{\cos\phi}{\sqrt{1 - e^2\sin^2\phi}}$$

$a\,m(\phi)$ is the radius of the circle of latitude ϕ.

Forward projection

$$x = k_0 a\lambda; \qquad y = k_0 a\psi$$

$$\begin{aligned}\psi &= \ln\tan\left(\frac{\pi}{4} + \frac{\phi}{2}\right) - \frac{1}{2}e\ln\left(\frac{1 + e\sin\phi}{1 - e\sin\phi}\right)\\ &= \sinh^{-1}\tan\phi - e\tanh^{-1}(e\sin\phi)\end{aligned}$$

Inverse projection

$$\lambda = \frac{x}{k_0 a}; \quad \psi = \frac{y}{k_0 a}$$

The latitude ϕ is found by inverting the equation for ψ. This follows the method given by [Karney2011tm]. Start by introducing the conformal latitude

$$\chi = \tan^{-1} \sinh \psi$$

The tangents of the latitudes $\tau = \tan \phi$ and $\tau' = \tan \chi = \sinh \psi$ are related by

$$\tau' = \tau \sqrt{1 + \sigma^2} - \sigma \sqrt{1 + \tau^2}$$

where

$$\sigma = \sinh\bigl(e \tanh^{-1}(e\tau/\sqrt{1 + \tau^2})\bigr)$$

This is obtained by taking the $\sinh$ of the equation for ψ and using the multiple argument formula. The equation for τ' can be solved to give τ using Newton's method using $\tau = \tau'/(1 - e^2)$ as an initial guess and with the needed derivative given by

$$\frac{d\tau'}{d\tau} = \frac{1 - e^2}{1 + (1 - e^2)\tau^2} \sqrt{1 + \tau'^2} \sqrt{1 + \tau^2}$$

This converges after no more than 2 iterations. Finally set $\phi = \tan^{-1} \tau$.

7.1.76.4 Further reading

1. Wikipedia
2. Wolfram Mathworld

7.1.77 Miller Oblated Stereographic

Classification	Azimuthal
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	mil_os
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.77.1 Parameters

Note: All parameters are optional for the projection.

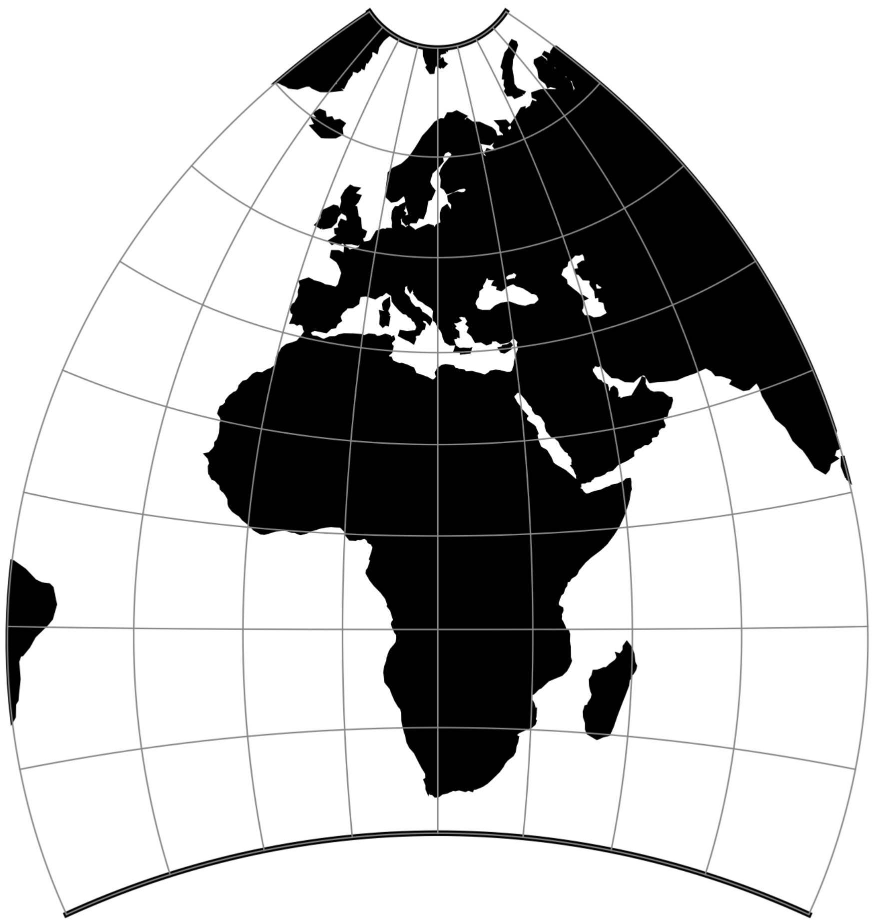


Fig. 73: proj-string: +proj=mil_os

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.78 Miller Cylindrical

The Miller cylindrical projection is a modified Mercator projection, proposed by Osborn Maitland Miller in 1942. The latitude is scaled by a factor of $\frac{4}{5}$, projected according to Mercator, and then the result is multiplied by $\frac{5}{4}$ to retain scale along the equator.

Classification	Neither conformal nor equal area cylindrical
Available forms	Forward and inverse spherical
Defined area	Global, but best used near the equator
Alias	mill
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.78.1 Usage

The Miller Cylindrical projection is used for world maps and in several atlases, including the National Atlas of the United States (USGS, 1970, p. 330-331) [Snyder1987].

Example using Central meridian 90°W:

```
$ echo -100 35 | proj +proj=mill +lon_0=90w
-1113194.91      4061217.24
```

7.1.78.2 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

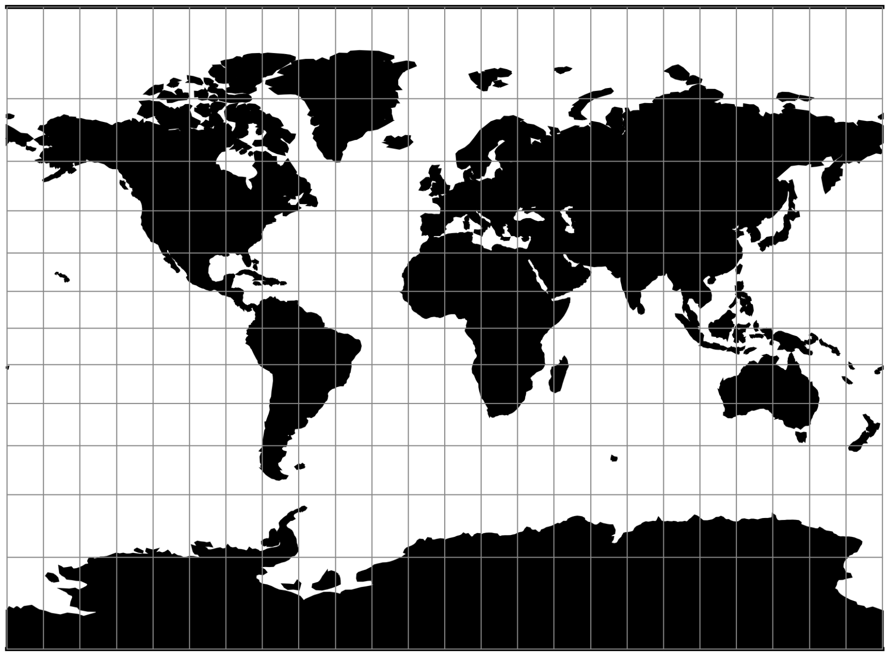


Fig. 74: proj-string: `+proj=mill`

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.78.3 Mathematical definition

The formulas describing the Miller projection are all taken from [Snyder1987].

Forward projection

$$x = \lambda$$

$$y = 1.25 * \ln \left[\tan \left(\frac{\pi}{4} + 0.4 * \phi \right) \right]$$

Inverse projection

$$\lambda = x$$

$$\phi = 2.5 * (\arctan\left[e^{0.8*y}\right] - \frac{\pi}{4})$$

7.1.78.4 Further reading

1. Wikipedia

7.1.79 Space oblique for MISR

Classification	Conformal
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	misrsom
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.79.1 Parameters

Required

+path=<value>

Selected path of satellite. Value between 1 and 233.

Optional

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

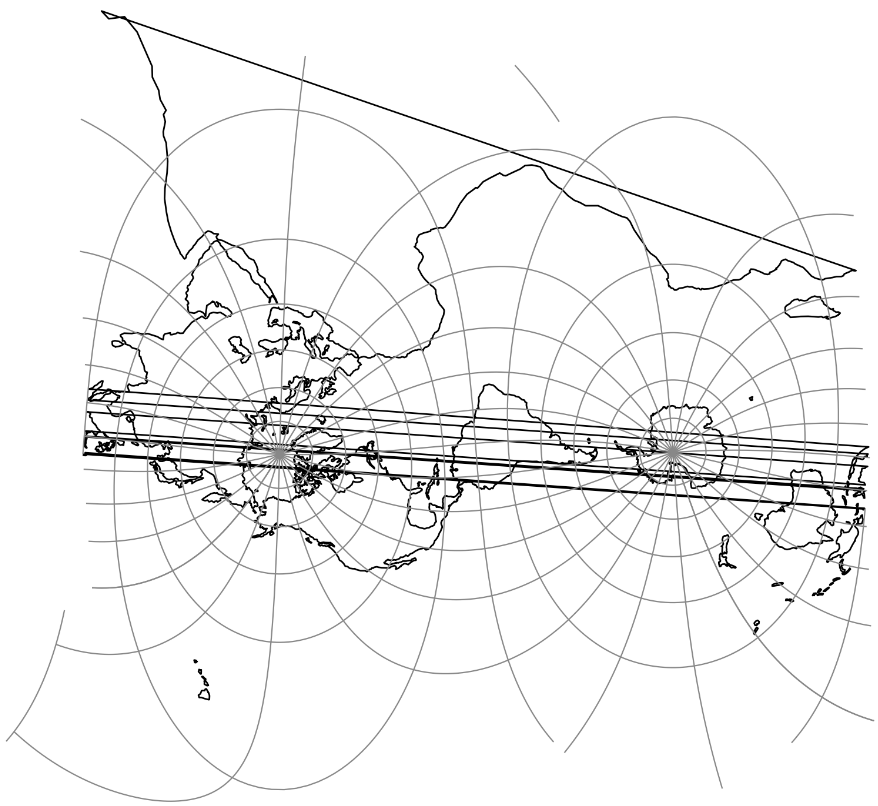


Fig. 75: proj-string: `+proj=misrsom +path=1`

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.80 Mollweide

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	moll
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

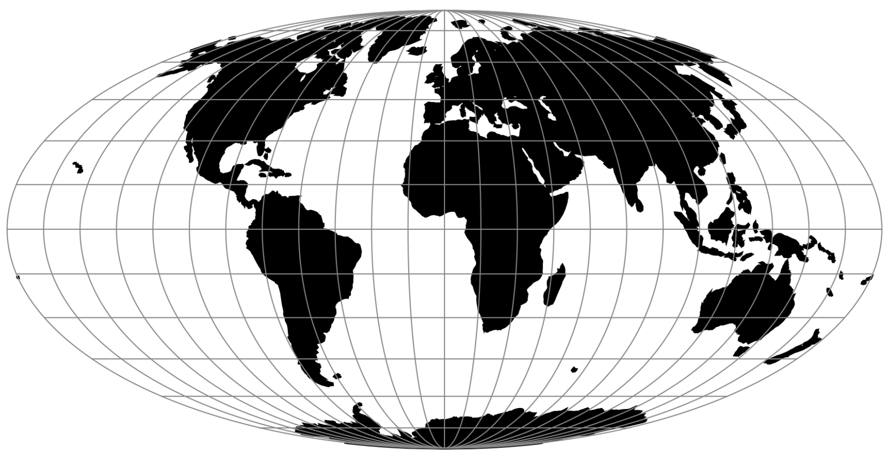


Fig. 76: proj-string: `+proj=moll`

7.1.80.1 Parameters

Note: All parameters are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.81 Murdoch I

Classification	Conical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	murd1
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 77: proj-string: `+proj=murd1 +lat_1=30 +lat_2=50`

7.1.81.1 Parameters

Required

`+lat_1=<value>`

First standard parallel.

Defaults to 0.0.

`+lat_2=<value>`

Second standard parallel.

Defaults to 0.0.

Optional

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.82 Murdoch II

Classification	Conical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	murd2
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.82.1 Parameters

Required

`+lat_1=<value>`

First standard parallel.

Defaults to 0.0.

`+lat_2=<value>`

Second standard parallel.

Defaults to 0.0.

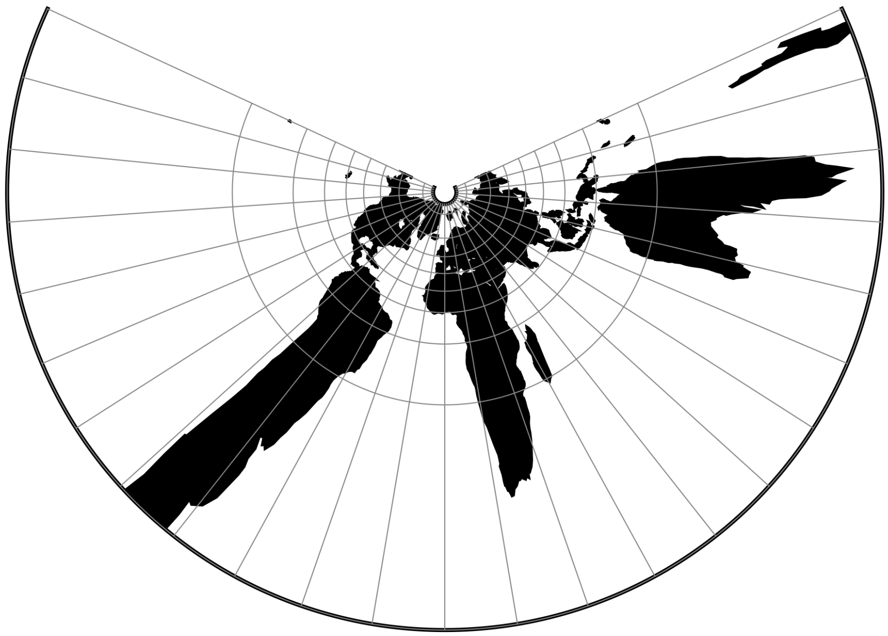


Fig. 78: proj-string: `+proj=murd2 +lat_1=30 +lat_2=50`

Optional

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.83 Murdoch III

Classification	Conical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	murd3
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 79: proj-string: `+proj=murd3 +lat_1=30 +lat_2=50`

7.1.83.1 Parameters

Required

`+lat_1=<value>`

First standard parallel.

Defaults to 0.0.

`+lat_2=<value>`

Second standard parallel.

Defaults to 0.0.

Optional

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.84 Natural Earth

Classification	Pseudo cylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	natearth
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

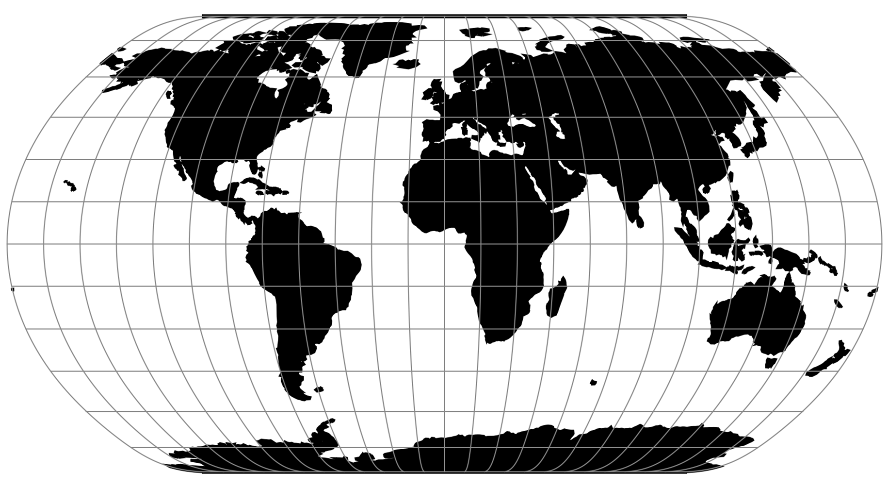


Fig. 80: proj-string: `+proj=natearth`

The Natural Earth projection is intended for making world maps. A distinguishing trait is its slightly rounded corners fashioned to emulate the spherical shape of Earth. The meridians (except for the central meridian) bend acutely inward as they approach the pole lines, giving the projection a hint of three-dimensionality. This bending also suggests that the meridians converge at the poles instead of truncating at the top and bottom edges. The distortion characteristics of the Natural Earth projection compare favorably to other world map projections.

7.1.84.1 Usage

The Natural Earth projection has no special options so usage is simple. Here is an example of an inverse projection on a sphere with a radius of 7500 m:

```
$ echo 3500 -8000 | proj -I +proj=natearth +a=7500
37d54'6.091"E  61d23'4.582"S
```

7.1.84.2 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>
Longitude of projection center.

Defaults to 0.0.

+R=<value>
Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.84.3 Further reading

1. Wikipedia

7.1.85 Natural Earth II

Classification	Pseudo cylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	natearth2
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

The Natural Earth II projection is intended for making world maps. At high latitudes, meridians bend steeply toward short pole lines resulting in a map with highly rounded corners that resembles an elongated globe.

See [Savric2015]

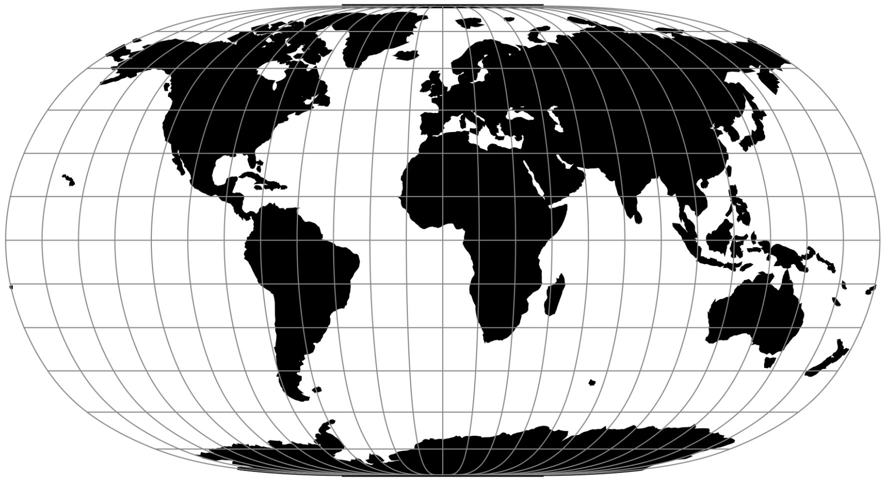


Fig. 81: proj-string: `+proj=natearth2`

7.1.85.1 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.86 Nell

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	nell
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

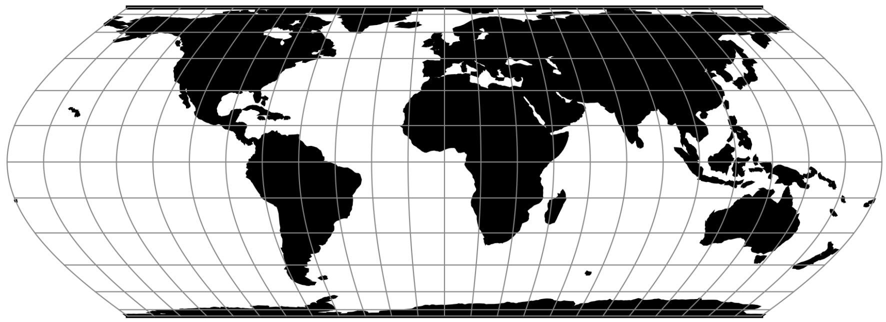


Fig. 82: proj-string: `+proj=nell`

7.1.86.1 Parameters

Note: All parameters are optional.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.87 Nell-Hammer

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	nell_h
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

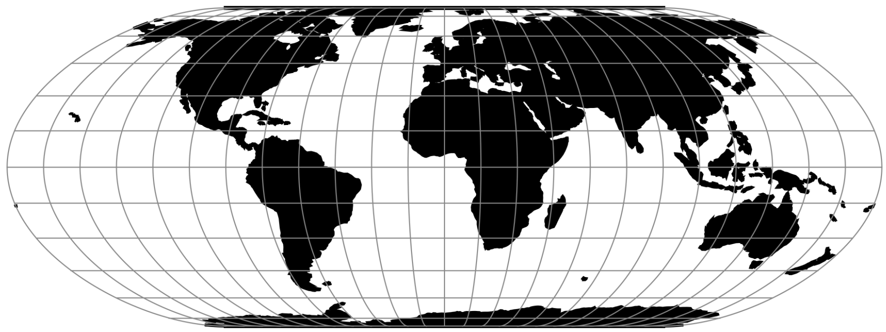


Fig. 83: proj-string: `+proj=nell_h`

7.1.87.1 Parameters

Note: All parameters are optional.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.88 Nicolosi Globular

Classification	Pseudoconical
Available forms	Forward spherical projection
Defined area	Global
Alias	nicol
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 84: proj-string: `+proj=nicol`

7.1.88.1 Parameters

Note: All parameters are optional.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.89 Near-sided perspective

The near-sided perspective projection simulates a view from a height h similar to how a satellite in orbit would see it.

Classification	Azimuthal. Neither conformal nor equal area.
Available forms	Forward and inverse spherical projection
Defined area	Global, although for one hemisphere at a time.
Alias	nsper
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 85: proj-string: `+proj=nsper +h=3000000 +lat_0=-20 +lon_0=145`

7.1.89.1 Parameters

Required

`+h=<value>`

Height of the view point above the Earth and must be in the same units as the radius of the sphere or semimajor axis of the ellipsoid.

Optional

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+lat_0=<value>`

Latitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.90 New Zealand Map Grid

7.1.90.1 Parameters

Note: All standard projection parameters are hard-coded for this projection

7.1.91 General Oblique Transformation

Classification	Cylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	ob_tran
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 86: proj-string: `+proj=nzmg`

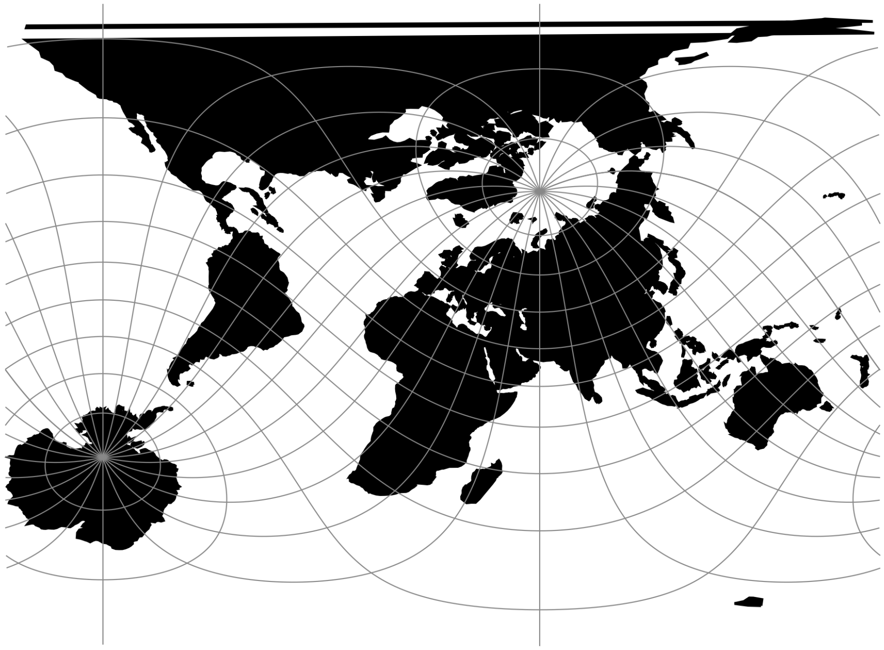


Fig. 87: proj-string: `+proj=ob_tran +o_proj=mill +o_lon_p=40 +o_lat_p=50 +lon_0=60`

7.1.91.1 Usage

All of the projections of spherical library can be used as an oblique projection by means of the General Oblique Transformation. The user performs the oblique transformation by selecting the oblique projection `+proj=ob_tran`, specifying the translation factors, *+o_lat_p*, and *+o_lon_p*, and the projection to be used, *+o_proj*. In the example of the Fairgrieve projection, the latitude and longitude of the North pole of the unrotated geographic CRS, α and β respectively, expressed in the rotated geographic CRS, are to be placed at 45°N and 90°W and the *Mollweide* projection is used. Because the central meridian of the translated coordinates will follow the β meridian it is necessary to translate the translated system so that the Greenwich meridian will pass through the center of the projection by offsetting the central meridian.

The final control for this projection is:

```
+proj=ob_tran +o_proj=moll +o_lat_p=45 +o_lon_p=-90 +lon_0=-90
```

7.1.91.2 Parameters

Required

+o_proj=<projection>

Oblique projection.

In addition to specifying an oblique projection, *how* to rotate the projection should be specified. This is done in one of three ways: Define a new pole, rotate the projection about a given point or define a new "equator" spanned by two points on the sphere. See the details below.

New pole

+o_lat_p=<latitude>
Latitude of the North pole of the unrotated source CRS, expressed in the rotated geographic CRS.

+o_lon_p=<longitude>
Longitude of the North pole of the unrotated source CRS, expressed in the rotated geographic CRS.

Rotate about point

+o_alpha=<value>
Angle to rotate the projection with.

+o_lon_c=<value>
Longitude of the point the projection will be rotated about.

+o_lat_c=<value>
Latitude of the point the projection will be rotated about.

New "equator" points

+lon_1=<value>
Longitude of first point.

+lat_1=<value>
Latitude of first point.

+lon_2=<value>
Longitude of second point.

+lat_2=<value>
Latitude of second point.

Optional

+lon_0=<value>
Longitude of projection center.

Defaults to 0.0.

+R=<value>
Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.92 Oblique Cylindrical Equal Area

Classification	Cylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	ocea
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

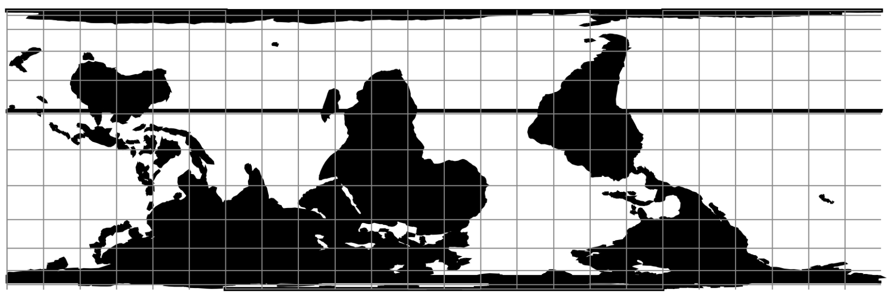


Fig. 88: proj-string: `+proj=ocea`

7.1.92.1 Parameters

Required

For the Oblique Cylindrical Equal Area projection a pole of rotation is needed. The pole can be defined in two ways: By a point and azimuth or by providing to points that make up the pole.

Point & azimuth

+lonc=<value>

Longitude of rotational pole point.

+alpha=<value>

Angle of rotational pole.

Two points

+lon_1=<value>

Longitude of first point.

+lat_1=<value>

Latitude of first point.

+lon_2=<value>

Longitude of second point.

`+lat_2=<value>`

Latitude of second point.

Optional

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

`+k_0=<value>`

Scale factor. Determines scale factor used in the projection.

Defaults to 1.0.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.93 Oblated Equal Area

Classification	Azimuthal
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	oea
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Described in [Snyder1988].

7.1.93.1 Parameters

Required

`+m=<value>`

`+n=<value>`

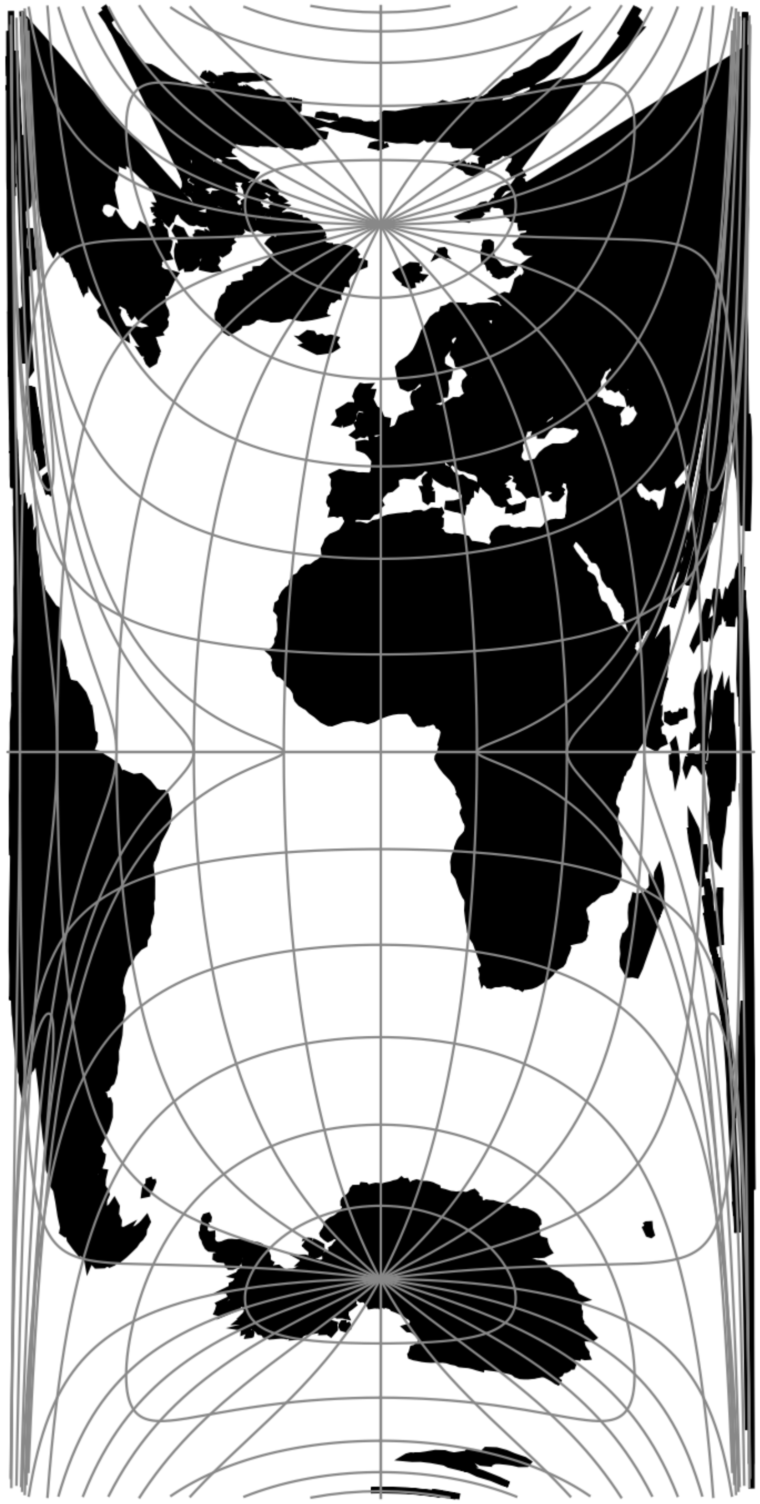


Fig. 89: proj-string: `+proj=oea +m=1 +n=2`

Optional

+theta=<value>

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.94 Oblique Mercator

The Oblique Mercator projection is a cylindrical map projection that closes the gap between the Mercator and the Transverse Mercator projections.

Classification	Conformal cylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global, but reasonably accurate only within 15 degrees of the oblique central line
Alias	omerc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

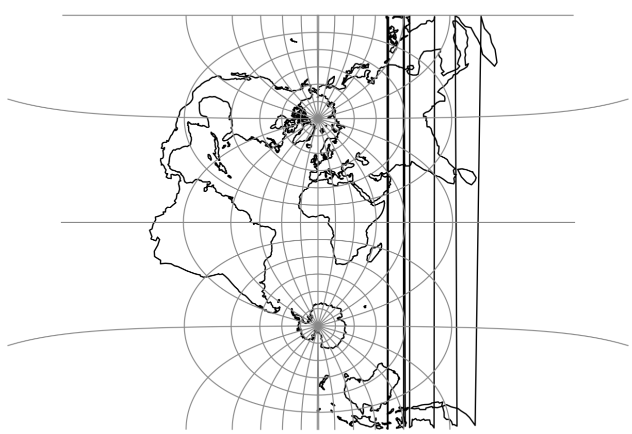


Fig. 90: proj-string: `+proj=omerc +lat_1=45 +lat_2=55`

Figuratively, the cylinder used for developing the Mercator projection touches the planet along the Equator, while that of the Transverse Mercator touches the planet along a meridian, i.e. along a line perpendicular to the Equator.

The cylinder for the Oblique Mercator, however, touches the planet along a line at an arbitrary angle with the Equator. Hence, the Oblique Mercator projection is useful for mapping areas having their greatest extent along a direction that is neither north-south, nor east-west.

The Mercator and the Transverse Mercator projections are both limiting forms of the Oblique Mercator: The Mercator projection is equivalent to an Oblique Mercator with central line along the Equator, while the Transverse Mercator is equivalent to an Oblique Mercator with central line along a meridian.

For the sphere, the construction of the Oblique Mercator projection can be imagined as "tilting the cylinder of a plain Mercator projection", so the cylinder, instead of touching the equator, touches an arbitrary great circle on the sphere. The great circle is defined by the tilt angle of the central line, hence putting land masses along that great circle near the centre of the map, where the Equator would go in the plain Mercator case.

The ellipsoidal case, developed by Hotine, and refined by Snyder [Snyder1987] is more complex, involving initial steps projecting from the ellipsoid to another curved surface, the "aposphere", then projection from the aposphere to the skew uv-plane, before finally rectifying the skew uv-plane onto the map XY plane.

7.1.94.1 Usage

The tilt angle (azimuth) of the central line can be given in two different ways. In the first case, the azimuth is given directly, using the option `+alpha` and defining the centre of projection using the options `+lonc` and `+lat_0`. In the second case, the azimuth is given indirectly by specifying two points on the central line, using the options `+lat_1`, `+lon_1`, `+lat_2`, and `+lon_2`.

Example: Verify that the Mercator projection is a limiting form of the Oblique Mercator

```
$ echo 12 55 | proj +proj=merc +ellps=GRS80
1335833.89   7326837.71

$ echo 12 55 | proj +proj=omerc +lonc=0 +alpha=90 +ellps=GRS80
1335833.89   7326837.71
```

Example: Second case - indirectly given azimuth

```
$ echo 12 55 | proj +proj=omerc +lon_1=-1 +lat_1=1 +lon_2=0 +lat_2=0 +ellps=GRS80
  349567.57   6839490.50
```

Example: An approximation of the Danish "System 34" from [Rittri2012]

```
$ echo 10.536498003 56.229892362 | proj +proj=omerc +axis=wnu +lonc=9.46 +lat_0=56.
↪13333333 +x_0=-266906.229 +y_0=189617.957 +k=0.9999537 +alpha=-0.76324 +gamma=0␣
↪+ellps=GRS80
200000.13   199999.89
```

The input coordinate represents the System 34 datum point "Agri Bavnehoj", with coordinates (200000, 200000) by definition. So at the datum point, the approximation is off by about 17 cm. This use case represents a datum shift from a cylinder projection on an old, slightly misaligned datum, to a similar projection on a modern datum.

7.1.94.2 Parameters

Central point and azimuth method

+alpha=<value>

Azimuth of centerline clockwise from north at the center point of the line. If *+gamma* is not given then *+alpha* determines the value of *+gamma*.

+gamma=<value>

Azimuth of centerline clockwise from north of the rectified bearing of centre line. If *+alpha* is not given, then *+gamma* is used to determine *+alpha*.

+lonc=<value>

Longitude of the central point.

+lat_0=<value>

Latitude of the central point.

Two point method

+lon_1=<value>

Longitude of first point.

+lat_1=<value>

Latitude of first point.

+lon_2=<value>

Longitude of second point.

+lat_2=<value>

Latitude of second point.

Optional

+no_rot

No rectification (not "no rotation" as one may well assume). Do not take the last step from the skew uv-plane to the map XY plane.

Note: This option is probably only marginally useful, but remains for (mostly) historical reasons.

+no_off

Do not offset origin to center of projection.

+k_0=<value>

Scale factor. Determines scale factor used in the projection.

Defaults to 1.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.95 Ortelius Oval

Classification	Pseudocylindrical
Available forms	Forward spherical projection
Defined area	Global
Alias	ortel
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

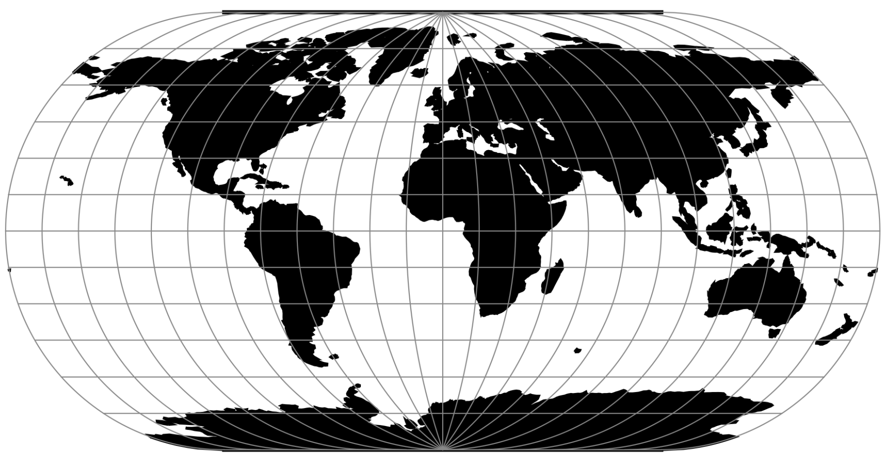


Fig. 91: proj-string: `+proj=ortel`

7.1.95.1 Parameters

Note: All parameters are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.96 Orthographic

The orthographic projection is a perspective azimuthal projection centered around a given latitude and longitude.

Classification	Azimuthal
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global, although only one hemisphere can be seen at a time
Alias	ortho
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Note: Before PROJ 7.2, only the spherical formulation was implemented. If wanting to replicate PROJ < 7.2 results with newer versions, the ellipsoid must be forced to a sphere, for example by adding a `+f=0` parameter.

7.1.96.1 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+ellps=<value>

See *proj -le* for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

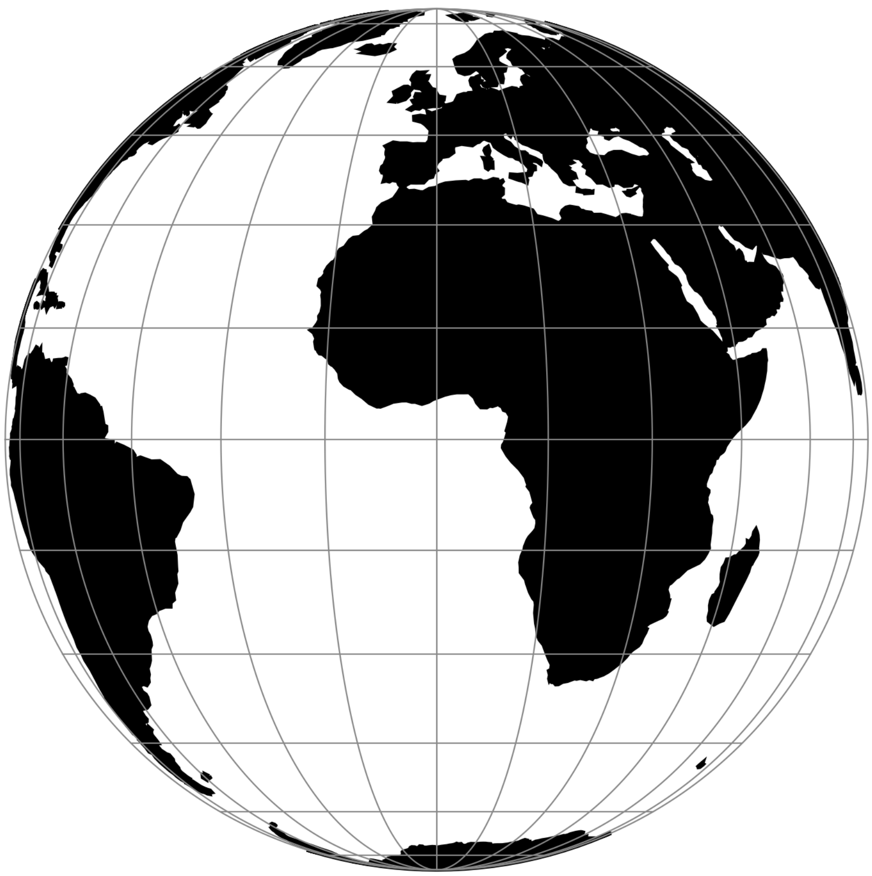


Fig. 92: proj-string: `+proj=ortho`

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.97 Patterson

The Patterson projection is a cylindrical map projection designed for general-purpose mapmaking.

See [Patterson2014]

Classification	Cylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	patterson
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

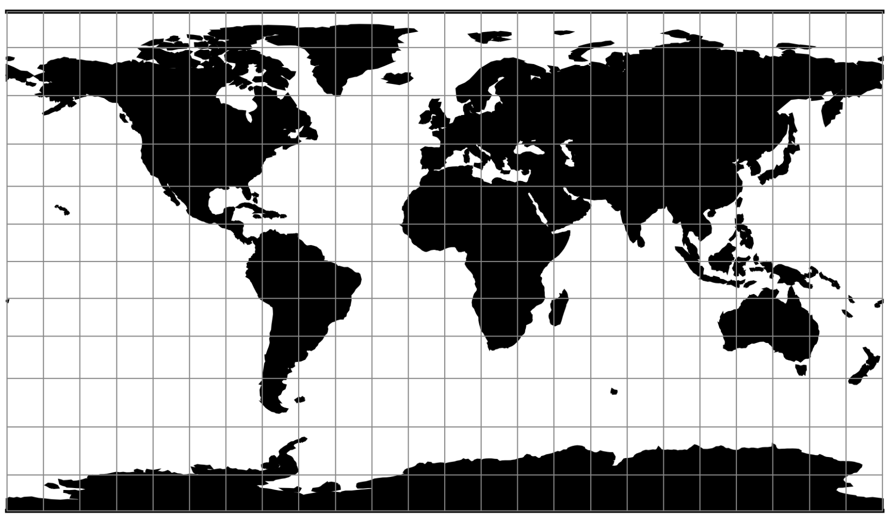


Fig. 93: proj-string: `+proj=patterson`

7.1.97.1 Parameters

Note: All parameters are optional for projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.98 Perspective Conic

Classification	Conical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	pconic
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 94: proj-string: +proj=pconic +lat_1=25 +lat_2=75

7.1.98.1 Parameters

Required

+lat_1=<value>

First standard parallel.

Defaults to 0.0.

+lat_2=<value>

Second standard parallel.

Defaults to 0.0.

Optional

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.99 Peirce Quincuncial

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	peirce_q
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 95: proj-string: `+proj=peirce_q`

7.1.99.1 Parameters

Note: All parameters are optional.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.100 Polyconic (American)

Classification	Pseudoconical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	poly
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.100.1 Parameters

Note: All parameters are optional for projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+ellps=<value>`

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

Fig. 96: proj-string: `+proj=poly`

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.101 Putnins P1

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	putp1
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

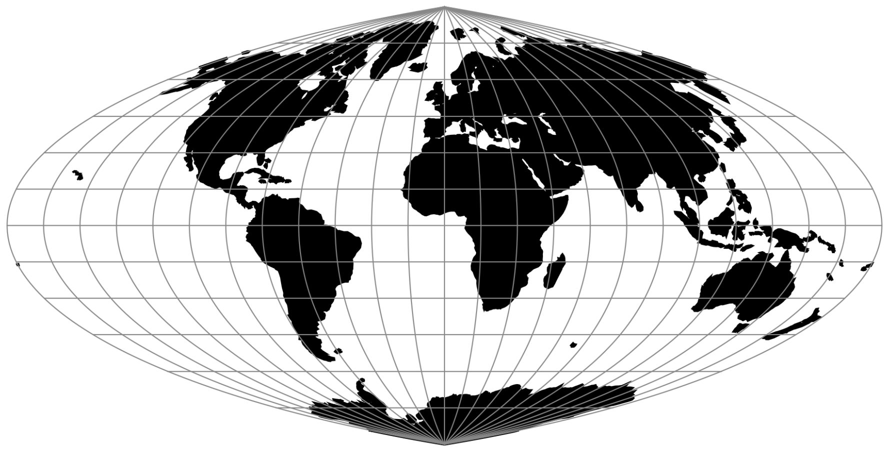


Fig. 97: proj-string: `+proj=putp1`

7.1.101.1 Parameters

Note: All parameters are optional for the Putnins P1 projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.102 Putnins P2

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	putp2
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

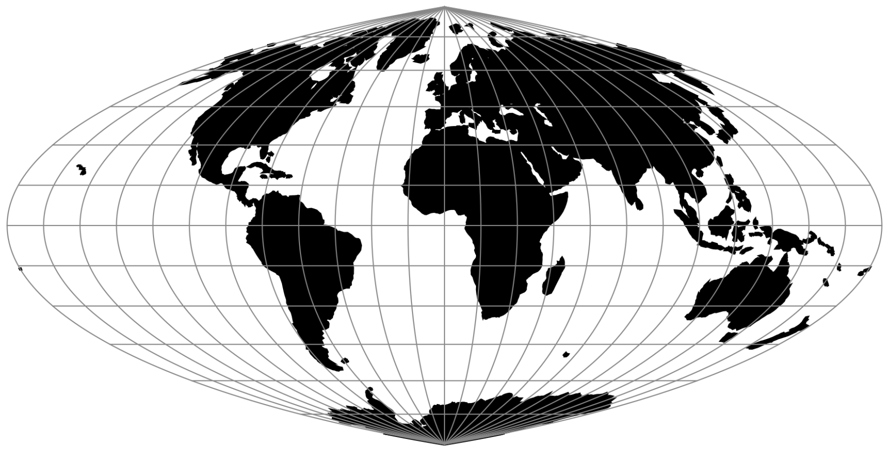


Fig. 98: proj-string: `+proj=putp2`

7.1.102.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.103 Putnins P3

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	putp3
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

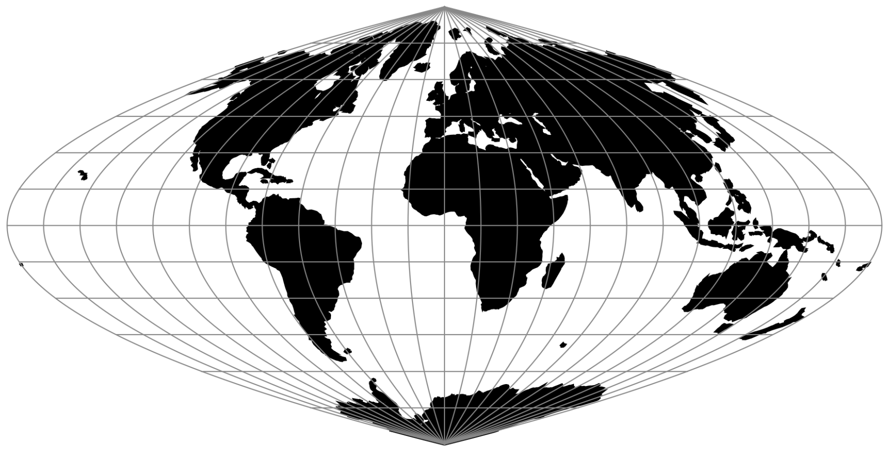


Fig. 99: proj-string: `+proj=putp3`

7.1.103.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.104 Putnins P3’

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	putp3p
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

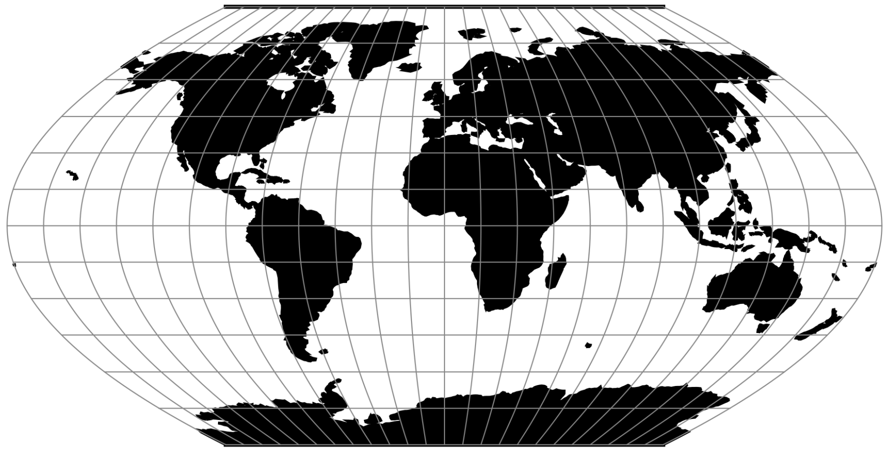


Fig. 100: proj-string: `+proj=putp3p`

7.1.104.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.105 Putnins P4'

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	putp4p
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

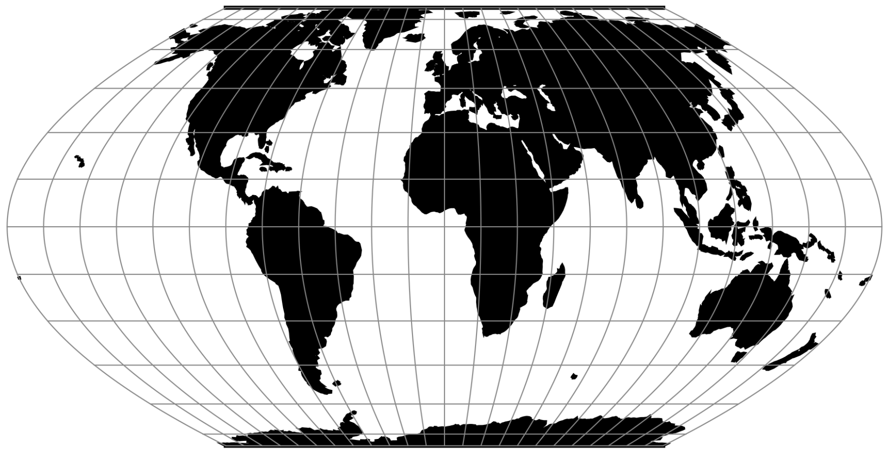


Fig. 101: proj-string: `+proj=putp4p`

7.1.105.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.106 Putnins P5

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	putp5
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

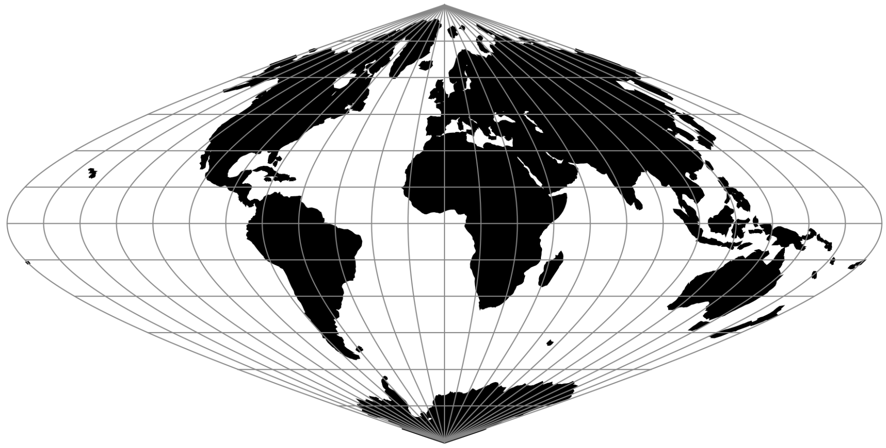


Fig. 102: proj-string: `+proj=putp5`

7.1.106.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.107 Putnins P5'

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	putp5p
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

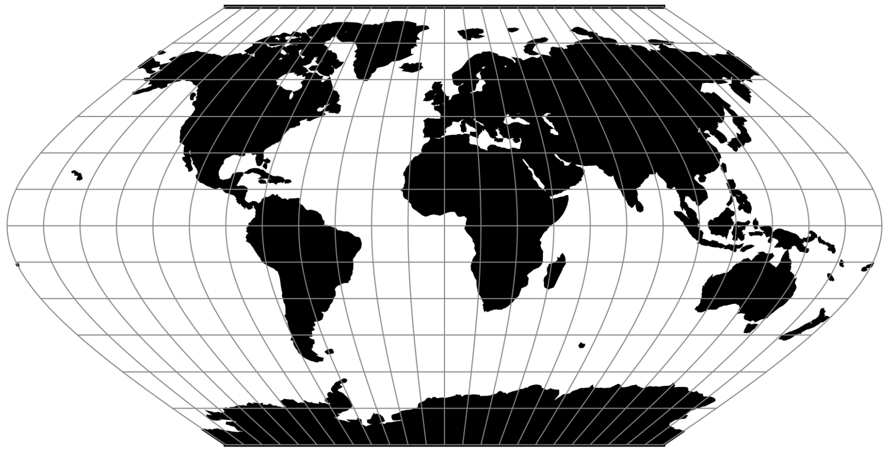


Fig. 103: proj-string: `+proj=putp5p`

7.1.107.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.108 Putnins P6

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	putp6
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

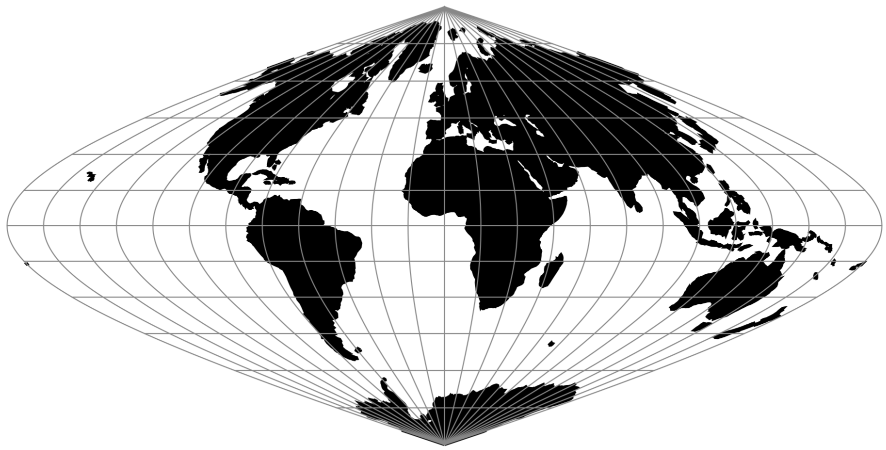


Fig. 104: proj-string: `+proj=putp6`

7.1.108.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.109 Putnins P6'

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	putp6p
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

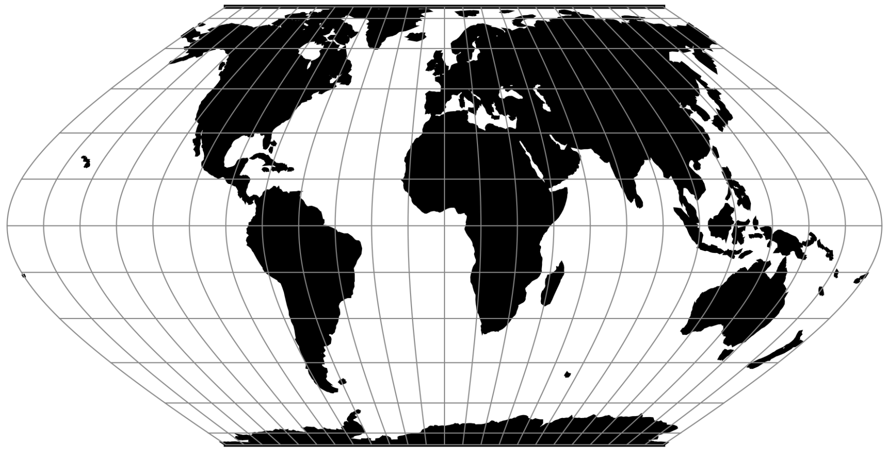


Fig. 105: proj-string: `+proj=putp6p`

7.1.109.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.110 Quartic Authalic

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	qua_aut
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

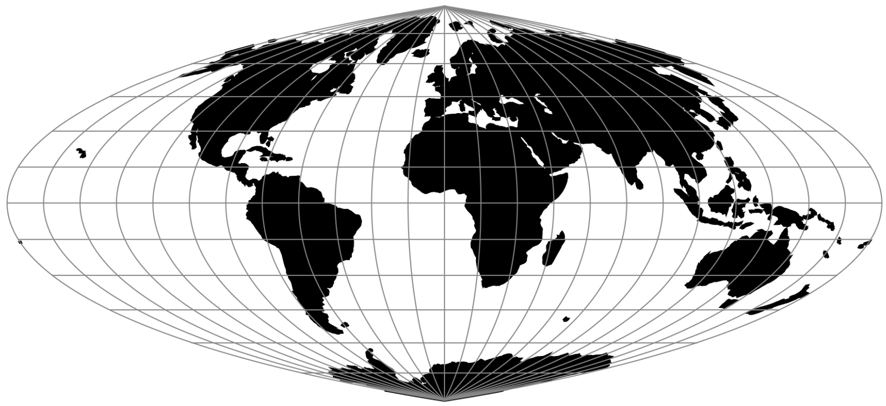


Fig. 106: proj-string: `+proj=qua_aut`

7.1.110.1 Parameters

Note: All parameters are optional for the Quartic Authalic projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

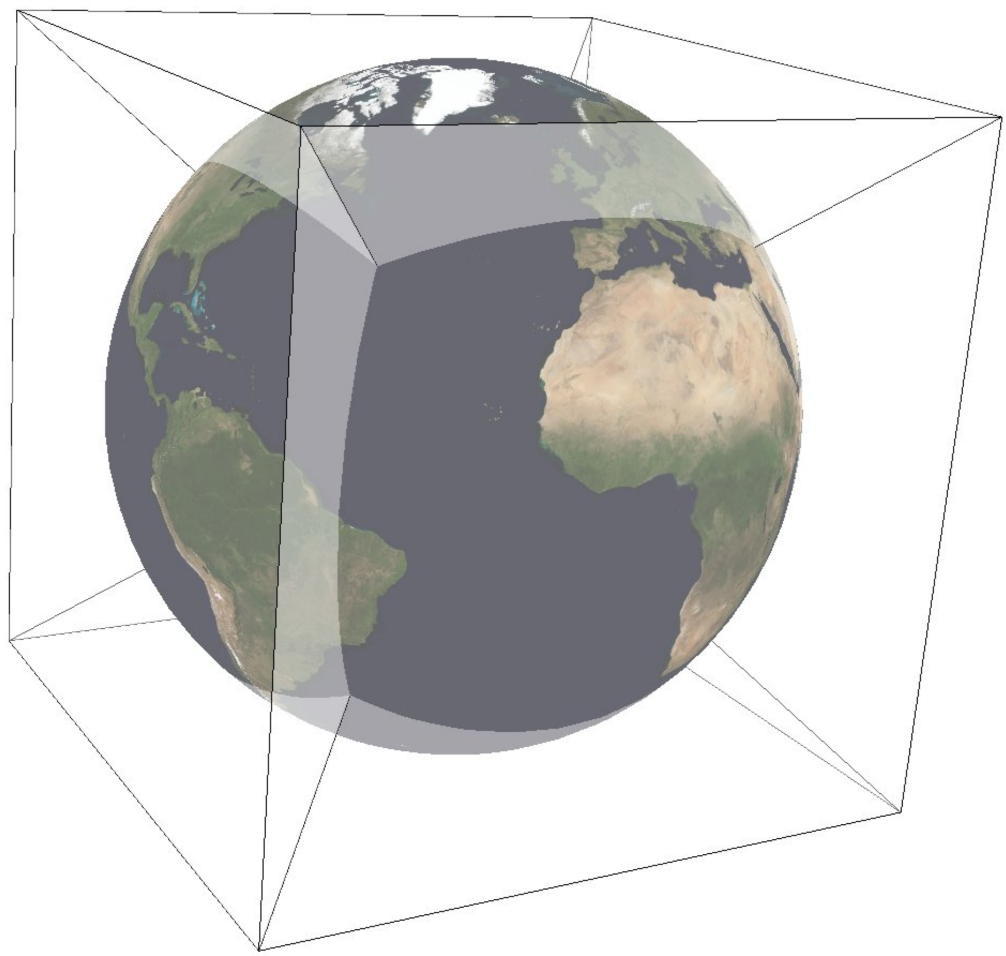
False northing.

Defaults to 0.0.

7.1.111 Quadrilateralized Spherical Cube

Classification	Azimuthal
Available forms	Forward and inverse, ellipsoidal
Defined area	Global
Alias	qsc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

The purpose of the Quadrilateralized Spherical Cube (QSC) projection is to project a sphere surface onto the six sides of a cube:



For this purpose, other alternatives can be used, notably *Gnomonic* or *HEALPix*. However, QSC projection has the following favorable properties:

It is an equal-area projection, and at the same time introduces only limited angular distortions. It treats all cube sides equally, i.e. it does not use different projections for polar areas and equatorial areas. These properties make QSC projection a good choice for planetary-scale terrain rendering. Map data can be organized in quadtree structures for each cube side. See [LambersKolb2012] for an example.

The QSC projection was introduced by [ONeilLaubscher1976], building on previous work by [ChanONeil1975]. For clarity: The earlier QSC variant described in [ChanONeil1975] became known as the COBE QSC since it was used by the NASA Cosmic Background Explorer (COBE) project; it is an approximately equal-area projection and is not the same as the QSC projection.

See also [CalabrettaGreisen2002] Sec. 5.6.2 and 5.6.3 for a description of both and some analysis.

In this implementation, the QSC projection projects onto one side of a circumscribed cube. The cube side is selected by choosing one of the following six projection centers:

`+lat_0=0 +lon_0=0`	front cube side
`+lat_0=0 +lon_0=90`	right cube side
`+lat_0=0 +lon_0=180`	back cube side
`+lat_0=0 +lon_0=-90`	left cube side
`+lat_0=90`	top cube side
`+lat_0=-90`	bottom cube side

Furthermore, this implementation allows the projection to be applied to ellipsoids. A preceding shift to a sphere is performed automatically; see [LambersKolb2012] for details.

7.1.111.1 Usage

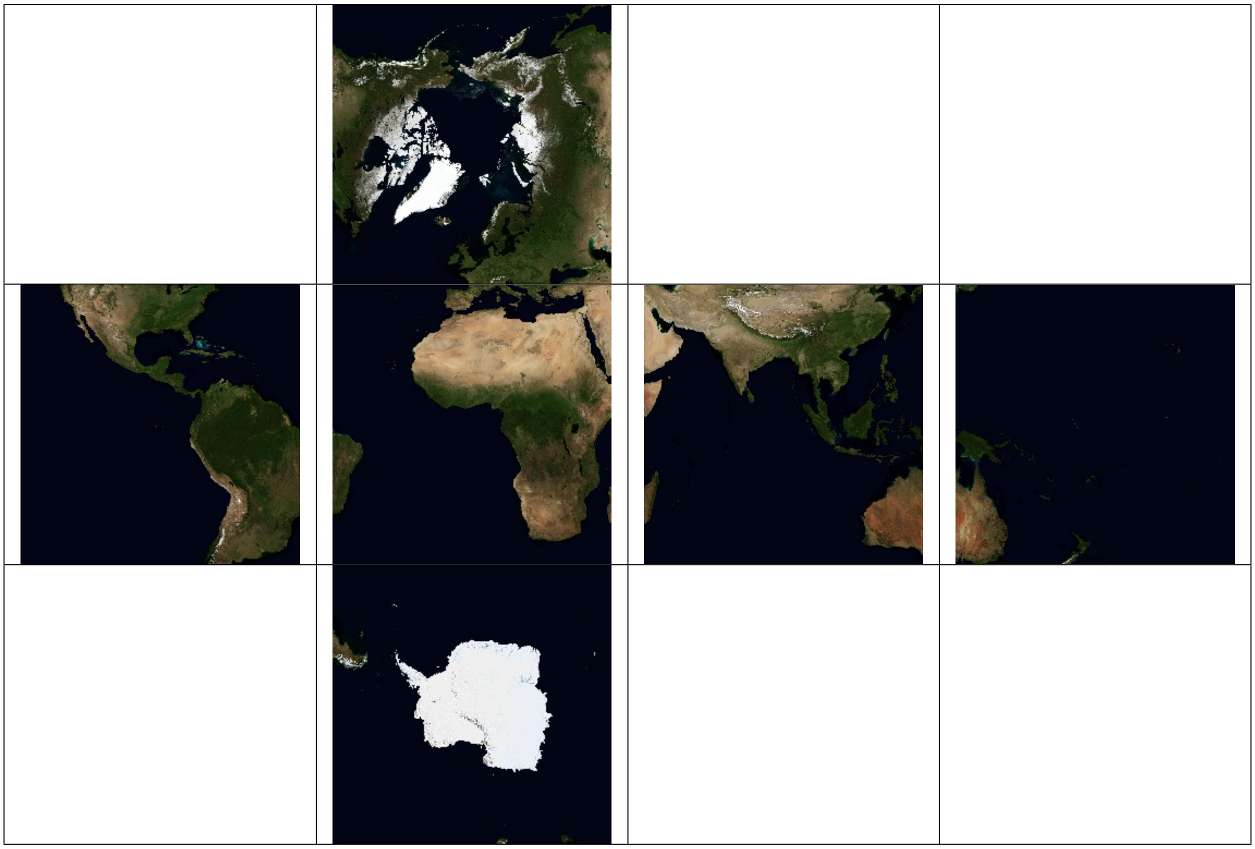
The following example uses QSC projection via GDAL to create the six cube side maps from a world map for the WGS84 ellipsoid:

```
gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84  +lat_0=0 +lon_0=0"       \
    -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137  \
    worldmap.tiff frontside.tiff

gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84 +lat_0=0 +lon_0=90"       \
    -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137  \
    worldmap.tiff rightside.tiff

gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84 +lat_0=0 +lon_0=180"      \
    -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137  \
    worldmap.tiff backside.tiff

gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84 +lat_0=0 +lon_0=-90"      \
    -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137  \
    worldmap.tiff leftside.tiff

gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84 +lat_0=90 +lon_0=0"       \
    -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137  \
    worldmap.tiff topside.tiff

gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84 +lat_0=-90 +lon_0=0"      \
    -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137  \
    worldmap.tiff bottomside.tiff
```

Explanation:

- QSC projection is selected with `+wktext +proj=qsc`.
- The WGS84 ellipsoid is specified with `+ellps=WGS84`.
- The cube side is selected with `+lat_0=... +lon_0=...`.
- The `-wo` options are necessary for GDAL to avoid holes in the output maps.
- The `-te` option limits the extends of the output map to the major axis diameter (from -radius to +radius in both x and y direction). These are the dimensions of one side of the circumscribing cube.

The resulting images can be laid out in a grid like below.



7.1.111.2 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.111.3 Further reading

1. Wikipedia
2. NASA

7.1.112 Robinson

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	robin
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

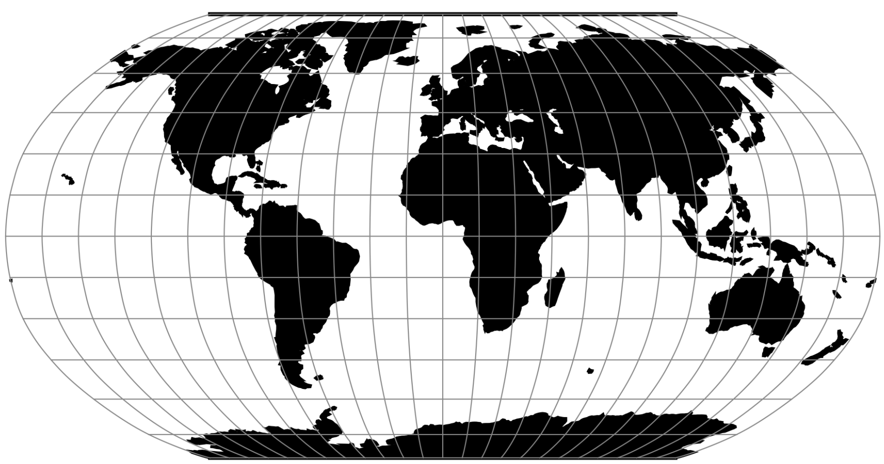


Fig. 107: proj-string: `+proj=robin`

7.1.112.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.113 Roussilhe Stereographic

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	rouss
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

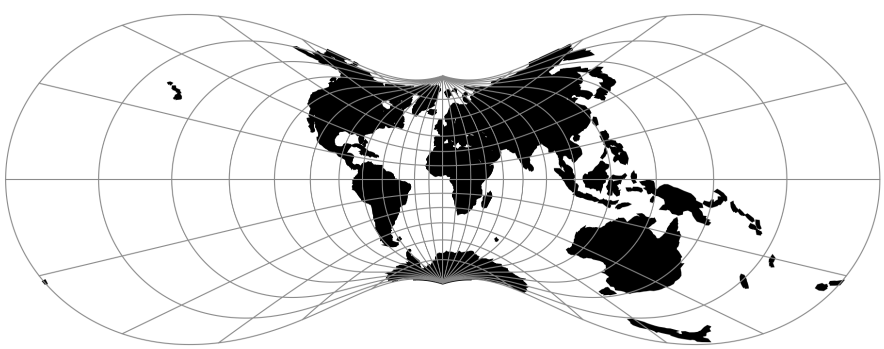


Fig. 108: proj-string: `+proj=rouss`

7.1.113.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.114 Rectangular Polyconic

Classification	Pseudoconical
Available forms	Forward spherical projection
Defined area	Global
Alias	rpoly
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

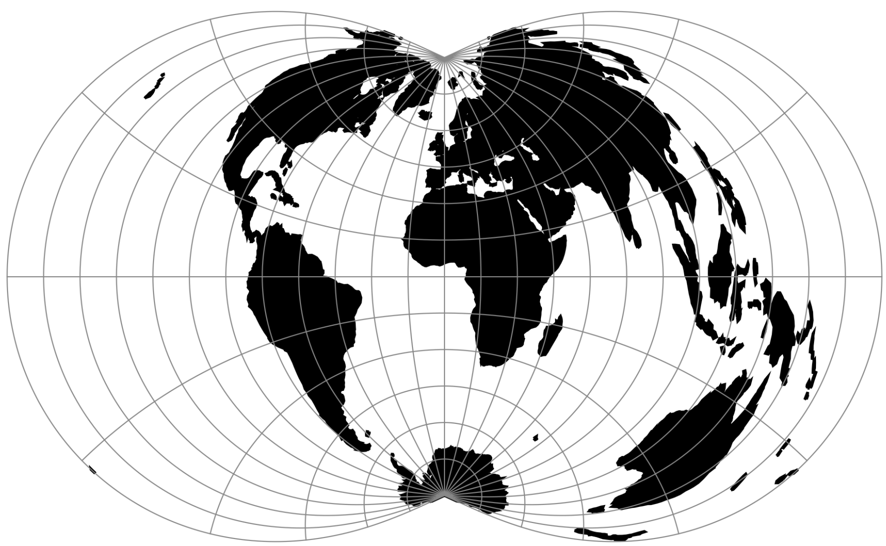


Fig. 109: proj-string: `+proj=rpoly`

7.1.114.1 Parameters

Note: All parameters are optional for the projection.

+lat_ts=<value>

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over +k_0 if both options are used together.

Defaults to 0.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.115 Spherical Cross-track Height

Classification	Miscellaneous
Available forms	Forward and inverse.
Defined area	Global
Alias	sch
Domain	3D
Input type	3D coordinates
Output type	Projected coordinates

proj-string: `+proj=sch +plat_0=XX +plon_0=XX +phdg_0=XX`

The SCH coordinate system is a sensor aligned coordinate system developed at JPL (Jet Propulsion Laboratory) for radar mapping missions.

See [Hensley2002]

7.1.115.1 Parameters

Required

+plat_0=<value>

Peg latitude (in degree)

+plon_0=<value>

Peg longitude (in degree)

+phdg_0=<value>

Peg heading (in degree)

Optional

+h_0=<value>

Average height (in metre)

Defaults to 0.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

+ellps=<value>

See *proj -le* for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

7.1.116 Sinusoidal (Sanson-Flamsteed)

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	sinu
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

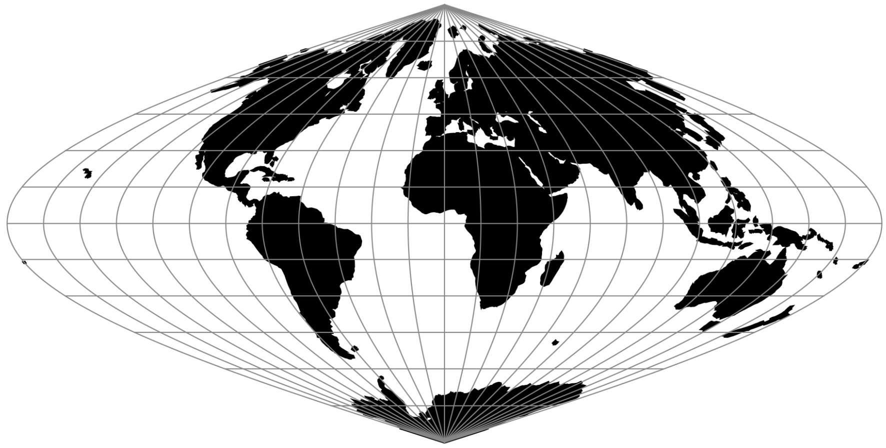


Fig. 110: proj-string: `+proj=sinu`

MacBryde and Thomas developed generalized formulas for several of the pseudocylindricals with sinusoidal meridians:

$$x = C\lambda(m + cos\theta)/(m + 1)$$

$$y = C\theta$$

$$C = \sqrt{(m + 1)/n}$$

7.1.116.1 Parameters

Note: All parameters are optional for the Sinusoidal projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.117 Swiss Oblique Mercator

Fig. 111: proj-string: `+proj=somerc`

7.1.117.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+ellps=<value>`

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+k_0=<value>

Scale factor. Determines scale factor used in the projection.

Defaults to 1.0.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.118 Stereographic

Classification	Azimuthal
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	stere
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.118.1 Parameters

Note: All parameters are optional for the projection.

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+lat_ts=<value>

Defines the latitude where scale is not distorted. It is only taken into account for Polar Stereographic formulations (+lat_0 = +/- 90), and then defaults to the +lat_0 value. If set to a value different from +/- 90, it takes precedence over +k_0 if both options are used together.

+k_0=<value>

Scale factor. Determines scale factor used in the projection.

Defaults to 1.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+ellps=<value>

See *proj -le* for a list of available ellipsoids.

Defaults to "GRS80".

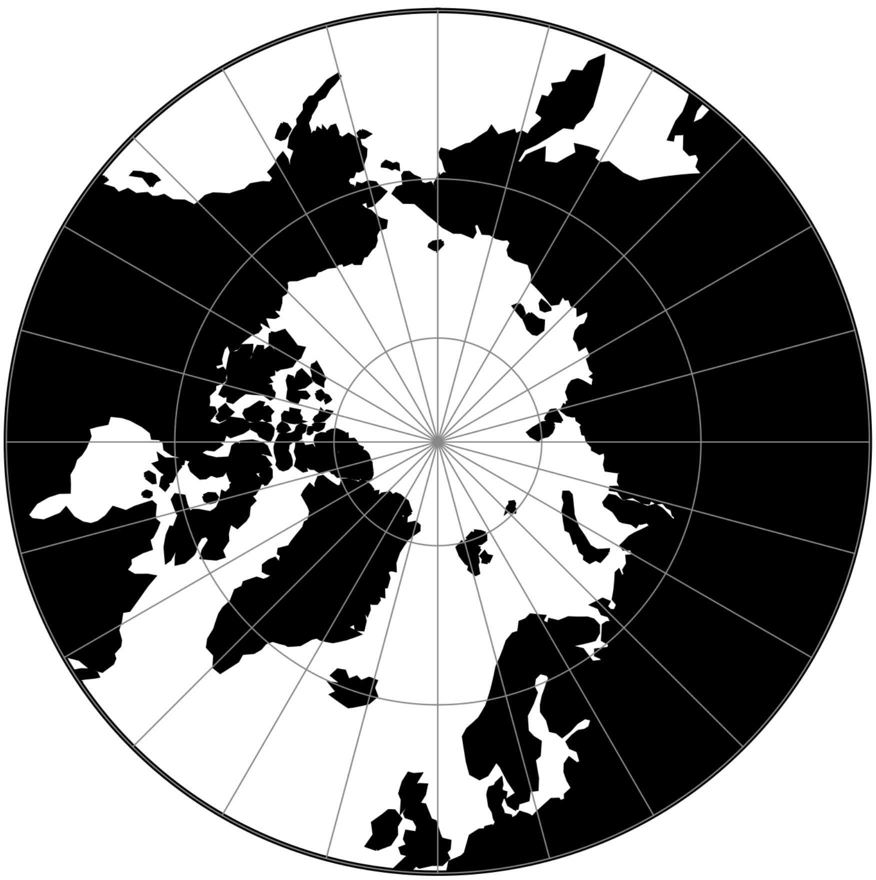


Fig. 112: proj-string: `+proj=stere +lat_0=90 +lat_ts=75`

+R=<value>
Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.119 Oblique Stereographic Alternative

Classification	Azimuthal
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global
Alias	sterea
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.119.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
Longitude of projection center.

Defaults to 0.0.

+lat_0=<value>
Latitude of projection center.

Defaults to 0.0.

+ellps=<value>
See *proj -le* for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>
Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

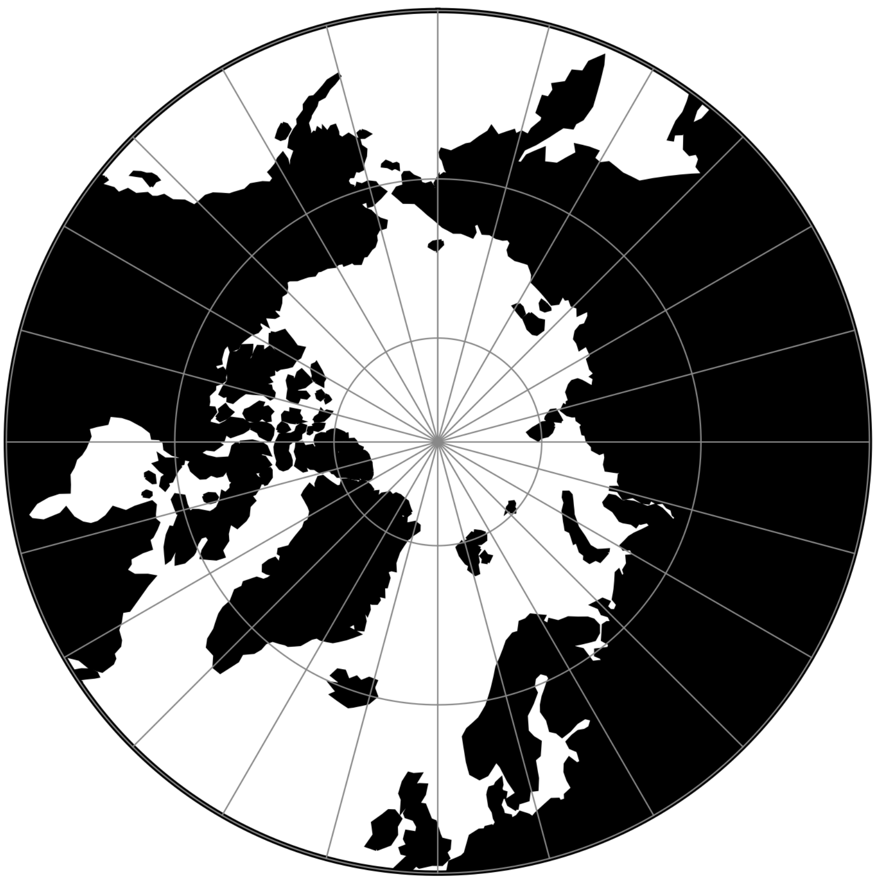


Fig. 113: proj-string: `+proj=sterea +lat_0=90`

7.1.120 Gauss-Schreiber Transverse Mercator (aka Gauss-Laborde Reunion)

Classification	Conformal
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	gstmerc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

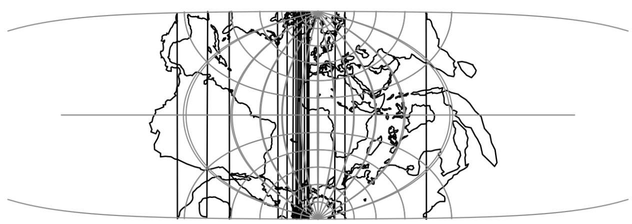


Fig. 114: proj-string: `+proj=gstmerc`

7.1.120.1 Parameters

Note: All parameters are optional for the projection.

+k_0=<value>

Scale factor. Determines scale factor used in the projection.

Defaults to 1.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.121 Transverse Central Cylindrical

Classification	Cylindrical
Available forms	Forward spherical projection
Defined area	Global
Alias	tcc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

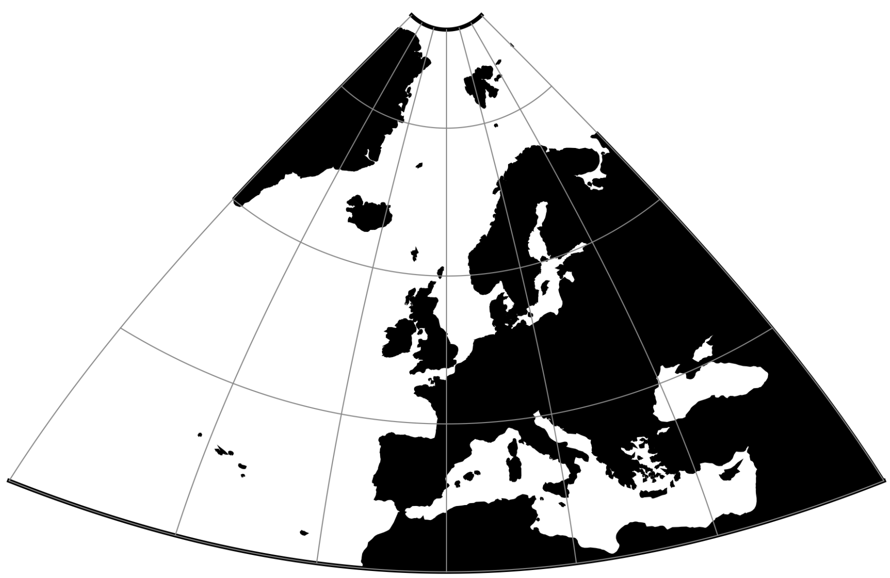


Fig. 115: proj-string: `+proj=tcc`

7.1.121.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.122 Transverse Cylindrical Equal Area

Classification	Cylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	tcea
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.122.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+k_0=<value>`

Scale factor. Determines scale factor used in the projection.

Defaults to 1.0.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

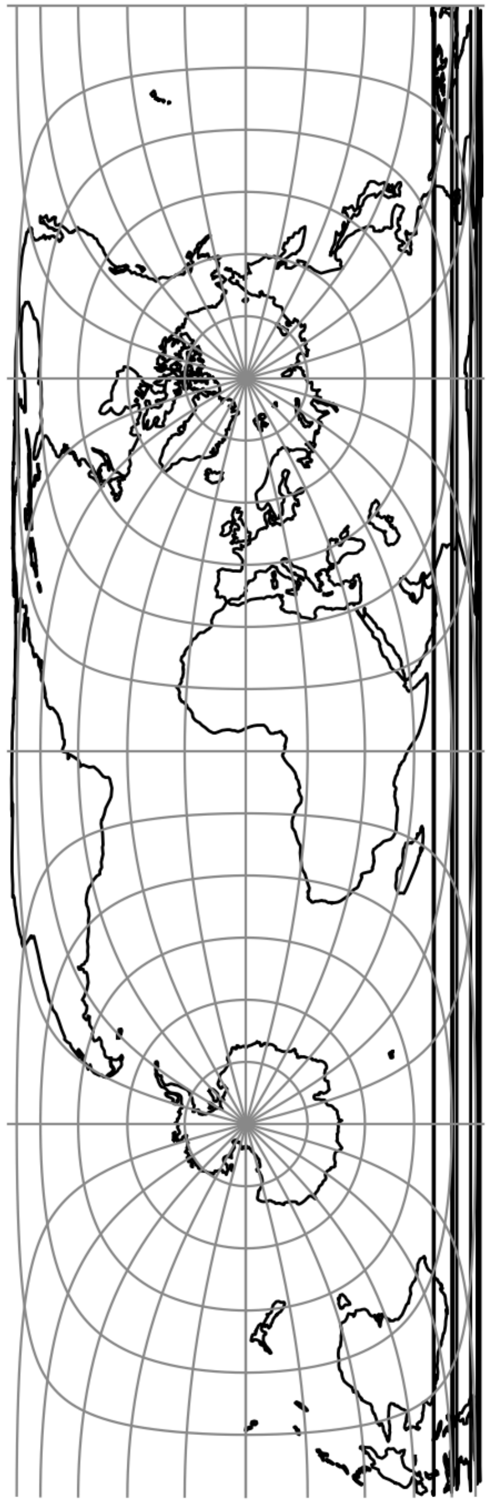


Fig. 116: proj-string: +proj=tcea

7.1.123 Times

See [Snyder1993], p.213-214.

Classification	Cylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	times
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

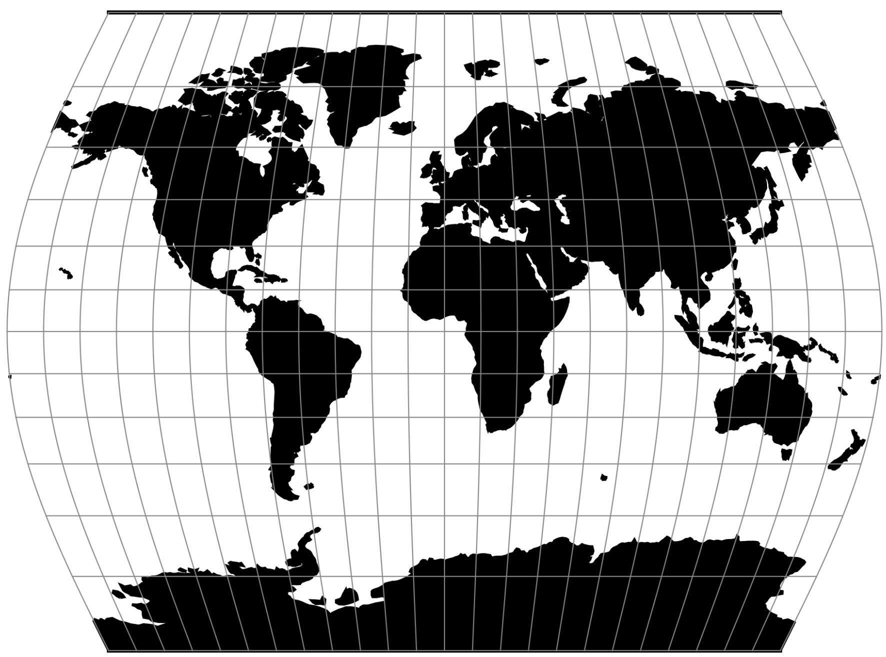


Fig. 117: proj-string: `+proj=times`

7.1.123.1 Parameters

Note: All parameters are optional for projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.124 Tissot

Fig. 118: proj-string: `+proj=tissot +lat_1=60 +lat_2=65`

7.1.124.1 Parameters

Required

+lat_1=<value>

First standard parallel.

Defaults to 0.0.

+lat_2=<value>

Second standard parallel.

Defaults to 0.0.

Optional

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.125 Transverse Mercator

The transverse Mercator projection in its various forms is the most widely used projected coordinate system for world topographical and offshore mapping. It is a conformal projection in which a chosen meridian projects to a straight line at constant scale.

Classification	Transverse and oblique cylindrical
Available forms	Forward and inverse, spherical and ellipsoidal
Defined area	Global, with full accuracy within 3900 km of the central meridian
Alias	tmerc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 119: proj-string: `+proj=tmerc`

7.1.125.1 Usage

Prior to the development of the Universal Transverse Mercator coordinate system, several European nations demonstrated the utility of grid-based conformal maps by mapping their territory during the interwar period. Calculating the distance between two points on these maps could be performed more easily in the field (using the Pythagorean theorem) than was possible using the trigonometric formulas required under the graticule-based system of latitude and longitude. In the post-war years, these concepts were extended into the Universal Transverse Mercator/Universal Polar Stereographic (UTM/UPS) coordinate system, which is a global (or universal) system of grid-based maps.

The following table gives special cases of the Transverse Mercator projection.

Projection Name	Areas	Central meridian	Zone width	Scale Factor
Transverse Mercator	World wide	Various	less than 1000 km	Various
Transverse Mercator south oriented	Southern Africa	2° intervals E of 11°E	2°	1.000
UTM North hemisphere	World wide equator to 84°N	6° intervals E & W of 3° E & W	Usually 6°, wider for Norway and Svalbard	0.9996
UTM South hemisphere	World wide north of 80°S to equator	6° intervals E & W of 3° E & W	Always 6°	0.9996
Gauss-Kruger	Former USSR, Yugoslavia, Germany, S. America, China	Various, according to area	Usually less than 6°, often less than 4°	1.0000
Gauss Boaga	Italy	Various, according to area	6°	0.9996

Example using Gauss-Kruger on Germany area (aka EPSG:31467)

```
$ echo 9 51 | proj +proj=tmerc +lat_0=0 +lon_0=9 +k_0=1 +x_0=3500000 +y_0=0 ␣
↪+ellps=bessel +units=m
3500000.00  5651505.56
```

Example using Gauss Boaga on Italy area (EPSG:3004)

```
$ echo 15 42 | proj +proj=tmerc +lat_0=0 +lon_0=15 +k_0=0.9996 +x_0=2520000 +y_0=0␣
↪+ellps=intl +units=m
2520000.00  4649858.60
```

7.1.125.2 Parameters

Note: All parameters for the projection are optional.

+approx

New in version 6.0.0.

Use the Evenden-Snyder algorithm described below under "Legacy ellipsoidal form". It is faster than the default algorithm, but is less accurate and diverges beyond 3° from the central meridian.

+algo=auto/evenden_snyder/poder_engsager

New in version 7.1.

Selects the algorithm to use. The hardcoded value and the one defined in *proj.ini* default to `poder_engsager`; that is the most precise one.

When using auto, a heuristics based on the input coordinate to transform is used to determine if the faster Evenden-Snyder method can be used, for faster computation, without causing an error greater than 0.1 mm (for an ellipsoid of the size of Earth)

Note that `+approx` and `+algo` are mutually exclusive.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+k_0=<value>

Scale factor. Determines scale factor used in the projection.

Defaults to 1.0.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.125.3 Mathematical definition

The formulation given here for the Transverse Mercator projection is due to Krüger [Krueger1912] who gave the series expansions accurate to n^4, where $n = (a-b)/(a+b)$ is the third flattening. These series were extended to sixth order by Engsager and Poder in [Poder1998] and [Engsager2007]. This gives full double-precision accuracy within 3900 km of the central meridian (about 57% of the surface of the earth) [Karney2011tm]. The error is less than 0.1 mm within 7000 km of the central meridian (about 89% of the surface of the earth).

This formulation consists of three steps: a conformal projection from the ellipsoid to a sphere, the spherical transverse Mercator projection, rectifying this projection to give constant scale on the central meridian.

The scale on the central meridian is k_0 and is set by `+k_0`.

Option *+lon_0* sets the central meridian; in the formulation below λ is the longitude relative to the central meridian.

Options *+lat_0*, *+x_0*, and *+y_0* serve to translate the projected coordinates so that at $(\phi, \lambda) = (\phi_0, \lambda_0)$, the projected coordinates are $(x, y) = (x_0, y_0)$. To simplify the formulas below, these options are set to zero (their default values).

Because the projection is conformal, the formulation is most conveniently given in terms of complex numbers. In particular, the unscaled projected coordinates η (proportional to the easting, x) and ξ (proportional to the northing, y) are combined into the single complex quantity $\zeta = \xi + i\eta$, where $i = \sqrt{-1}$. Then any analytic function $f(\zeta)$ defines a conformal mapping (this follows from the Cauchy-Riemann conditions).

Spherical form

Because the full (ellipsoidal) projection includes the spherical projection as one of the components, we present the spherical form first with the coordinates tagged with primes, ϕ', λ', $\zeta' = \xi' + i\eta'$, x', y', so that they can be distinguished from the corresponding ellipsoidal coordinates (without the primes). The projected coordinates for the sphere are given by

$$x' = k_0 R \eta'; \qquad y' = k_0 R \xi'$$

Forward projection

$$\xi' = \tan^{-1}\left(\frac{\tan\phi'}{\cos\lambda'}\right)$$

$$\eta' = \sinh^{-1}\left(\frac{\sin\lambda'}{\sqrt{\tan^2\phi' + \cos^2\lambda'}}\right)$$

Inverse projection

$$\phi' = \tan^{-1}\left(\frac{\sin\xi'}{\sqrt{\sinh^2\eta' + \cos^2\xi'}}\right)$$

$$\lambda' = \tan^{-1}\left(\frac{\sinh\eta'}{\cos\xi'}\right)$$

Ellipsoidal form

The projected coordinates are given by

$$\zeta = \xi + i\eta; \qquad x = k_0 A\eta; \qquad y = k_0 A\xi$$

$$A = \frac{a}{1+n}\left(1 + \frac{1}{4}n^2 + \frac{1}{64}n^4 + \frac{1}{256}n^6\right)$$

The series for conversion between ellipsoidal and spherical geographic coordinates and ellipsoidal and spherical projected coordinates are given in matrix notation where $\mathbf{S}(\theta)$ and $\mathbf{N}$ are the row and column vectors of length 6

$$\mathbf{S}(\theta) = \begin{pmatrix}\sin 2\theta & \sin 4\theta & \sin 6\theta & \sin 8\theta & \sin 10\theta & \sin 12\theta\end{pmatrix}$$

$$\mathbf{N} = \begin{pmatrix} n \\ n^2 \\ n^3 \\ n^4 \\ n^5 \\ n^6 \end{pmatrix}$$

and $\mathsf{C}_{\alpha,\beta}$ are upper triangular 6×6 matrices.

Relation between geographic coordinates

$$\lambda' = \lambda$$

$$\phi' = \tan^{-1}\sinh\left(\sinh^{-1}\tan\phi - e\tanh^{-1}(e\sin\phi)\right)$$

Instead of using this analytical formula for ϕ', the conversions between ϕ and ϕ' use the series approximations:

$$\phi' = \phi + \mathbf{S}(\phi)\cdot\mathsf{C}_{\chi,\phi}\cdot\mathbf{N}$$

$$\phi = \phi' + \mathbf{S}(\phi')\cdot\mathsf{C}_{\phi,\chi}\cdot\mathbf{N}$$

$$\mathsf{C}_{\chi,\phi} = \begin{pmatrix} -2 & \frac{2}{3} & \frac{4}{3} & -\frac{82}{45} & \frac{32}{45} & \frac{4642}{4725} \\ & \frac{5}{3} & -\frac{16}{15} & -\frac{13}{9} & \frac{904}{315} & -\frac{1522}{945} \\ & & -\frac{26}{15} & \frac{34}{21} & \frac{8}{5} & -\frac{12686}{2835} \\ & & & \frac{1237}{630} & -\frac{12}{5} & -\frac{24832}{14175} \\ & & & & -\frac{734}{315} & \frac{109598}{31185} \\ & & & & & \frac{444337}{155925} \end{pmatrix}$$

$$\mathsf{C}_{\phi,\chi} = \begin{pmatrix} 2 & -\frac{2}{3} & -2 & \frac{116}{45} & \frac{26}{45} & -\frac{2854}{675} \\ & \frac{7}{3} & -\frac{8}{5} & -\frac{227}{45} & \frac{2704}{315} & \frac{2323}{945} \\ & & \frac{56}{15} & -\frac{136}{35} & -\frac{1262}{105} & \frac{73814}{2835} \\ & & & \frac{4279}{630} & -\frac{332}{35} & -\frac{399572}{14175} \\ & & & & \frac{4174}{315} & -\frac{144838}{6237} \\ & & & & & \frac{601676}{22275} \end{pmatrix}$$

Here ϕ' is the conformal latitude (sometimes denoted by χ) and $\mathsf{C}_{\chi,\phi}$ and $\mathsf{C}_{\phi,\chi}$ are the coefficients in the trigonometric series for converting between ϕ and χ.

Relation between projected coordinates

$$\zeta = \zeta' + \mathbf{S}(\zeta') \cdot \mathsf{C}_{\mu,\chi} \cdot \mathbf{N}$$

$$\zeta' = \zeta + \mathbf{S}(\zeta) \cdot \mathsf{C}_{\chi,\mu} \cdot \mathbf{N}$$

$$\mathsf{C}_{\mu,\chi} = \begin{pmatrix} \frac{1}{2} & -\frac{2}{3} & \frac{5}{16} & \frac{41}{180} & -\frac{127}{288} & \frac{7891}{37800} \\ & \frac{13}{48} & -\frac{3}{5} & \frac{557}{1440} & \frac{281}{630} & -\frac{1983433}{1935360} \\ & & \frac{61}{240} & -\frac{103}{140} & \frac{15061}{26880} & \frac{167603}{181440} \\ & & & \frac{49561}{161280} & -\frac{179}{168} & \frac{6601661}{7257600} \\ & & & & \frac{34729}{80640} & -\frac{3418889}{1995840} \\ & & & & & \frac{212378941}{319334400} \end{pmatrix}$$

$$\mathsf{C}_{\chi,\mu} = \begin{pmatrix} -\frac{1}{2} & \frac{2}{3} & -\frac{37}{96} & \frac{1}{360} & \frac{81}{512} & -\frac{96199}{604800} \\ & -\frac{1}{48} & -\frac{1}{15} & \frac{437}{1440} & -\frac{46}{105} & \frac{1118711}{3870720} \\ & & -\frac{17}{480} & \frac{37}{840} & \frac{209}{4480} & -\frac{5569}{90720} \\ & & & -\frac{4397}{161280} & \frac{11}{504} & \frac{830251}{7257600} \\ & & & & -\frac{4583}{161280} & \frac{108847}{3991680} \\ & & & & & -\frac{20648693}{638668800} \end{pmatrix}$$

On the central meridian ($\lambda = \lambda' = 0$), $\zeta' = \phi'$ is the conformal latitude χ and ζ plays the role of the rectifying latitude (sometimes denoted by μ). $\mathsf{C}_{\mu,\chi}$ and $\mathsf{C}_{\chi,\mu}$ are the coefficients in the trigonometric series for converting between χ and μ.

Legacy ellipsoidal form

The formulas below describe the algorithm used when giving the `+approx` option. They are originally from [Snyder1987], but here quoted from [Evenden1995] and [Evenden2005]. These are less accurate that the formulation above and are only valid within about 5 degrees of the central meridian. Here $M(\phi)$ is the meridional distance.

Forward projection

$$N = \frac{k_0}{(1 - e^2 \sin^2 \phi)^{1/2}}$$

$$R = \frac{k_0(1 - e^2)}{(1 - e^2 \sin^2 \phi)^{3/2}}$$

$$t = \tan \phi$$

$$\eta = \frac{e^2}{1-e^2}\cos^2\phi$$

$$\begin{aligned}
x = {} & k_0\lambda\cos\phi \\
& + \frac{k_0\lambda^3\cos^3\phi}{3!}(1-t^2+\eta^2) \\
& + \frac{k_0\lambda^5\cos^5\phi}{5!}(5-18t^2+t^4+14\eta^2-58t^2\eta^2) \\
& + \frac{k_0\lambda^7\cos^7\phi}{7!}(61-479t^2+179t^4-t^6)
\end{aligned}$$

$$\begin{aligned}
y = {} & M(\phi) \\
& + \frac{k_0\lambda^2\sin\phi\cos\phi}{2!} \\
& + \frac{k_0\lambda^4\sin\phi\cos^3\phi}{4!}(5-t^2+9\eta^2+4\eta^4) \\
& + \frac{k_0\lambda^6\sin\phi\cos^5\phi}{6!}(61-58t^2+t^4+270\eta^2-330t^2\eta^2) \\
& + \frac{k_0\lambda^8\sin\phi\cos^7\phi}{8!}(1385-3111t^2+543t^4-t^6)
\end{aligned}$$

Inverse projection

$$\phi_1 = M^{-1}(y)$$

$$N_1 = \frac{k_0}{1-e^2\sin^2\phi_1)^{1/2}}$$

$$R_1 = \frac{k_0(1-e^2)}{(1-e^2\sin^2\phi_1)^{3/2}}$$

$$t_1 = \tan(\phi_1)$$

$$\eta_1 = \frac{e^2}{1-e^2}\cos^2\phi_1$$

$$\begin{aligned}
\phi = {} & \phi_1 \\
& - \frac{t_1x^2}{2!R_1N_1} \\
& + \frac{t_1x^4}{4!R_1N_1^3}(5+3t_1^2+\eta_1^2-4\eta_1^4-9\eta_1^2t_1^2) \\
& - \frac{t_1x^6}{6!R_1N_1^5}(61+90t_1^2+46\eta_1^2+45t_1^4-252t_1^2\eta_1^2) \\
& + \frac{t_1x^8}{8!R_1N_1^7}(1385+3633t_1^2+4095t_1^4+1575t_1^6)
\end{aligned}$$

$$\begin{aligned}
\lambda = {} & \frac{x}{\cos\phi N_1} \\
& - \frac{x^3}{3!\cos\phi N_1^3}(1+2t_1^2+\eta_1^2) \\
& + \frac{x^5}{5!\cos\phi N_1^5}(5+6\eta_1^2+28t_1^2-3\eta_1^2+8t_1^2\eta_1^2) \\
& - \frac{x^7}{7!\cos\phi N_1^7}(61+662t_1^2+1320t_1^4+720t_1^6)
\end{aligned}$$

7.1.125.4 Further reading

1. Wikipedia

7.1.126 Tobler-Mercator

New in version 6.0.0.

Equal area cylindrical projection with the same latitudinal spacing as Mercator projection.

Classification	Cylindrical equal area
Available forms	Forward and inverse, spherical only
Defined area	Global, conventionally truncated at about 80 degrees north and south
Alias	tobmerc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

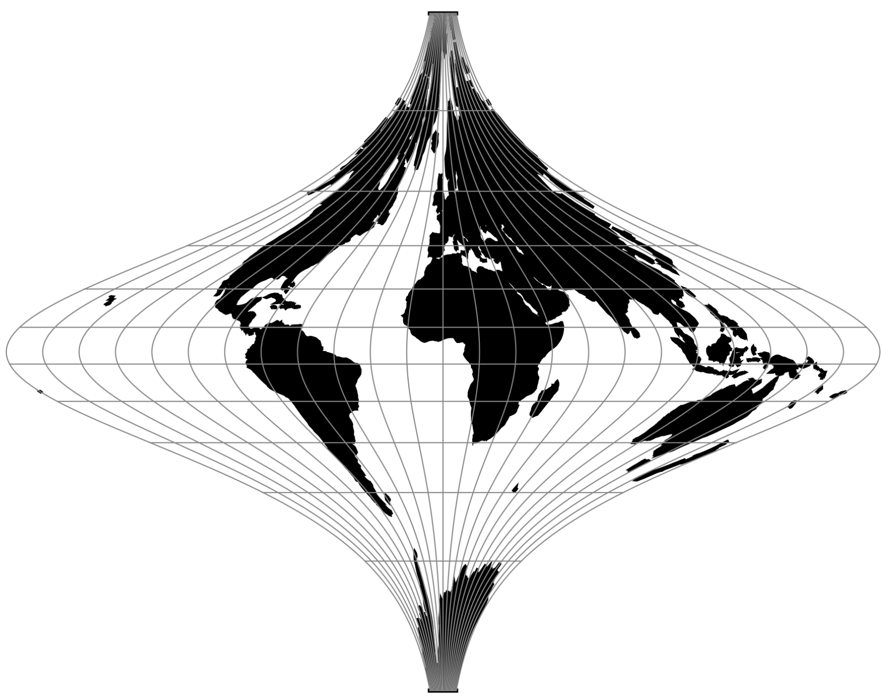


Fig. 120: proj-string: `+proj=tobmerc`

7.1.126.1 Usage

The inappropriate use of the Mercator projection has declined but still occasionally occurs. One method of contrasting the Mercator projection is to present an alternative in the form of an equal area projection. The map projection derived here is thus not simply a pretty Christmas tree ornament: it is instead a complement to Mercator's conformal navigation anamorphosis and can be displayed as an alternative. The equations for the new map projection preserve the latitudinal stretching of the Mercator while adjusting the longitudinal spacing. This allows placement of the new map adjacent to that of Mercator. The surface area, while drastically warped, maintains the correct magnitude.

7.1.126.2 Parameters

Note: All parameters for the projection are optional.

`+k_0=<value>`

Scale factor. Determines scale factor used in the projection.

Defaults to 1.0.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

7.1.126.3 Mathematical definition

The formulas describing the Tobler-Mercator are taken from Waldo Tobler's article [Tobler2018]

Spherical form

For the spherical form of the projection we introduce the scaling factor:

$$k_0 = \cos^2 \phi_{ts}$$

Forward projection

$$x = k_0 \lambda$$

$$y = k_0 \ln \left[\tan \left(\frac{\pi}{4} + \frac{\phi}{2} \right) \right]$$

Inverse projection

$$\lambda = \frac{x}{k_0}$$

$$\phi = \frac{\pi}{2} - 2 \arctan \left[e^{-y/k_0} \right]$$

7.1.127 Two Point Equidistant

Classification	Azimuthal
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	tpeqd
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.127.1 Parameters

Note: All parameters are optional for the projection.

+lon_1=<value>

Longitude of first point.

+lat_1=<value>

Latitude of first point.

+lon_2=<value>

Longitude of second point.

+lat_2=<value>

Latitude of second point.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

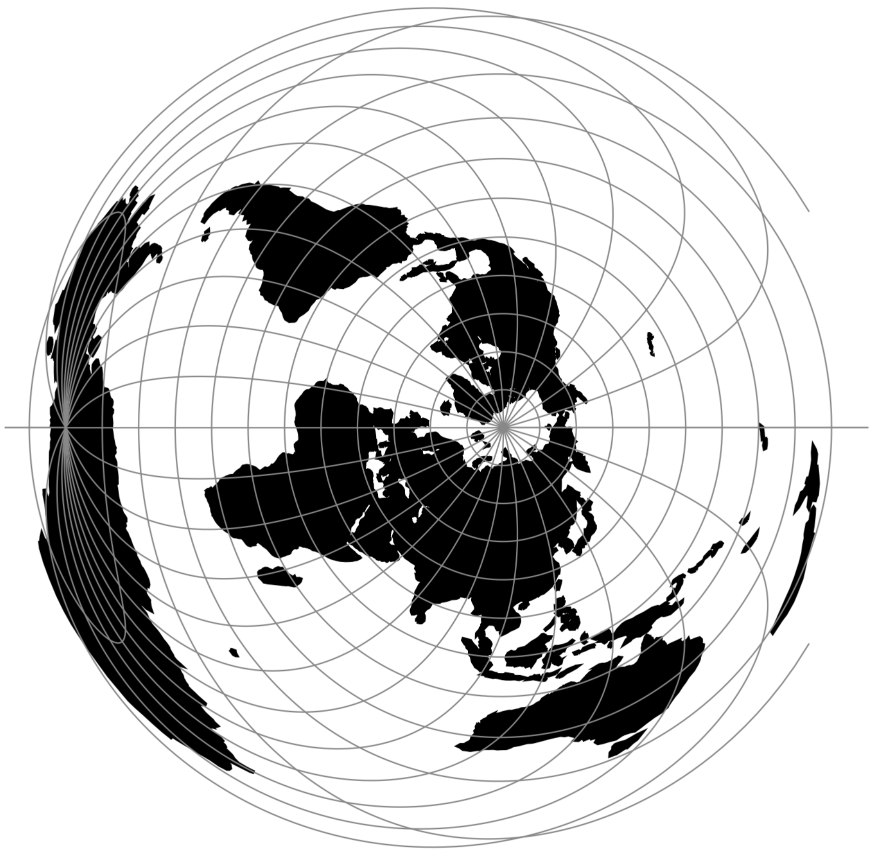


Fig. 121: proj-string: `+proj=tpeqd +lat_1=60 +lat_2=65`

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.128 Tilted perspective

Classification	Azimuthal
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	tpers
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 122: proj-string: `+proj=tpers +h=5500000 +lat_0=40`

Tilted Perspective is similar to *Near-sided perspective* (nsper) in that it simulates a perspective view from a height. Where nsper projects onto a plane tangent to the surface, Tilted Perspective orients the plane towards the direction of the view. Thus, extra parameters specifying azimuth and tilt are required beyond *nsper* ``s h. As with nsper, lat_0 & lon_0 are also required for satellite position.

7.1.128.1 Parameters

Required

+h=<value>

Height of the view point above the Earth and must be in the same units as the radius of the sphere or semimajor axis of the ellipsoid.

Optional

+azi=<value>

Bearing in degrees away from north.

Defaults to 0.0.

+tilt=<value>

Angle in degrees away from nadir.

Defaults to 0.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+lat_0=<value>

Latitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.129 Universal Polar Stereographic

Fig. 123: proj-string: `+proj=ups`

7.1.129.1 Parameters

Note: All parameters are optional for the projection.

`+south`

South polar aspect.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+ellps=<value>`

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

`+R=<value>`
: Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`
: False easting.

  Defaults to 0.0.

`+y_0=<value>`
: False northing.

  Defaults to 0.0.

7.1.130 Urmaev V

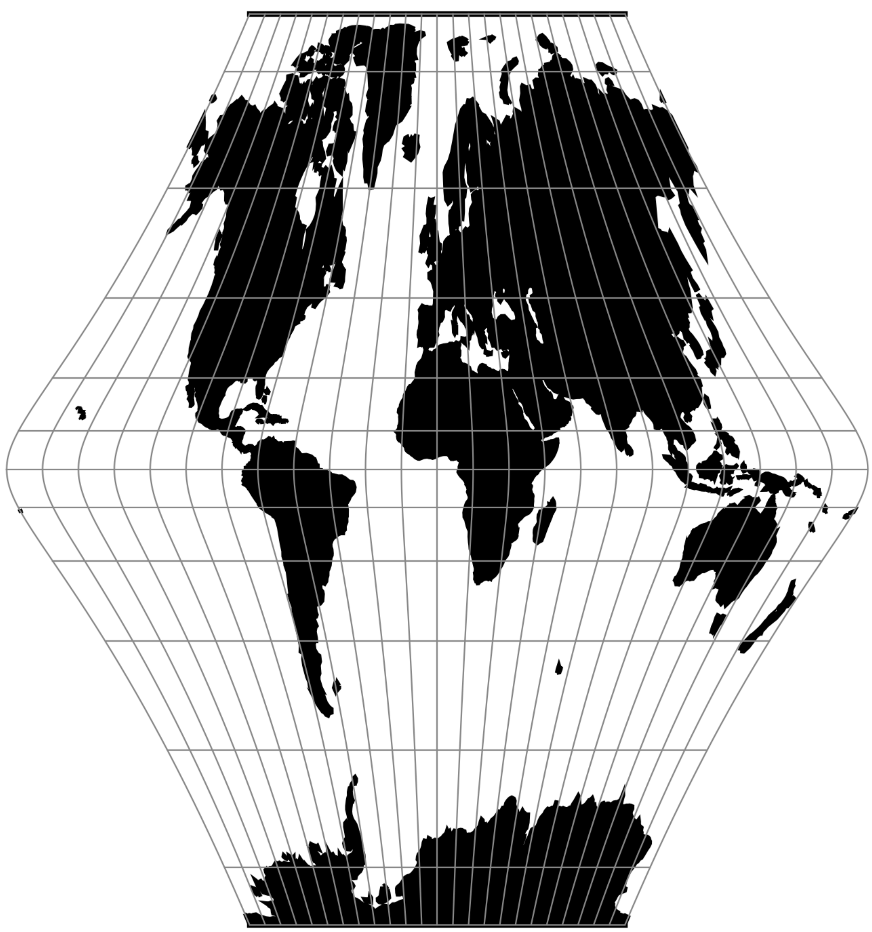


Fig. 124: proj-string: `+proj=urm5 +n=0.9 +alpha=2 +q=4`

7.1.130.1 Parameters

Required parameters

+n=<value>

Set the n constant. Value between 0 and 1.

Optional parameters

+q=<value>

Set the q constant.

+alpha=<value>

Set the α constant.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.131 Urmaev Flat-Polar Sinusoidal

7.1.131.1 Parameters

Note: All parameters are optional for the projection.

+n=<value>

Set the n constant. Value between 0 and 1.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

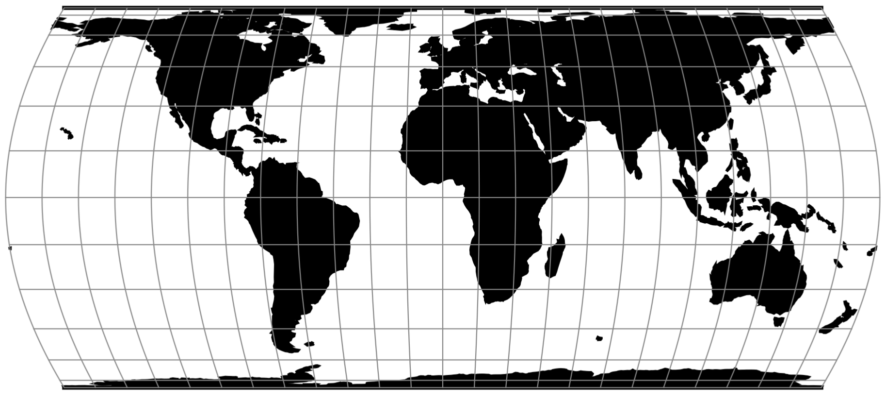


Fig. 125: proj-string: `+proj=urmfps +n=0.5`

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.132 Universal Transverse Mercator (UTM)

The Universal Transverse Mercator is a system of map projections divided into sixty zones across the globe, with each zone corresponding to 6 degrees of longitude.

Classification	Transverse cylindrical, conformal
Available forms	Forward and inverse, ellipsoidal only
Defined area	Within the used zone, but transformations of coordinates in adjacent zones can be expected to be accurate as well
Alias	utm
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

UTM projections are really the *Transverse Mercator* to which specific parameters, such as central meridians, have been applied. The Earth is divided into 60 zones each generally 6° wide in longitude. Bounding meridians are evenly divisible by 6°, and zones are numbered from 1 to 60 proceeding east from the 180th meridian from Greenwich with minor exceptions [Snyder1987].

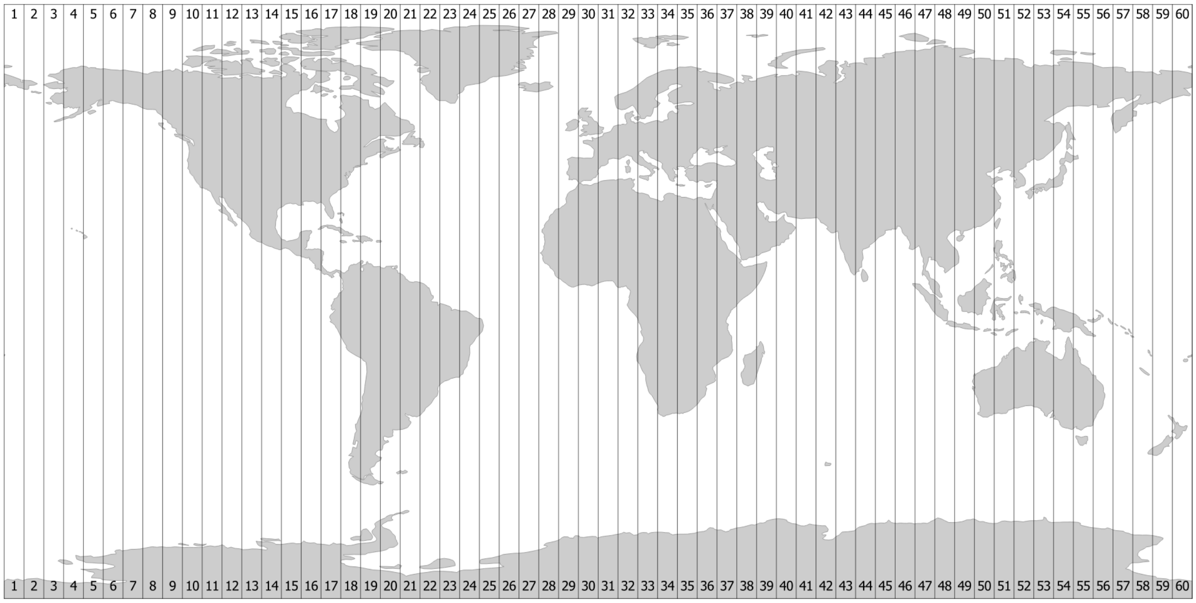


Fig. 126: UTM zones.

7.1.132.1 Usage

Convert geodetic coordinate to UTM Zone 32 on the northern hemisphere:

```
$ echo 12 56 | proj +proj=utm +zone=32
687071.44       6210141.33
```

Convert geodetic coordinate to UTM Zone 59 on the southern hemisphere:

```
$ echo 174 -44 | proj +proj=utm +zone=59 +south
740526.32       5123750.87
```

7.1.132.2 Parameters

Required

+zone=<value>

Select which UTM zone to use. Can be a value between 1-60.

Optional

+south

Add this flag when using the UTM on the southern hemisphere.

+approx

New in version 6.0.0.

Use faster, less accurate algorithm for the Transverse Mercator.

+algo=auto/evenden_snyder/poder_engsager

New in version 7.1.

Selects the algorithm to use. The hardcoded value and the one defined in *proj.ini* default to poder_engsager, that is the most precise one.

When using auto, a heuristics based on the input coordinate to transform is used to determine if the faster Evenden-Snyder method can be used, for faster computation, without causing an error greater than 0.1 mm (for an ellipsoid of the size of Earth)

Note that *+approx* and *+algo* are mutually exclusive.

+ellps=<value>

See proj -le for a list of available ellipsoids.

Defaults to "GRS80".

7.1.132.3 Further reading

1. Wikipedia

7.1.133 van der Grinten (I)

Classification	Miscellaneous
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	vandg
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.133.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

Fig. 127: proj-string: +proj=vandg

7.1.134 van der Grinten II

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	vandg2
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 128: proj-string: `+proj=vandg2`

7.1.134.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.135 van der Grinten III

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	vandg3
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.135.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

Fig. 129: proj-string: `+proj=vandg3`

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.136 van der Grinten IV

Classification	Miscellaneous
Available forms	Forward spherical projection
Defined area	Global
Alias	vandg4
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

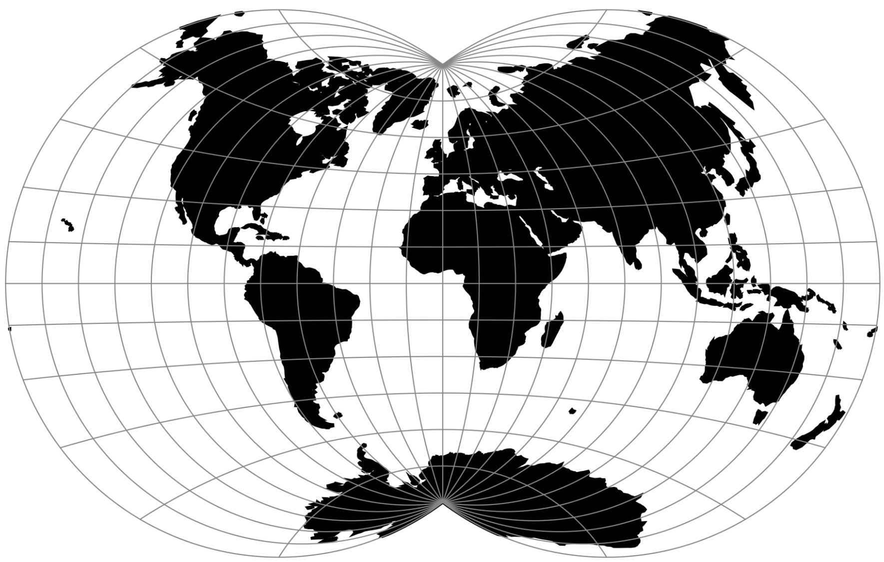


Fig. 130: proj-string: `+proj=vandg4`

7.1.136.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.137 Vitkovsky I

Classification	Conical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	vitk1
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

Fig. 131: proj-string: `+proj=vitk1 +lat_1=45 +lat_2=55`

7.1.137.1 Parameters

Required

`+lat_1=<value>`
First standard parallel.

Defaults to 0.0.

`+lat_2=<value>`
Second standard parallel.

Defaults to 0.0.

Optional

`+lon_0=<value>`
Longitude of projection center.

Defaults to 0.0.

`+R=<value>`
Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`
False easting.

Defaults to 0.0.

`+y_0=<value>`
False northing.

Defaults to 0.0.

7.1.138 Wagner I (Kavraisky VI)

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	wag1
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

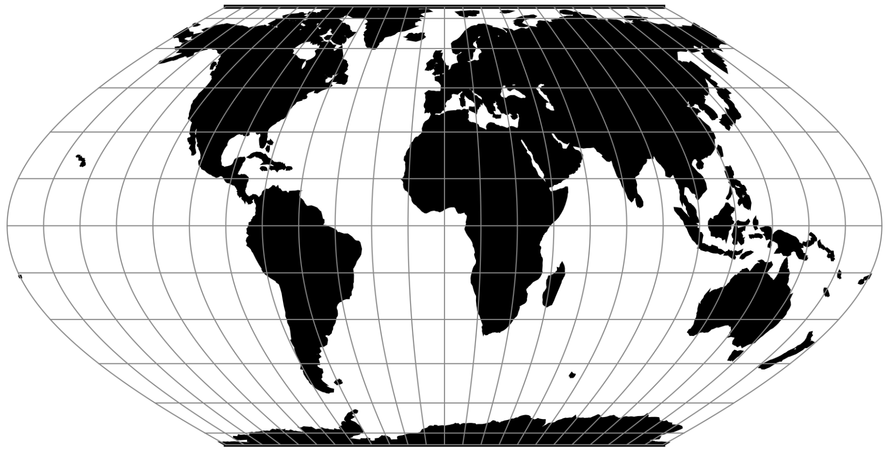


Fig. 132: proj-string: `+proj=wag1`

7.1.138.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.139 Wagner II

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	wag2
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

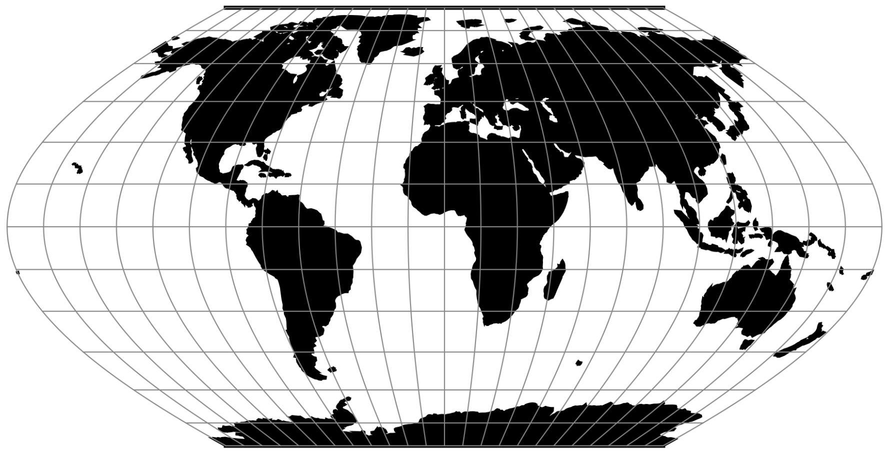


Fig. 133: proj-string: `+proj=wag2`

$$x = 0.92483\lambda \cos\theta$$
$$y = 1.38725\theta$$
$$\sin\theta = 0.88022\sin(0.8855\phi)$$

7.1.139.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.140 Wagner III

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	wag3
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

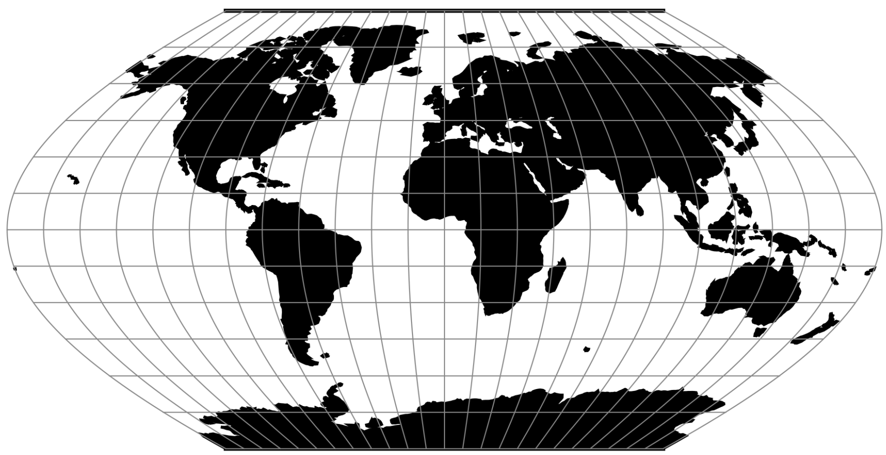


Fig. 134: proj-string: `+proj=wag3`

$$x = [\cos \phi_{ts} / \cos(2\phi_{ts}/3)] \lambda \cos(2\phi/3)$$
$$y = \phi$$

7.1.140.1 Parameters

Note: All parameters are optional for the projection.

`+lat_ts=<value>`

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over `+k_0` if both options are used together.

Defaults to 0.0.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.141 Wagner IV

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	wag4
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

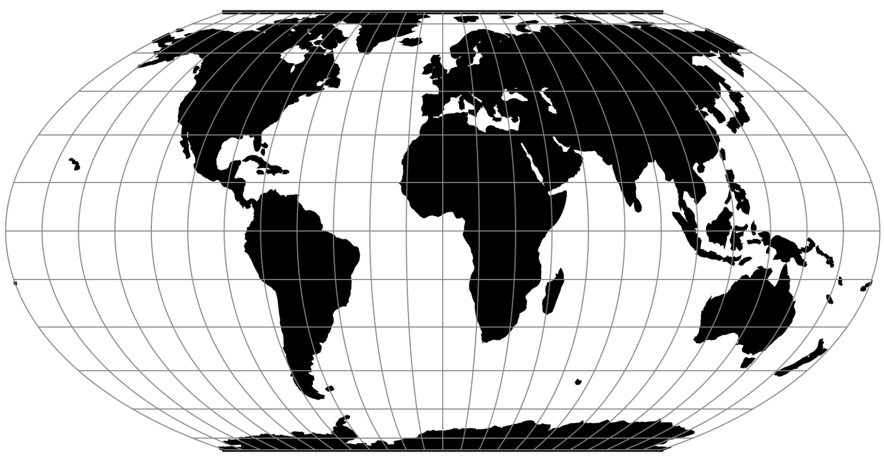


Fig. 135: proj-string: `+proj=wag4`

7.1.141.1 Parameters

Note: All parameters are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.142 Wagner V

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	wag5
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

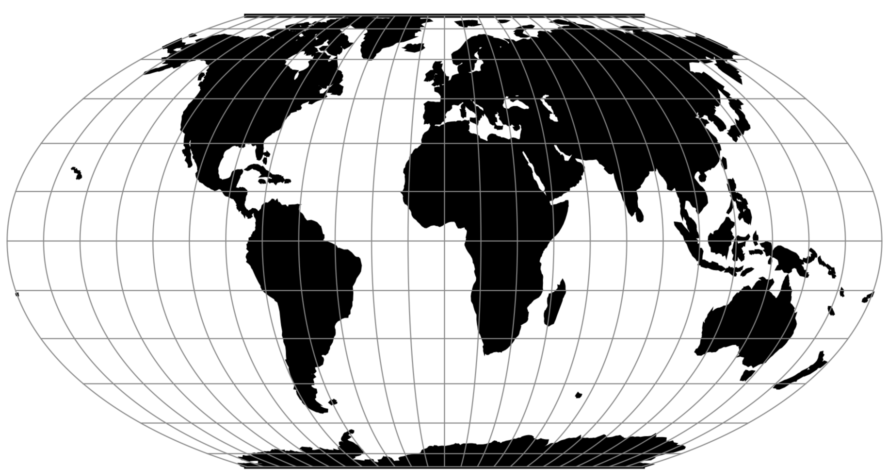


Fig. 136: proj-string: `+proj=wag5`

7.1.142.1 Parameters

Note: All parameters are optional.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`
Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`
False easting.

Defaults to 0.0.

`+y_0=<value>`
False northing.

Defaults to 0.0.

7.1.143 Wagner VI

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	wag6
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

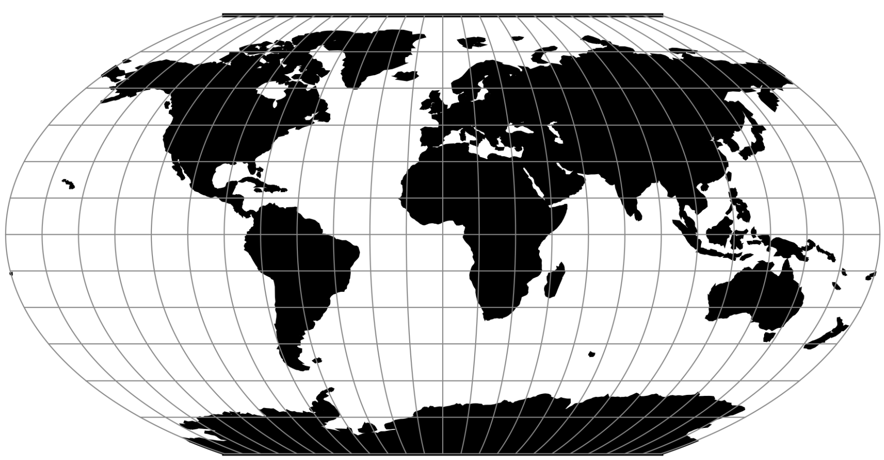


Fig. 137: proj-string: `+proj=wag6`

7.1.143.1 Parameters

Note: All parameters are optional for the Wagner VI projection.

`+lon_0=<value>`
Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.144 Wagner VII

Classification	Azimuthal
Available forms	Forward spherical projection
Defined area	Global
Alias	wag7
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

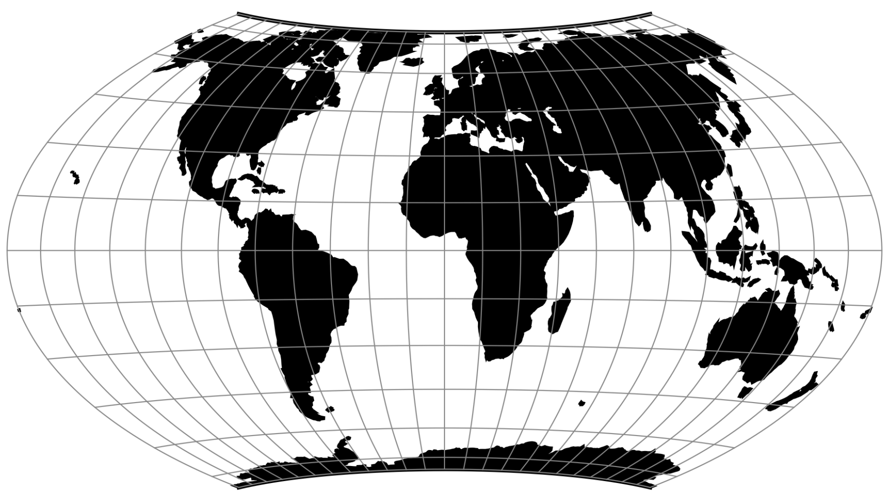


Fig. 138: proj-string: `+proj=wag7`

7.1.145 Web Mercator / Pseudo Mercator

New in version 5.1.0.

The Web Mercator / Pseudo Mercator projection is a cylindrical map projection. This is a variant of the regular *Mercator* projection, except that the computation is done on a sphere, using the semi-major axis of the ellipsoid.

From Wikipedia:

> This projection is widely used by the Web Mercator, Google Web Mercator, Spherical Mercator, WGS 84 Web Mercator[1] or WGS 84/Pseudo-Mercator is a variant of the Mercator projection and is the de facto standard for Web mapping applications. [. . .] It is used by virtually all major online map providers [. . .] Its official EPSG identifier is EPSG:3857, although others have been used historically.

Classification	Cylindrical (non conformant if used with ellipsoid)
Available forms	Forward and inverse
Defined area	Global
Alias	webmerc
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.145.1 Usage

Example:

```
$ echo 2 49 | proj +proj=webmerc +datum=WGS84
222638.98       6274861.39
```

7.1.145.2 Parameters

Note: All parameters for the projection are optional, except the ellipsoid definition, which is WGS84 for the typical use case of EPSG:3857. In which case, the other parameters are set to their default 0 value.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.145.3 Mathematical definition

The formulas describing the Mercator projection are all taken from G. Evenden's libproj manuals [Evenden2005].

Forward projection

$$x = \lambda$$
$$y = \ln\left[\tan\left(\frac{\pi}{4} + \frac{\phi}{2}\right)\right]$$

Inverse projection

$$\lambda = x$$
$$\phi = \frac{\pi}{2} - 2\arctan\left[e^{-y}\right]$$

7.1.145.4 Further reading

1. Wikipedia

7.1.146 Werenskiold I

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	weren
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.146.1 Parameters

Note: All parameters are optional for the projection.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

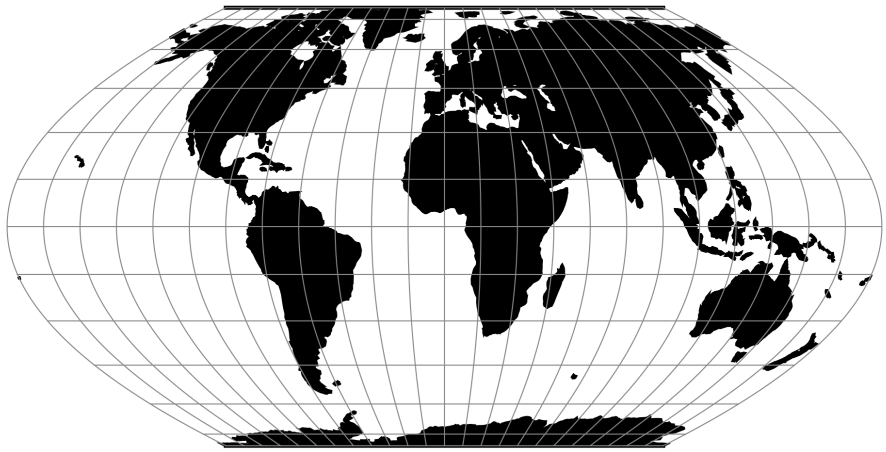


Fig. 139: proj-string: +proj=weren

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.147 Winkel I

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	wink1
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

7.1.147.1 Parameters

Note: All parameters are optional for the projection.

+lat_ts=<value>

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over +k_0 if both options are used together.

Defaults to 0.0.

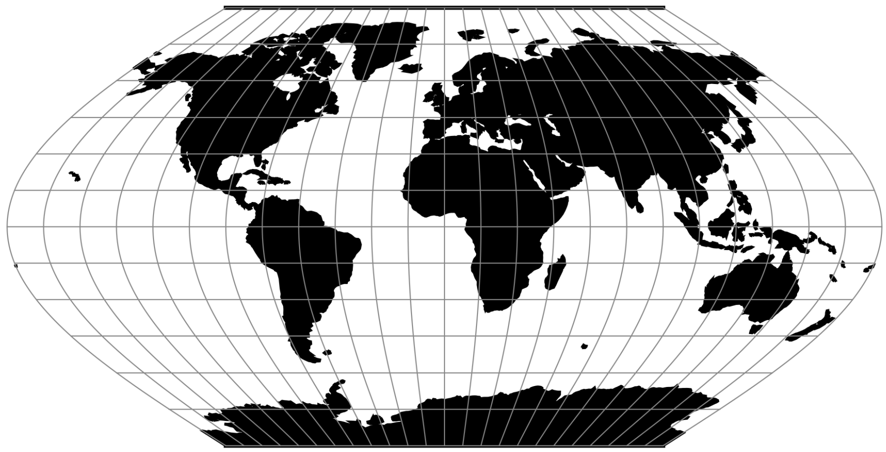


Fig. 140: proj-string: `+proj=wink1`

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

`+x_0=<value>`

False easting.

Defaults to 0.0.

`+y_0=<value>`

False northing.

Defaults to 0.0.

7.1.148 Winkel II

Classification	Pseudocylindrical
Available forms	Forward and inverse, spherical projection
Defined area	Global
Alias	wink2
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

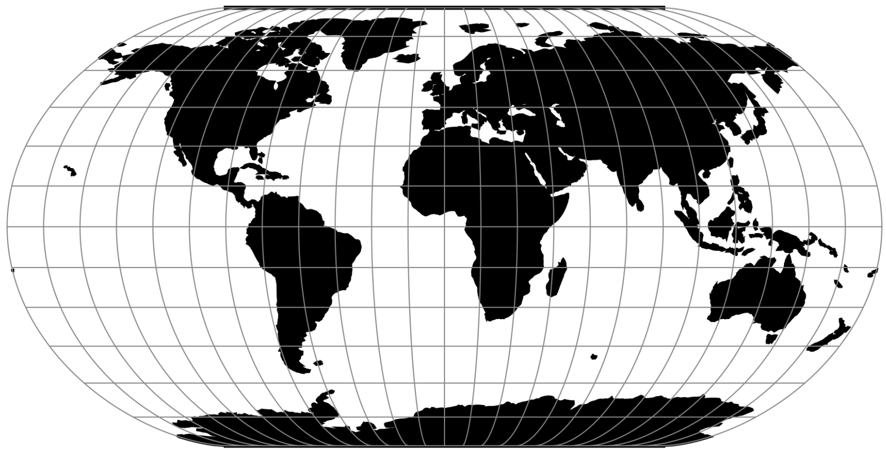


Fig. 141: proj-string: `+proj=wink2`

7.1.148.1 Parameters

Note: All parameters are optional for the projection.

+lat_ts=<value>

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over +k_0 if both options are used together.

Defaults to 0.0.

+lon_0=<value>

Longitude of projection center.

Defaults to 0.0.

+R=<value>

Radius of the sphere given in meters. If used in conjunction with +ellps, +R takes precedence.

+x_0=<value>

False easting.

Defaults to 0.0.

+y_0=<value>

False northing.

Defaults to 0.0.

7.1.149 Winkel Tripel

Classification	Pseudoazimuthal
Available forms	Forward spherical projection
Defined area	Global
Alias	wintri
Domain	2D
Input type	Geodetic coordinates
Output type	Projected coordinates

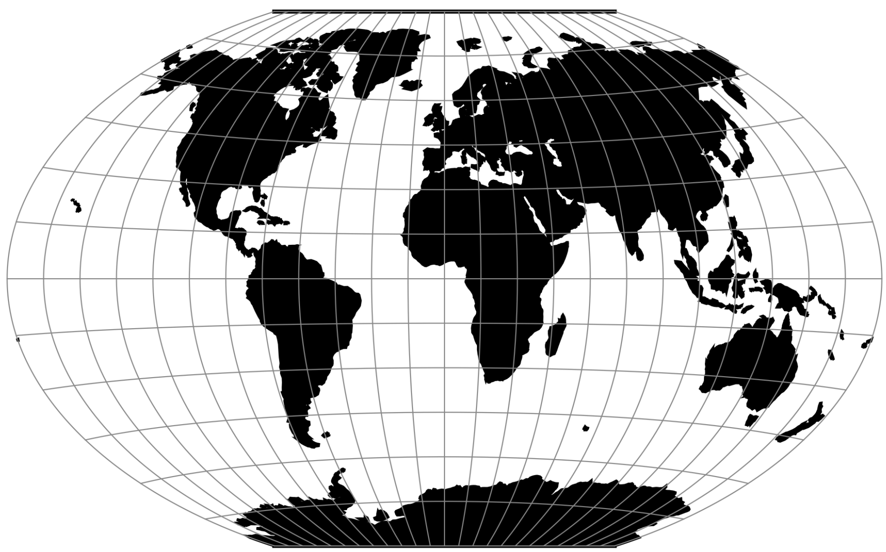


Fig. 142: proj-string: `+proj=wintri`

7.1.149.1 Parameters

Note: All parameters are optional for the projection.

`+lat_1=<value>`

First standard parallel.

Defaults to 0.0.

`+lon_0=<value>`

Longitude of projection center.

Defaults to 0.0.

`+R=<value>`

Radius of the sphere given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

+x_0=<value>
False easting.

Defaults to 0.0.

+y_0=<value>
False northing.

Defaults to 0.0.

7.2 Conversions

Conversions are coordinate operations in which both coordinate reference systems are based on the same datum. In PROJ projections are differentiated from conversions.

7.2.1 Axis swap

New in version 5.0.0.

Change the order and sign of 2,3 or 4 axes.

Alias	axisswap
Domain	2D, 3D or 4D
Input type	Any
Output type	Any

Each of the possible four axes are numbered with 1–4, such that the first input axis is 1, the second is 2 and so on. The output ordering is controlled by a list of the input axes re-ordered to the new mapping.

7.2.1.1 Usage

Reversing the order of the axes:

```
+proj=axisswap +order=4,3,2,1
```

Swapping the first two axes (x and y):

```
+proj=axisswap +order=2,1,3,4
```

The direction, or sign, of an axis can be changed by adding a minus in front of the axis-number:

```
+proj=axisswap +order=1,-2,3,4
```

It is only necessary to specify the axes that are affected by the swap operation:

```
+proj=axisswap +order=2,1
```

7.2.1.2 Parameters

+order=<list>

Ordered comma-separated list of axis, e.g. *+order=2,1,3,4*. Adding a minus in front of an axis number results in a change of direction for that axis, e.g. southward instead of northward.

Required.

7.2.2 Geodetic to cartesian conversion

New in version 5.0.0.

Convert geodetic coordinates to cartesian coordinates (in the forward path).

Alias	cart
Domain	3D
Input type	Geodetic coordinates
Output type	Geocentric cartesian coordinates

This conversion converts geodetic coordinate values (longitude, latitude, elevation above ellipsoid) to their geocentric (X, Y, Z) representation, where the first axis (X) points from the Earth centre to the point of longitude=0, latitude=0, the second axis (Y) points from the Earth centre to the point of longitude=90, latitude=0 and the third axis (Z) points to the North pole.

7.2.2.1 Usage

Convert geodetic coordinates to GRS80 cartesian coordinates:

```
echo 17.7562015132 45.3935192042 133.12 2017.8 | cct +proj=cart +ellps=GRS80
4272922.1553   1368283.0597  4518261.3501     2017.8000
```

7.2.2.2 Parameters

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

7.2.3 Geocentric Latitude

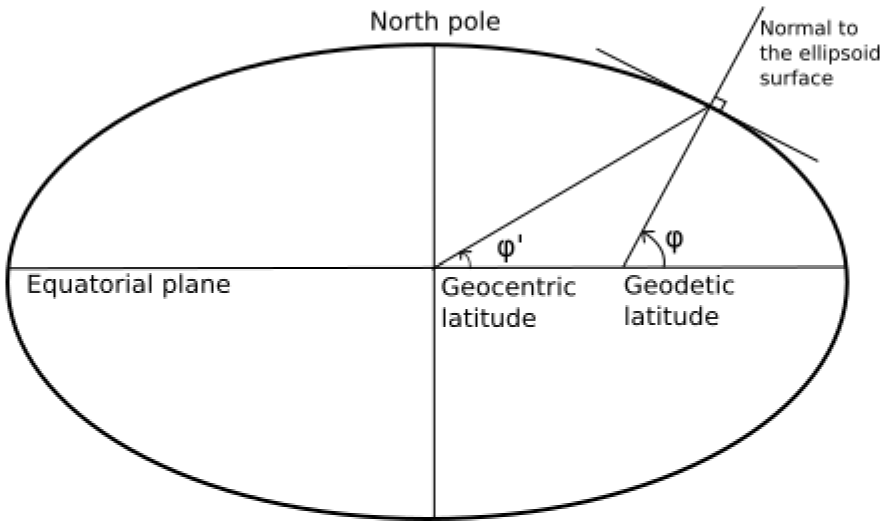
New in version 5.0.0.

Convert from Geodetic Latitude to Geocentric Latitude (in the forward path).

Alias	geoc
Domain	2D
Input type	Geodetic coordinates
Output type	Geocentric angular coordinates

The geodetic (or geographic) latitude (also called planetographic latitude in the context of non-Earth bodies) is the angle between the equatorial plane and the normal (vertical) to the ellipsoid surface at the considered point. The geodetic latitude is what is normally used everywhere in PROJ when angular coordinates are expected or produced.

The geocentric latitude (also called planetocentric latitude in the context of non-Earth bodies) is the angle between the equatorial plane and a line joining the body centre to the considered point.



Note: This conversion must be distinguished from the *Geodetic to cartesian conversion* which converts geodetic coordinates to geocentric coordinates in the cartesian domain.

7.2.3.1 Mathematical definition

The formulas describing the conversion are taken from [Snyder1987] (equation 3-28)

Let ϕ' to be the geocentric latitude and ϕ the geodetic latitude, then

$$\phi' = \arctan\left[(1 - e^2)\tan(\phi)\right]$$

The geocentric latitude is consequently lesser (in absolute value) than the geodetic latitude, except at the equator and the poles where they are equal.

On a sphere, they are always equal.

7.2.3.2 Usage

Converting from geodetic latitude to geocentric latitude:

```
+proj=geoc +ellps=GRS80
```

Converting from geocentric latitude to geodetic latitude:

```
+proj=pipeline +step +proj=geoc +inv +ellps=GRS80
```

7.2.3.3 Parameters

+ellps=<value>

See *proj -le* for a list of available ellipsoids.

Defaults to "GRS80".

7.2.4 Lat/long (Geodetic alias)

Passes geodetic coordinates through unchanged.

Aliases	latlon, latlong, lonlat, longlat
Domain	2D
Input type	Geodetic coordinates
Output type	Geodetic coordinates

Note: Can not be used with the **proj** application.

7.2.4.1 Parameters

No parameters will affect the output of the operation if used on it's own. However, the parameters below can be used in a declarative manner when used with **cs2cs** or in a *transformation pipeline* .

+ellps=<value>

See *proj -le* for a list of available ellipsoids.

Defaults to "GRS80".

+datum=<value>

Declare the datum used with the coordinates. See `cs2cs -ld` for a list of available datums.

+towgs84=<list>

A list of three or seven *Helmert* parameters that maps the input coordinates to the WGS84 datum.

7.2.5 No operation

New in version 6.1.0.

Pass a coordinate through unchanged.

Alias	noop
Domain	4D
Input type	Any
Output type	Any

The no operation is a dummy operation that returns whatever is passed to it as seen in this example:

```
$ echo 12 34 56 78 | cct +proj=noop
  12.0000        34.0000       56.0000       78.0000
```

The operation has no options and default options will not affect the output.

7.2.6 Pop coordinate value to pipeline stack

New in version 6.0.0.

Retrieve components of a coordinate that was saved in a previous pipeline step.

Alias	pop
Domain	4D
Input type	Any
Output type	Any

This operations makes it possible to retrieve coordinate components that was saved in previous pipeline steps. A retrieved coordinate component is loaded, or *popped*, from a memory stack that is part of a *pipeline*. The pipeline coordinate stack is inspired by the stack data structure that is commonly used in computer science. There's four stacks available: One four each coordinate dimension. The dimensions, or coordinate components, are numbered 1–4. It is only possible to move data to and from the stack within the same coordinate component number. Values can be saved to the stack by using the *push operation*.

If the pop operation is used by itself, e.g. not in a pipeline, it will function as a no-operation that passes the coordinate through unchanged. Similarly, if no coordinate component is available on the stack to be popped the operation does nothing.

7.2.6.1 Examples

A common use of the *push* and pop operations is in 3D *Helmert* transformations where only the horizontal components are needed. This is often the case when combining heights from a legacy vertical reference with a modern geocentric reference. Below is a an example of such a transformation, where the horizontal part is transformed with a Helmert operation but the vertical part is kept exactly as the input was.

```
$ echo 12 56 12.3 2020 | cct +proj=pipeline  \
+step +proj=push +v_3                        \
+step +proj=cart +ellps=GRS80                \
+step +proj=helmert +x=3000 +y=1000 +z=2000  \
+step +proj=cart +ellps=GRS80 +inv           \
+step +proj=pop +v_3                         \

 12.0056753463   55.9866540552       12.3000     2000.0000
```

Note that the third coordinate component in the output is the same as the input.

The same transformation without the push and pop operations would look like this:

```
$ echo 12 56 12.3 2020 | cct +proj=pipeline  \
+step +proj=cart +ellps=GRS80                \
+step +proj=helmert +x=3000 +y=1000 +z=2000  \
+step +proj=cart +ellps=GRS80 +inv           \

      12.0057        55.9867     3427.7404     2000.0000
```

Here the vertical component is adjusted significantly.

7.2.6.2 Parameters

+v_1

Retrieves the first coordinate component from the pipeline stack

+v_2

Retrieves the second coordinate component from the pipeline stack

+v_3

Retrieves the third coordinate component from the pipeline stack

+v_4

Retrieves the fourth coordinate component from the pipeline stack

7.2.6.3 Further reading

1. Stack data structure on Wikipedia

7.2.7 Push coordinate value to pipeline stack

New in version 6.0.0.

Save components of a coordinate from one step of a pipeline and make it available for retrieving in another pipeline step.

Alias	push
Domain	4D
Input type	Any
Output type	Any

This operations allows for components of coordinates to be saved for application in a later step. A saved coordinate component is moved, or *pushed*, to a memory stack that is part of a *pipeline*. The pipeline coordinate stack is inspired by the stack data structure that is commonly used in computer science. There's four stacks available: One four each coordinate dimension. The dimensions, or coordinate components, are numbered 1–4. It is only possible to move data to and from the stack within the same coordinate component number. Values can be moved off the stack again by using the *pop operation*.

If the push operation is used by itself, e.g. not in a pipeline, it will function as a no-operation that passes the coordinate through unchanged.

7.2.7.1 Examples

A common use of the push and *pop* operations is in 3D *Helmert* transformations where only the horizontal components are needed. This is often the case when combining heights from a legacy vertical reference with a modern geocentric reference. Below is a an example of such a transformation, where the horizontal part is transformed with a Helmert operation but the vertical part is kept exactly as the input was.

```
$ echo 12 56 12.3 2020 | cct +proj=pipeline  \
+step +proj=push +v_3                        \
+step +proj=cart +ellps=GRS80                \
+step +proj=helmert +x=3000 +y=1000 +z=2000  \
+step +proj=cart +ellps=GRS80 +inv           \
```

(continues on next page)

(continued from previous page)

```
+step +proj=pop +v_3                            \

 12.0056753463   55.9866540552      12.3000     2000.0000
```

Note that the third coordinate component in the output is the same as the input.

The same transformation without the push and pop operations would look like this:

```
$ echo 12 56 12.3 2020 | cct +proj=pipeline  \
+step +proj=cart +ellps=GRS80                 \
+step +proj=helmert +x=3000 +y=1000 +z=2000  \
+step +proj=cart +ellps=GRS80 +inv           \

      12.0057        55.9867     3427.7404     2000.0000
```

Here the vertical component is adjusted significantly.

7.2.7.2 Parameters

+v_1

Stores the first coordinate component on the pipeline stack

+v_2

Stores the second coordinate component on the pipeline stack

+v_3

Stores the third coordinate component on the pipeline stack

+v_4

Stores the fourth coordinate component on the pipeline stack

7.2.7.3 Further reading

1. Stack data structure on Wikipedia

7.2.8 Set coordinate value

New in version 7.0.0.

Set component(s) of a coordinate to a fixed value.

Alias	set
Domain	4D
Input type	Any
Output type	Any

This operations allows for components of coordinates to be set to a fixed value. This may be useful in *pipeline* when a step requires some component, typically an elevation or a date, to be set to a fixed value.

7.2.8.1 Example

In the ETRS89 to Dutch RD with NAP height transformation, the used ellipsoidal height for the Helmert transformation is not the NAP height, but the height is set to 0 m. This is an unconventional trick to get the same results as when the effect of the Helmert transformation is included in the horizontal NTv2 grid. For the forward transformation from ETRS89 to RD with NAP height, we need to set the ellipsoidal ETRS89 height for the Helmert transformation to the equivalent of 0 m NAP. This is 43 m for the centre of the Netherlands and this value can be used as an approximation elsewhere (the effect of this approximation is below 1 mm for the horizontal coordinates, in an area up to hundreds of km outside the Netherlands).

The `+proj=set +v_3=0` close to the end of the pipeline is to make it usable in the reverse direction.

```
$ cct -t 0 -d 4 +proj=pipeline \
     +step +proj=unitconvert +xy_in=deg +xy_out=rad \
     +step +proj=axisswap +order=2,1 \
     +step +proj=vgridshift +grids=nlgeo2018.gtx \
     +step +proj=push +v_3 \
     +step +proj=set +v_3=43 \
     +step +proj=cart +ellps=GRS80 \
     +step +proj=helmert +x=-565.7346 +y=-50.4058 +z=-465.2895 +rx=-0.395023 +ry=0.
↪330776 +rz=-1.876073 +s=-4.07242 +convention=coordinate_frame +exact \
     +step +proj=cart +inv +ellps=bessel \
     +step +proj=hgridshift +inv +grids=rdcorr2018.gsb,null \
     +step +proj=sterea +lat_0=52.156160556 +lon_0=5.387638889 +k=0.9999079 +x_0=155000␣
↪+y_0=463000 +ellps=bessel \
     +step +proj=set +v_3=0 \
     +step +proj=pop +v_3
```

7.2.8.2 Parameters

+v_1=value

Set the first coordinate component to the specified value

+v_2=value

Set the second coordinate component to the specified value

+v_3=value

Set the third coordinate component to the specified value

+v_4=value

Set the fourth coordinate component to the specified value

7.2.9 Geocentric to topocentric conversion

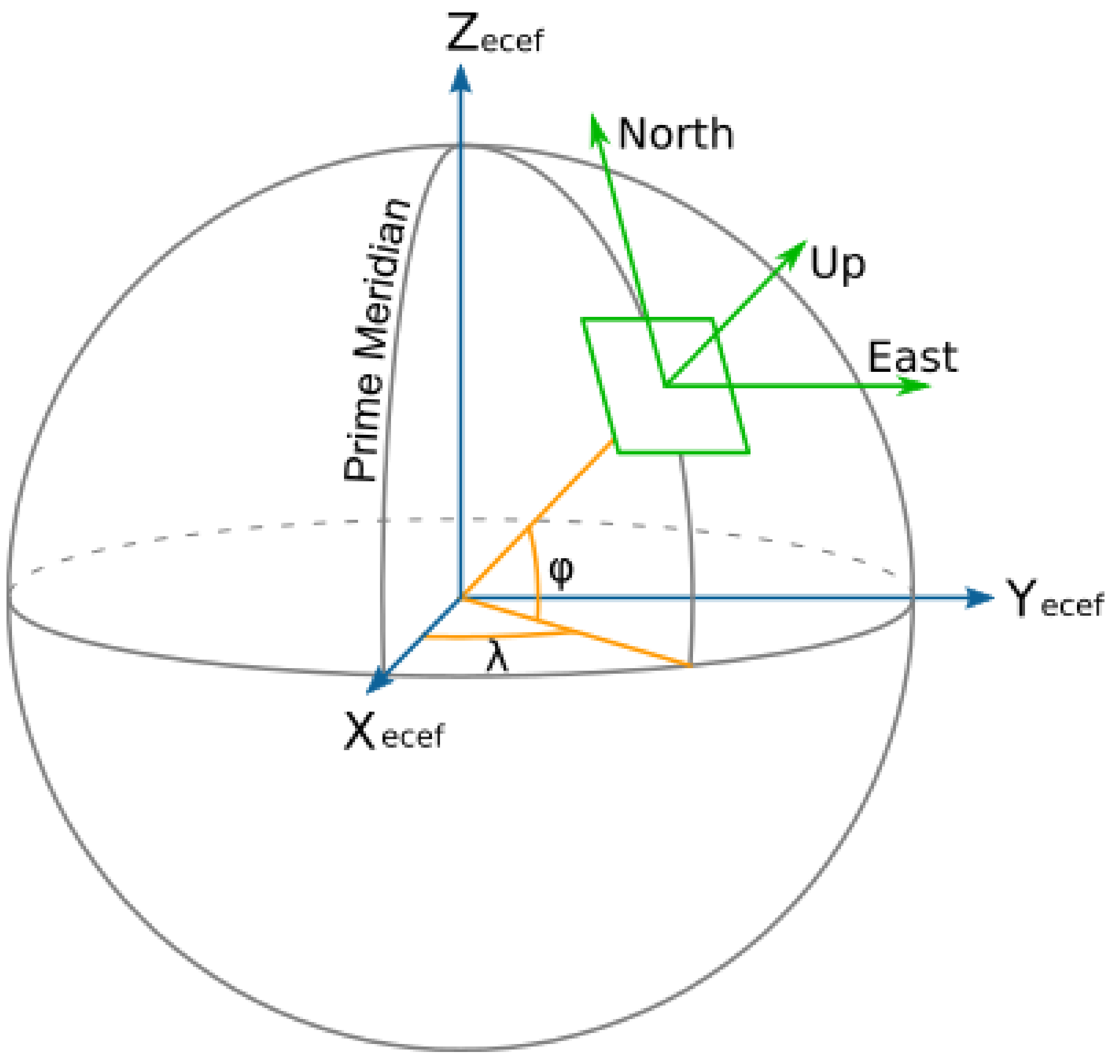
New in version 8.0.0.

Convert geocentric coordinates to topocentric coordinates (in the forward path).

Alias	topocentric
Domain	3D
Input type	Geocentric cartesian coordinates
Output type	Topocentric cartesian coordinates

This operation converts geocentric coordinate values (X, Y, Z) to topocentric (E/East, N/North, U/Up) values. This is also sometimes known as the ECEF (Earth Centered Earth Fixed) to ENU conversion.

Topocentric coordinates are expressed in a frame whose East and North axis form a local tangent plane to the Earth's ellipsoidal surface fixed to a specific location (the topocentric origin), and the Up axis points upwards along the normal to that plane.



The topocentric origin is a required parameter of the conversion, and can be expressed either as geocentric coordinates (`X_0`, `Y_0` and `Z_0`) or as geographic coordinates (`lat_0`, `lon_0`, `h_0`).

When conversion between geographic and topocentric coordinates is desired, the topocentric conversion must be preceded by the *Geodetic to cartesian conversion* conversion to perform the initial geographic to geocentric coordinates conversion.

The formulas used come from the "Geocentric/topocentric conversions" paragraph of [IOGP2018]

7.2.9.1 Usage

Convert geocentric coordinates to topocentric coordinates, with the topocentric origin specified in geocentric coordinates:

```
echo 3771793.968 140253.342 5124304.349 2020 | \
    cct -d 3 +proj=topocentric +ellps=WGS84 +X_0=3652755.3058 +Y_0=319574.6799 +Z_
↪0=5201547.3536

-189013.869    -128642.040     -4220.171     2020.0000
```

Convert geographic coordinates to topocentric coordinates, with the topocentric origin specified in geographic coordinates:

```
echo 2.12955 53.80939444 73 2020 | cct -d 3 +proj=pipeline \
    +step +proj=cart +ellps=WGS84 \
    +step +proj=topocentric +ellps=WGS84 +lon_0=5 +lat_0=55 +h_0=200

-189013.869    -128642.040     -4220.171     2020.0000
```

7.2.9.2 Parameters

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

Topocentric origin described as geocentric coordinates

Note: The below options are mutually exclusive with the ones to express the origin as geographic coordinates.

+X_0=<value>

Geocentric X value of the topocentric origin (in metre)

+Y_0=<value>

Geocentric Y value of the topocentric origin (in metre)

+Z_0=<value>

Geocentric Z value of the topocentric origin (in metre)

Topocentric origin described as geographic coordinates

Note: The below options are mutually exclusive with the ones to express the origin as geocentric coordinates.

+lat_0=<value>

Latitude of topocentric origin (in degree)

+lon_0=<value>

Longitude of topocentric origin (in degree)

+h_0=<value>

Ellipsoidal height of topocentric origin (in metre)

Defaults to 0.0.

7.2.10 Unit conversion

New in version 5.0.0.

Convert between various distance, angular and time units.

Alias	unitconvert
Domain	2D, 3D or 4D
Input type	Any
Output type	Any

There are many examples of coordinate reference systems that are expressed in other units than the meter. There are also many cases where temporal data has to be translated to different units. The *unitconvert* operation takes care of that.

Many North American systems are defined with coordinates in feet. For example in Vermont:

```
+proj=pipeline
+step +proj=tmerc +lat_0=42.5 +lon_0=-72.5 +k_0=0.999964286 +x_0=500000.00001016 +y_0=0
+step +proj=unitconvert +xy_in=m +xy_out=us-ft
```

Often when working with GNSS data the timestamps are presented in GPS-weeks, but when the data transformed with the *helmert* operation timestamps are expected to be in units of decimalyears. This can be fixed with *unitconvert*:

```
+proj=pipeline
+step +proj=unitconvert +t_in=gps_week +t_out=decimalyear
+step +proj=helmert +epoch=2000.0 +t_obs=2017.5 ...
```

7.2.10.1 Parameters

+xy_in=<unit> or <conversion_factor>

Horizontal input units. See *Distance units* and *Angular units* for a list of available units. *<conversion_factor>* is the conversion factor from the input unit to metre for linear units, or to radian for angular units.

+xy_out=<unit> or <conversion_factor>

Horizontal output units. See *Distance units* and *Angular units* for a list of available units. *<conversion_factor>* is the conversion factor from the output unit to metre for linear units, or to radian for angular units.

+z_in=<unit> or <conversion_factor>

Vertical output units. See *Distance units* and *Angular units* for a list of available units. *<conversion_factor>* is the conversion factor from the input unit to metre for linear units, or to radian for angular units.

+z_out=<unit> or <conversion_factor>

Vertical output units. See *Distance units* and *Angular units* for a list of available units. *<conversion_factor>* is the conversion factor from the output unit to metre for linear units, or to radian for angular units.

`+t_in=<unit>`

Temporal input units. See *Time units* for a list of available units.

`+t_out=<unit>`

Temporal output units. See *Time units* for a list of available units.

7.2.10.2 Distance units

In the table below all distance units supported by PROJ are listed. The same list can also be produced on the command line with **proj** or **cs2cs**, by adding the *-lu* flag when calling the utility.

Label	Name
km	Kilometer
m	Meter
dm	Decimeter
cm	Centimeter
mm	Millimeter
kmi	International Nautical Mile
in	International Inch
ft	International Foot
yd	International Yard
mi	International Statute Mile
fath	International Fathom
ch	International Chain
link	International Link
us-in	U.S. Surveyor's Inch
us-ft	U.S. Surveyor's Foot
us-yd	U.S. Surveyor's Yard
us-ch	U.S. Surveyor's Chain
us-mi	U.S. Surveyor's Statute Mile
ind-yd	Indian Yard
ind-ft	Indian Foot
ind-ch	Indian Chain

7.2.10.3 Angular units

New in version 5.2.0.

In the table below all angular units supported by PROJ *unitconvert* are listed.

Label	Name
deg	Degree
grad	Grad
rad	Radian

7.2.10.4 Time units

In the table below all time units supported by PROJ are listed.

Label	Name
mjd	Modified Julian date
decimalyear	Decimal year
gps_week	GPS Week
yyyymmdd	Date in yyyymmdd format

7.3 Transformations

Transformations coordinate operation in which the two coordinate reference systems are based on different datums.

7.3.1 Affine transformation

New in version 6.0.0.

The affine transformation applies translation and scaling/rotation terms on the x,y,z coordinates, and translation and scaling on the temporal coordinate.

Alias	affine
Domain	4D
Input type	XYZT
output type	XYZT

By default, the parameters are set for an identity transforms. The transformation is reversible unless the determinant of the sji matrix is 0, or *tscale* is 0

7.3.1.1 Parameters

Optional

+xoff=<value>

Offset in X. Default value: 0

+yoff=<value>

Offset in Y. Default value: 0

+zoff=<value>

Offset in Z. Default value: 0

+toff=<value>

Offset in T. Default value: 0

+s11=<value>

Rotation/scaling term. Default value: 1

+s12=<value>

Rotation/scaling term. Default value: 0

`+s13=<value>`
: Rotation/scaling term. Default value: 0

`+s21=<value>`
: Rotation/scaling term. Default value: 0

`+s22=<value>`
: Rotation/scaling term. Default value: 1

`+s23=<value>`
: Rotation/scaling term. Default value: 0

`+s31=<value>`
: Rotation/scaling term. Default value: 0

`+s32=<value>`
: Rotation/scaling term. Default value: 0

`+s33=<value>`
: Rotation/scaling term. Default value: 1

`+tscale=<value>`
: Time scaling term. Default value: 1

Mathematical description

$$\begin{bmatrix} X \\ Y \\ Z \\ T \end{bmatrix}^{dest} = \begin{bmatrix} xoff \\ yoff \\ zoff \\ toff \end{bmatrix} + \begin{bmatrix} s11 & s12 & s13 & 0 \\ s21 & s22 & s23 & 0 \\ s31 & s32 & s33 & 0 \\ 0 & 0 & 0 & tscale \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ T \end{bmatrix}^{source} \tag{7.1}$$

7.3.2 Multi-component time-based deformation model

New in version 7.1.0.

Alias	defmodel
Input type	Geodetic or projected coordinates (horizontal), meters (vertical), decimalyear (temporal)
Output type	Geodetic or projected coordinates (horizontal), meters (vertical), decimalyear (temporal)
Domain	4D
Available forms	Forward and inverse

The defmodel transformation can be used to represent most deformation models currently in use, in particular for areas subject to complex deformation, including large scale secular crustal deformation near plate boundaries and vertical deformation due to Glacial Isostatic Adjustment (GIA). These can often be represented by a constant velocity model. Additionally, many areas suffer episodic deformation events such as earthquakes and aseismic slow slip event.

The transformation relies on a “master” JSON file, describing general metadata on the deformation model, its spatial and temporal extent, and listing spatial components whose values are stored in *Geodetic TIFF grids (GTG)*. The valuation of each component is modulated by a time function (constant, step, reverse step, velocity, piecewise, exponential).

All details on the content of this JSON file are given in the Proposal for encoding of a Deformation Model

If input coordinates are given in the geographic domain (resp. projected domain), the output will also be in the geographic domain (resp. projected domain). The domain should be the corresponding to the source_crs metadata of the model.

This transformation is a generalization of the *Kinematic datum shifting utilizing a deformation model* transformation.

7.3.2.1 Parameters

Required

+model=<filename>

Filename to the JSON master file for the deformation model.

7.3.2.2 Example

Transforming a point with the LINZ NZGD2000 deformation model:

```
echo 166.7133850980 -44.5105886020 293.3700 2007.689 | cct +proj=defmodel
↪+model=nzgd2000-20180701.json
```

7.3.3 Kinematic datum shifting utilizing a deformation model

New in version 5.0.0.

Perform datum shifts means of a deformation/velocity model.

Alias	deformation
Input type	Cartesian coordinates (spatial), decimalyears (temporal).
Output type	Cartesian coordinates (spatial), decimalyears (temporal).
Domain	4D
Input type	Geodetic coordinates
Output type	Geodetic coordinates

The deformation operation is used to adjust coordinates for intraplate deformations. Usually the transformation parameters for regional plate-fixed reference frames such as the ETRS89 does not take intraplate deformation into account. It is assumed that tectonic plate of the region is rigid. Often times this is true, but near the plate boundary and in areas with post-glacial uplift the assumption breaks. Intraplate deformations can be modelled and then applied to the coordinates so that they represent the physical world better. In PROJ this is done with the deformation operation.

The horizontal grid is stored in CTable2 format and the vertical grid is stored in the GTX format. Both grids are expected to contain grid-values in units of mm/year. GDAL both reads and writes both file formats. Using GDAL for construction of new grids is recommended.

Starting with PROJ 7.0, use of a GeoTIFF format is recommended to store both the horizontal and vertical velocities.

More complex deformations can be done with the *Multi-component time-based deformation model* transformation.

7.3.3.1 Example

In [Hakli2016] coordinate transformation including a deformation model is described. The paper describes how coordinates from the global ITRFxx frames are transformed to the local Nordic realisations of ETRS89. Scandinavia is an area with significant post-glacial rebound. The deformations from the post-glacial uplift is not accounted for in the official ETRS89 transformations so in order to get accurate transformations in the Nordic countries it is necessary to apply the deformation model. The transformation from ITRF2008 to the Danish realisation of ETRS89 is in PROJ described as:

```
proj =  pipeline ellps = GRS80
        # ITRF2008@t_obs -> ITRF2000@t_obs
step    init = ITRF2008:ITRF2000
        # ITRF2000@t_obs -> ETRF2000@t_obs
step    proj=helmert t_epoch = 2000.0 convention=position_vector
        x =  0.054  rx =  0.000891 drx =  8.1e-05
        y =  0.051  ry =  0.00539  dry =  0.00049
        z = -0.048  rz = -0.008712 drz = -0.000792
        # ETRF2000@t_obs -> NKG_ETRF00@2000.0
step    proj = deformation t_epoch = 2000.0
        grids = ./eur_nkg_nkgrf03vel_realigned.tif
        inv
        # NKG_ETRF@2000.0 -> ETRF92@2000.0
step    proj=helmert convention=position_vector s = -0.009420e
        x = 0.03863 rx = 0.00617753
        y = 0.147   ry = 5.064e-05
        z = 0.02776 rz = 4.729e-05
        # ETRF92@2000.0 -> ETRF92@1994.704
step    proj = deformation dt = -5.296
        grids = ./eur_nkg_nkgrf03vel_realigned.tif
```

From this we can see that the transformation from ITRF2008 to the Danish realisation of ETRS89 is a combination of Helmert transformations and adjustments with a deformation model. The first use of the deformation operation is:

```
proj = deformation t_epoch = 2000.0 grids = ./eur_nkg_nkgrf03vel_realigned.tif
```

Here we set the central epoch of the transformation, 2000.0. The observation epoch is expected as part of the input coordinate tuple. The deformation model is described by two grids, specified with *+xy_grids* and *+z_grids*. The first is the horizontal part of the model and the second is the vertical component.

7.3.3.2 Parameters

+xy_grids=<list>

Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will the not complain if the grid is not available.

Grids for the horizontal component of a deformation model is expected to be in CTable2 format.

Note: *+xy_grids* is mutually exclusive with *+grids*

+z_grids=<list>

Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will the not complain if the grid is not available.

Grids for the vertical component of a deformation model is expected to be in either GTX format.

Note: *+z_grids* is mutually exclusive with *+grids*

+grids=<list>

New in version 7.0.0.

Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will the not complain if the grid is not available.

Grids should be in GeoTIFF format with the first 3 components being respectively the easting, northing and up velocities in mm/year. Setting the Description and Unit Type GDAL band metadata items is strongly recommended, so that gdalinfo reports:

```
Band 1 Block=... Type=Float32, ColorInterp=Gray
    Description = east_velocity
    Unit Type: mm/year
Band 2 Block=... Type=Float32, ColorInterp=Undefined
    Description = north_velocity
    Unit Type: mm/year
Band 3 Block=... Type=Float32, ColorInterp=Undefined
    Description = up_velocity
    Unit Type: mm/year
```

Note: *+grids* is mutually exclusive with *+xy_grids* and *+z_grids*

+t_epoch=<value>

Central epoch of transformation given in decimalyears. Will be used in conjunction with the observation time from the input coordinate to determine dt as used in eq. (7.1) below.

Note: *+t_epoch* is mutually exclusive with *+dt*

+dt=<value>

New in version 6.0.0.

dt as used in eq. (7.1) below. Is useful when no observation time is available in the input coordinate or when a deformation for a specific timespan needs to be applied in a transformation. dt is given in units of decimalyears.

Note: *+dt* is mutually exclusive with *+t_epoch*

7.3.3.3 Mathematical description

Mathematically speaking, application of a deformation model is simple. The deformation model is represented as a grid of velocities in three dimensions. Coordinate corrections are applied in cartesian space. For a given coordinate, (X, Y, Z), velocities (V_X, V_Y, V_Z) can be interpolated from the gridded model. The time span between t_{obs} and t_c determine the magnitude of the coordinate correction as seen in eq. (7.1) below.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_B = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_A + (t_{obs} - t_c) \begin{pmatrix} V_X \\ V_Y \\ V_Z \end{pmatrix} \tag{7.1}$$

Corrections are done in cartesian space.

Coordinates of the gridded model are in ENU (east, north, up) space because it would otherwise require an enormous 3 dimensional grid to handle the corrections in cartesian space. Keeping the correction in lat/long space reduces the complexity of the grid significantly. Consequently though, the input coordinates needs to be converted to lat/long space when searching for corrections in the grid. This is done with the *cart* operation. The converted grid corrections can then be applied to the input coordinates in cartesian space. The conversion from ENU space to cartesian space is done in the following way:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} -\sin\phi\cos\lambda N - \sin\lambda E + \cos\phi\cos\lambda U \\ -\sin\phi\sin\lambda N + \sin\lambda E + \cos\phi\sin\lambda U \\ \cos\phi N + \sin\phi U \end{pmatrix} \tag{7.1}$$

where ϕ and λ are the latitude and longitude of the coordinate that is searched for in the grid. (E, N, U) are the grid values in ENU-space and (X, Y, Z) are the corrections converted to cartesian space.

7.3.3.4 See also

1. *Behavioural changes from version 5 to 6*

7.3.4 Geographic offsets

New in version 6.0.0.

The Geographic offsets transformation adds an offset to the geographic longitude, latitude coordinates, and an offset to the ellipsoidal height.

Alias	geogoffset
Domain	3D
Input type	Geodetic coordinates (horizontal), meters (vertical)
output type	Geodetic coordinates (horizontal), meters (vertical)

This method is normally only used when low accuracy is tolerated. It is documented as coordinate operation method code 9619 (for geographic 2D) and 9660 (for geographic 3D) in the EPSG dataset ([IOGP2018])

It can also be used to implement the method Geographic2D with Height Offsets (code 9618) by noting that the input vertical component is a gravity-related height and the output vertical component is the ellipsoid height (dh being the geoid undulation).

It can also be used to implement the method Vertical offset (code 9616)

The reverse transformation simply consists in subtracting the offsets.

This method is a conveniency wrapper for the more general *Affine transformation*.

7.3.4.1 Examples

Geographic offset from the old Greek geographic 2D CRS to the newer GGRS87 CRS:

```
proj=geogoffset dlon=0.28 dlat=-5.86
```

Conversion from Tokyo + JSLD69 height to WGS 84:

```
proj=geogoffset dlon=-13.97 dlat=7.94 dh=26.9
```

Conversion from Baltic 1977 height to Black Sea height:

```
proj=geogoffset dh=0.4
```

7.3.4.2 Parameters

Optional

+dlon=<value>
Offset in longitude, expressed in arc-second, to add.

+dlat=<value>
Offset in latitude, expressed in arc-second, to add.

+dh=<value>
Offset in height, expressed in meter, to add.

7.3.5 Helmert transform

New in version 5.0.0.

The Helmert transformation changes coordinates from one reference frame to another by means of 3-, 4-and 7-parameter shifts, or one of their 6-, 8- and 14-parameter kinematic counterparts.

Alias	helmert
Domain	2D, 3D and 4D
Input type	Cartesian coordinates (spatial), decimalyears (temporal).
Output type	Cartesian coordinates (spatial), decimalyears (temporal).
Input type	Cartesian coordinates
Output type	Cartesian coordinates

The Helmert transform, in all its various incarnations, is used to perform reference frame shifts. The transformation operates in cartesian space. It can be used to transform planar coordinates from one datum to another, transform 3D cartesian coordinates from one static reference frame to another or it can be used to do fully kinematic transformations from global reference frames to local static frames.

All of the parameters described in the table above are marked as optional. This is true as long as at least one parameter is defined in the setup of the transformation. The behavior of the transformation depends on which parameters are used in the setup. For instance, if a rate of change parameter is specified a kinematic version of the transformation is used.

The kinematic transformations require an observation time of the coordinate, as well as a central epoch for the transformation. The latter is usually documented alongside the rest of the transformation parameters for a given transformation. The central epoch is controlled with the parameter *t_epoch*. The observation time is given as part of the coordinate when using PROJ's 4D-functionality.

7.3.5.1 Examples

Transforming coordinates from NAD72 to NAD83 using the 4 parameter 2D Helmert:

```
proj=helmert convention=coordinate_frame x=-9597.3572 y=.6112 s=0.304794780637 theta=-1.
↪244048
```

Simplified transformations from ITRF2008/IGS08 to ETRS89 using 7 parameters:

```
proj=helmert convention=coordinate_frame x=0.67678    y=0.65495   z=-0.52827
            rx=-0.022742 ry=0.012667 rz=0.022704  s=-0.01070
```

Transformation from *ITRF2000* to *ITRF93* using 15 parameters:

```
proj=helmert convention=position_vector
     x=0.0127     y=0.0065     z=-0.0209  s=0.00195
     dx=-0.0029   dy=-0.0002   dz=-0.0006 ds=0.00001
     rx=-0.00039  ry=0.00080   rz=-0.00114
     drx=-0.00011 dry=-0.00019 drz=0.00007
     t_epoch=1988.0
```

7.3.5.2 Parameters

Note: All parameters are optional but at least one should be used, otherwise the operation will return the coordinates unchanged.

`+convention=coordinate_frame/position_vector`

New in version 5.2.0.

Indicates the convention to express the rotational terms when a 3D-Helmert / 7-parameter more transform is involved. As soon as a rotational parameter is specified (one of `rx`, `ry`, `rz`, `drx`, `dry`, `drz`), `convention` is required.

The two conventions are equally popular and a frequent source of confusion. The coordinate frame convention is also described as an clockwise rotation of the coordinate frame. It corresponds to EPSG method code 1032 (in the geocentric domain) or 9607 (in the geographic domain) The position vector convention is also described as an anticlockwise (counter-clockwise) rotation of the coordinate frame. It corresponds to as EPSG method code 1033 (in the geocentric domain) or 9606 (in the geographic domain).

This parameter is ignored when only a 3-parameter (translation terms only: `x`, `y`, `z`) , 4-parameter (3-parameter and `theta`) or 6-parameter (3-parameter and their derivative terms) is used.

The result obtained with parameters specified in a given convention can be obtained in the other convention by negating the rotational parameters (`rx`, `ry`, `rz`, `drx`, `dry`, `drz`)

Note: This parameter obsoletes `transpose` which was present in PROJ 5.0 and 5.1, and is forbidden starting with PROJ 5.2

`+x=<value>`

Translation of the x-axis given in meters.

+y=<value>
Translation of the y-axis given in meters.

+z=<value>
Translation of the z-axis given in meters.

+s=<value>
Scale factor given in ppm.

+rx=<value>
X-axis rotation in the 3D Helmert given arc seconds.

+ry=<value>
Y-axis rotation in the 3D Helmert given in arc seconds.

+rz=<value>
Z-axis rotation in the 3D Helmert given in arc seconds.

+theta=<value>
Rotation angle in the 2D Helmert given in arc seconds.

+dx=<value>
Translation rate of the x-axis given in m/year.

+dy=<value>
Translation rate of the y-axis given in m/year.

+dz=<value>
Translation rate of the z-axis given in m/year.

+ds=<value>
Scale rate factor given in ppm/year.

+drx=<value>
Rotation rate of the x-axis given in arc seconds/year.

+dry=<value>
Rotation rate of the y-axis given in arc seconds/year.

+drz=<value>
Rotation rate of the y-axis given in arc seconds/year.

+t_epoch=<value>
Central epoch of transformation given in decimalyear. Only used spatiotemporal transformations.

+exact
Use exact transformation equations.

See (7.6)

+transpose
Deprecated since version 5.2.0: (removed)

Transpose rotation matrix and follow the **Position Vector** rotation convention. If `+transpose` is not added the **Coordinate Frame** rotation convention is used.

7.3.5.3 Mathematical description

In the notation used below, $\hat{P}$ is the rate of change of a given transformation parameter P. $\dot{P}$ is the kinematically adjusted version of P, described by

$$\dot{P} = P + \hat{P}\left(t - t_{central}\right) \tag{7.1}$$

where t is the observation time of the coordinate and $t_{central}$ is the central epoch of the transformation. Equation (7.1) can be used to propagate all transformation parameters in time.

Superscripts of vectors denote the reference frame the coordinates in the vector belong to.

2D Helmert

The simplest version of the Helmert transform is the 2D case. In the 2-dimensional case only the horizontal coordinates are changed. The coordinates can be translated, rotated and scale. Translation is controlled with the *x* and *y* parameters. The rotation is determined by *theta* and the scale is controlled with the *s* parameters.

Note: The scaling parameter *s* is unitless for the 2D Helmert, as opposed to the 3D version where the scaling parameter is given in units of ppm.

Mathematically the 2D Helmert is described as:

$$\begin{bmatrix} X \\ Y \end{bmatrix}^B = \begin{bmatrix} T_x \\ T_y \end{bmatrix} + s \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix}^A \tag{7.2}$$

(7.2) can be extended to a time-varying kinematic version by adjusting the parameters with (7.1) to (7.2), which yields the kinematic 2D Helmert transform:

$$\begin{bmatrix} X \\ Y \end{bmatrix}^B = \begin{bmatrix} \dot{T_x} \\ \dot{T_y} \end{bmatrix} + s(t) \begin{bmatrix} \cos\dot{\theta} & \sin\dot{\theta} \\ -\sin\ \dot{\theta} & \cos\dot{\theta} \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix}^A \tag{7.2}$$

All parameters in (7.2) are determined by the use of (7.1), which applies the rate of change to each individual parameter for a given timespan between t and $t_{central}$.

3D Helmert

The general form of the 3D Helmert is

$$V^B = T + \left(1 + s \times 10^{-6}\right) \mathbf{R} V^A \tag{7.2}$$

Where T is a vector consisting of the three translation parameters, s is the scaling factor and $\mathbf{R}$ is a rotation matrix. V^A and V^B are coordinate vectors, with V^A being the input coordinate and V^B is the output coordinate.

In the *Position Vector* convention, we define $R_x = radians\left(rx\right)$, $R_z = radians\left(ry\right)$ and $R_z = radians\left(rz\right)$

In the *Coordinate Frame* convention, $R_x = -radians\left(rx\right)$, $R_z = -radians\left(ry\right)$ and $R_z = -radians\left(rz\right)$

The rotation matrix is composed of three rotation matrices, one for each axis.

$$\mathbf{R}_X = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos R_x & -\sin R_x \\ 0 & \sin R_x & \cos R_x \end{bmatrix} \tag{7.2}$$

$$\mathbf{R}_Y = \begin{bmatrix} \cos R_y & 0 & \sin R_y \\ 0 & 1 & 0 \\ -\sin R_y & 0 & \cos R_y \end{bmatrix} \tag{7.3}$$

$$\mathbf{R}_Z = \begin{bmatrix} \cos R_z & -\sin R_z & 0 \\ \sin R_z & \cos R_z & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{7.4}$$

The three rotation matrices can be combined in one:

$$\mathbf{R} = \mathbf{R_X}\mathbf{R_Y}\mathbf{R_Y} \tag{7.5}$$

For $\mathbf{R}$, this yields:

$$\begin{bmatrix} \cos R_y \cos R_z & -\cos R_x \sin R_z + & \sin R_x \sin R_z + \\ & \sin R_x \sin R_y \cos R_z & \cos R_x \sin R_y \cos R_z \\ \cos R_y \sin R_z & \cos R_x \cos R_z + & -\sin R_x \cos R_z + \\ & \sin R_x \sin R_y \sin R_z & \cos R_x \sin R_y \sin R_z \\ -\sin R_y & \sin R_x \cos R_y & \cos R_x \cos R_y \end{bmatrix} \tag{7.6}$$

Using the small angle approximation the rotation matrix can be simplified to

$$\mathbf{R} = \begin{bmatrix} 1 & -R_z & R_y \\ Rz & 1 & -R_x \\ -Ry & R_x & 1 \end{bmatrix} \tag{7.7}$$

Which allow us to express the most common version of the Helmert transform, using the approximated rotation matrix:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + \left(1 + s \times 10^{-6}\right) \begin{bmatrix} 1 & -R_z & R_y \\ Rz & 1 & -R_x \\ -Ry & R_x & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A \tag{7.7}$$

If the rotation matrix is transposed, or the sign of the rotation terms negated, the rotational part of the transformation is effectively reversed. This is what happens when switching between the 2 conventions `position_vector` and `coordinate_frame`

Applying (7.1) we get the kinematic version of the approximated 3D Helmert:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} \dot{T_x} \\ \dot{T_y} \\ \dot{T_z} \end{bmatrix} + \left(1 + \dot{s} \times 10^{-6}\right) \begin{bmatrix} 1 & -\dot{R_z} & \dot{R_y} \\ \dot{R_z} & 1 & -\dot{R_x} \\ -\dot{R_y} & \dot{R_x} & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A \tag{7.7}$$

The Helmert transformation can be applied without using the rotation parameters, in which case it becomes a simple translation of the origin of the coordinate system. When using the Helmert in this version equation (7.2) simplifies to:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A \tag{7.7}$$

That after application of (7.1) has the following kinematic counterpart:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} \dot{T_x} \\ \dot{T_y} \\ \dot{T_z} \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A \tag{7.7}$$

7.3.6 Horner polynomial evaluation

New in version 5.0.0.

Alias	horner
Domain	2D and 3D
Input type	Geodetic and projected coordinates
Output type	Geodetic and projected coordinates

The Horner polynomial evaluation scheme is used for transformations between reference frames where one or both are inhomogeneous or internally distorted. This will typically be reference frames created before the introduction of space geodetic techniques such as GPS.

Horner polynomials, or Multiple Regression Equations as they are also known as, have their strength in being able to create complicated mappings between coordinate reference frames while still being lightweight in both computational cost and disk space used.

PROJ implements two versions of the Horner evaluation scheme: Real and complex polynomial evaluation. Below both are briefly described. For more details consult [Ruffhead2016] and [IOGP2018].

The polynomial evaluation in real number space is defined by the following equations:

$$\begin{aligned}\Delta X &= \sum_{i,j} u_{i,j} U^i V^j \\ \Delta Y &= \sum_{i,j} v_{i,j} U^i V^j\end{aligned} \tag{7.7}$$

where

$$\begin{aligned}U &= X_{in} - X_{origin} \\ V &= Y_{in} - Y_{origin}\end{aligned} \tag{7.8}$$

and $u_{i,j}$ and $v_{i,j}$ are coefficients that make up the polynomial.

The final coordinates are determined as

$$\begin{aligned}X_{out} &= X_{in} + \Delta X \\ Y_{out} &= Y_{in} + \Delta Y\end{aligned} \tag{7.9}$$

The inverse transform is the same as the above but requires a different set of coefficients.

Evaluation of the complex polynomials are defined by the following equations:

$$\Delta X + i\Delta Y = \sum_{j=1}^{n} (c_{2j-1} + ic_{2j})(U + iV)^j \tag{7.10}$$

Where n is the degree of the polynomial. U and V are defined as in (7.8) and the resulting coordinates are again determined by (7.9).

7.3.6.1 Examples

Mapping between Danish TC32 and ETRS89/UTM zone 32 using polynomials in real number space:

```
+proj=horner
+ellps=intl
+range=500000
+fwd_origin=877605.269066,6125810.306769
+inv_origin=877605.760036,6125811.281773
+deg=4
+fwd_v=6.1258112678e+06,9.9999971567e-01,1.5372750011e-10,5.9300860915e-15,2.2609497633e-
↪19,4.3188227445e-05,2.8225130416e-10,7.8740007114e-16,-1.7453997279e-19,1.6877465415e-
↪10,-1.1234649773e-14,-1.7042333358e-18,-7.9303467953e-15,-5.2906832535e-19,3.
↪9984284847e-19
+fwd_u=8.7760574982e+05,9.9999752475e-01,2.8817299305e-10,5.5641310680e-15,-1.
↪5544700949e-18,-4.1357045890e-05,4.2106213519e-11,2.8525551629e-14,-1.9107771273e-18,3.
↪3615590093e-10,2.4380247154e-14,-2.0241230315e-18,1.2429019719e-15,5.3886155968e-19,-1.
↪0167505000e-18
+inv_v=6.1258103208e+06,1.0000002826e+00,-1.5372762184e-10,-5.9304261011e-15,-2.
↪2612705361e-19,-4.3188331419e-05,-2.8225549995e-10,-7.8529116371e-16,1.7476576773e-19,-
↪1.6875687989e-10,1.1236475299e-14,1.7042518057e-18,7.9300735257e-15,5.2881862699e-19,-
↪3.9990736798e-19
+inv_u=8.7760527928e+05,1.0000024735e+00,-2.8817540032e-10,-5.5627059451e-15,1.
↪5543637570e-18,4.1357152105e-05,-4.2114813612e-11,-2.8523713454e-14,1.9109017837e-18,-
↪3.3616407783e-10,-2.4382678126e-14,2.0245020199e-18,-1.2441377565e-15,-5.3885232238e-
↪19,1.0167203661e-18
```

Mapping between Danish System Storebælt and ETRS89/UTM zone 32 using complex polynomials:

```
+proj=horner
+ellps=intl
+range=500000
+fwd_origin=4.94690026817276e+05,6.13342113183056e+06
+inv_origin=6.19480258923588e+05,6.13258568148837e+06
+deg=3
+fwd_c=6.13258562111350e+06,6.19480105709997e+05,9.99378966275206e-01,-2.82153291753490e-
↪02,-2.27089979140026e-10,-1.77019590701470e-09,1.08522286274070e-14,2.11430298751604e-
↪15
+inv_c=6.13342118787027e+06,4.94690181709311e+05,9.99824464710368e-01,2.82279070814774e-
↪02,7.66123542220864e-11,1.78425334628927e-09,-1.05584823306400e-14,-3.32554258683744e-
↪15
```

7.3.6.2 Parameters

Setting up Horner polynomials requires many coefficients being explicitly written, even for polynomials of low degree. For this reason it is recommended to store the polynomial definitions in an *init file* for easier writing and reuse.

Required

Below is a list of required parameters that can be set for the Horner polynomial transformation. As stated above, the transformation takes to forms, either using real or complex polynomials. These are divided into separate sections below. Parameters from the two sections are mutually exclusive, that is parameters describing real and complex polynomials can't be mixed.

+ellps=<value>

See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

+deg=<value>

Degree of polynomial

+fwd_origin=<northing,easting>

Coordinate of origin for the forward mapping

+inv_origin=<northing,easting>

Coordinate of origin for the inverse mapping

Real polynomials

The following parameters has to be set if the transformation consists of polynomials in real space. Each parameter takes a comma-separated list of coefficients. The number of coefficients is governed by the degree, d, of the polynomial:

$$N = \frac{(d+1)(d+2)}{2}$$

+fwd_u=<u_11,u_12,...,u_ij,..,u_mn>

Coefficients for the forward transformation i.e. latitude to northing as described in (7.7).

+fwd_v=<v_11,v_12,...,v_ij,..,v_mn>

Coefficients for the forward transformation i.e. longitude to easting as described in (7.7).

+inv_u=<u_11,u_12,...,u_ij,..,u_mn>

Coefficients for the inverse transformation i.e. latitude to northing as described in (7.7).

+inv_v=<v_11,v_12,...,v_ij,..,v_mn>

Coefficients for the inverse transformation i.e. longitude to easting as described in (7.7).

Complex polynomials

The following parameters has to be set if the transformation consists of polynomials in complex space. Each parameter takes a comma-separated list of coefficients. The number of coefficients is governed by the degree, d, of the polynomial:

$$N = 2d + 2$$

+fwd_c=<c_1,c_2,...,c_N>

Coefficients for the complex forward transformation as described in (7.10).

+inv_c=<c_1,c_2,...,c_N>

Coefficients for the complex inverse transformation as described in (7.10).

Optional

+range=<value>
Radius of the region of validity.

+uneg
Express latitude as southing. Only applies for complex polynomials.

+vneg
Express longitude as westing. Only applies for complex polynomials.

7.3.6.3 Further reading

1. Wikipedia

7.3.7 Molodensky transform

New in version 5.0.0.

The Molodensky transformation resembles a *Helmert transform* with zero rotations and a scale of unity, but converts directly from geodetic coordinates to geodetic coordinates, without the intermediate shifts to and from cartesian geocentric coordinates, associated with the Helmert transformation. The Molodensky transformation is simple to implement and to parametrize, requiring only the 3 shifts between the input and output frame, and the corresponding differences between the semimajor axes and flattening parameters of the reference ellipsoids. Due to its algorithmic simplicity, it was popular prior to the ubiquity of digital computers. Today, it is mostly interesting for historical reasons, but nevertheless indispensable due to the large amount of data that has already been transformed that way [EversKnudsen2017].

Alias	molodensky
Domain	3D
Input type	Geodetic coordinates (horizontal), meters (vertical)
output type	Geodetic coordinates (horizontal), meters (vertical)

The Molodensky transform can be used to perform a datum shift from coordinate (ϕ_1, λ_1, h_1) to (ϕ_2, λ_2, h_2) where the two coordinates are referenced to different ellipsoids. This is based on three assumptions:

1. The cartesian axes, X, Y, Z, of the two ellipsoids are parallel.
2. The offset, $\delta X, \delta Y, \delta Z$, between the two ellipsoid are known.
3. The characteristics of the two ellipsoids, expressed as the difference in semimajor axis (δa) and flattening (δf), are known.

The Molodensky transform is mostly used for transforming between old systems dating back to the time before computers. The advantage of the Molodensky transform is that it is fairly simple to compute by hand. The ease of computation come at the cost of limited accuracy.

A derivation of the mathematical formulas for the Molodensky transform can be found in [Deakin2004].

7.3.7.1 Examples

The abridged Molodensky:

```
proj=molodensky a=6378160 rf=298.25 da=-23 df=-8.120449e-8  dx=-134 dy=-48 dz=149␣
↪abridged
```

The same transformation using the standard Molodensky:

```
proj=molodensky a=6378160 rf=298.25 da=-23 df=-8.120449e-8  dx=-134 dy=-48 dz=149
```

7.3.7.2 Parameters

Required

+da=<value>
Difference in semimajor axis of the defining ellipsoids.

+df=<value>
Difference in flattening of the defining ellipsoids.

+dx=<value>
Offset of the X-axes of the defining ellipsoids.

+dy=<value>
Offset of the Y-axes of the defining ellipsoids.

+dz=<value>
Offset of the Z-axes of the defining ellipsoids.

+ellps=<value>
See `proj -le` for a list of available ellipsoids.

Defaults to "GRS80".

Optional

+abridged
Use the abridged version of the Molodensky transform.

7.3.8 Molodensky-Badekas transform

New in version 6.0.0.

The Molodensky-Badekas transformation changes coordinates from one reference frame to another by means of a 10-parameter shift.

Note: It should not be confused with the *Molodensky transform* transform which operates directly in the geodetic coordinates. Molodensky-Badekas can rather be seen as a variation of *Helmert transform*

Alias	molobadekas
Domain	3D
Input type	Cartesian coordinates
Output type	Cartesian coordinates

The Molodensky-Badekas transformation is a variation of the *Helmert transform* where the rotational terms are not directly applied to the ECEF coordinates, but on cartesian coordinates relative to a reference point (usually close to Earth surface, and to the area of use of the transformation). When `px` = `py` = `pz` = 0, this is equivalent to a 7-parameter Helmert transformation.

7.3.8.1 Example

Transforming coordinates from La Canoa to REGVEN:

```
proj=molobadekas convention=coordinate_frame
       x=-270.933 y=115.599 z=-360.226 rx=-5.266 ry=-1.238 rz=2.381
       s=-5.109 px=2464351.59 py=-5783466.61 pz=974809.81
```

7.3.8.2 Parameters

Note: All parameters (except convention) are optional but at least one should be used, otherwise the operation will return the coordinates unchanged.

+convention=coordinate_frame/position_vector

Indicates the convention to express the rotational terms when a 3D-Helmert / 7-parameter more transform is involved.

The two conventions are equally popular and a frequent source of confusion. The coordinate frame convention is also described as an clockwise rotation of the coordinate frame. It corresponds to EPSG method code 1034 (in the geocentric domain) or 9636 (in the geographic domain) The position vector convention is also described as an anticlockwise (counter-clockwise) rotation of the coordinate frame. It corresponds to as EPSG method code 1061 (in the geocentric domain) or 1063 (in the geographic domain).

The result obtained with parameters specified in a given convention can be obtained in the other convention by negating the rotational parameters (`rx`, `ry`, `rz`)

+x=<value>

Translation of the x-axis given in meters.

+y=<value>

Translation of the y-axis given in meters.

+z=<value>

Translation of the z-axis given in meters.

+s=<value>

Scale factor given in ppm.

+rx=<value>

X-axis rotation given arc seconds.

+ry=<value>
Y-axis rotation given in arc seconds.

+rz=<value>
Z-axis rotation given in arc seconds.

+px=<value>
Coordinate along the x-axis of the reference point given in meters.

+py=<value>
Coordinate along the y-axis of the reference point given in meters.

+pz=<value>
Coordinate along the z-axis of the reference point given in meters.

7.3.8.3 Mathematical description

In the *Position Vector* convention, we define $R_x = radians\left(rx\right)$, $R_z = radians\left(ry\right)$ and $R_z = radians\left(rz\right)$

In the *Coordinate Frame* convention, $R_x = -radians\left(rx\right)$, $R_z = -radians\left(ry\right)$ and $R_z = -radians\left(rz\right)$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^{output} = \begin{bmatrix} T_x + P_x \\ T_y + P_y \\ T_z + P_z \end{bmatrix} + \left(1 + s \times 10^{-6}\right) \begin{bmatrix} 1 & -R_z & R_y \\ Rz & 1 & -R_x \\ -Ry & R_x & 1 \end{bmatrix} \begin{bmatrix} X^{input} - P_x \\ Y^{input} - P_y \\ Z^{input} - P_z \end{bmatrix} \tag{7.11}$$

7.3.9 Horizontal grid shift

New in version 5.0.0.

Change of horizontal datum by grid shift.

Alias	hgridshift
Domain	2D, 3D and 4D
Input type	Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)
Output type	Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)

The horizontal grid shift is done by offsetting the planar input coordinates by a specific amount determined by the loaded grids. The simplest use case of the horizontal grid shift is applying a single grid:

```
+proj=hgridshift +grids=nzgr2kgrid0005.gsb
```

More than one grid can be loaded at the same time, for instance in case the dataset needs to be transformed spans several countries. In this example grids of the continental US, Alaska and Canada is loaded at the same time:

```
+proj=hgridshift +grids=@conus,@alaska,@ntv2_0.gsb,@ntv_can.dat
```

The `@` in the above example states that the grid is optional, in case the grid is not found in the PROJ search path. The list of grids is prioritized so that grids in the start of the list takes precedence over the grids in the back of the list.

PROJ supports CTable2, NTv1 and NTv2 files for horizontal grid corrections. Details about all three formats can be found in the GDAL documentation and/or driver source code. GDAL reads and writes all three formats. Using GDAL for construction of new grids is recommended.

7.3.9.1 Temporal gridshifting

New in version 5.1.0.

By initializing the horizontal gridshift operation with a central epoch, it can be used as a step function applying the grid offsets only if a coordinate is transformed from an epoch before grids central epoch to an epoch after. This is handy in transformations where it is necessary to handle deformations caused by seismic activity.

The central epoch of the grid is controlled with *+t_epoch* and the final epoch of the coordinate is set with *+t_final*. The observation epoch of the coordinate is part of the coordinate tuple.

Suppose we want to model the deformation of the 2008 earthquake in Iceland in a transformation of data from 2005 to 2009:

```
echo 63.992 -21.014 10.0 2005.0 | cct +proj=hgridshift +grids=iceland2008.gsb +t_
↪epoch=2008.4071 +t_final=2009.0
63.9920021 -21.0140013 10.0 2005.0
```

Note: The timestamp of the resulting coordinate is still 2005.0. The observation time is always kept unchanged as it would otherwise be impossible to do the inverse transformation.

Temporal gridshifting is especially powerful in transformation pipelines where several gridshifts can be chained together, effectively acting as a series of step functions that can be applied to a coordinate that is propagated through time. In the following example we establish a pipeline that allows transformation of coordinates from any given epoch up until the current date, applying only those gridshifts that have central epochs between the observation epoch and the final epoch:

```
+proj=pipeline +t_final=now
+step +proj=hgridshift +grids=earthquake_1.gsb +t_epoch=2010.421
+step +proj=hgridshift +grids=earthquake_2.gsb +t_epoch=2013.853
+step +proj=hgridshift +grids=earthquake_3.gsb +t_epoch=2017.713
```

Note: The special epoch *now* is used when specifying the final epoch with *+t_final*. This results in coordinates being transformed to the current date. Additionally, *+t_final* is used as a *global pipeline parameter*, which means that it is applied to all the steps in the pipeline.

In the above transformation, a coordinate with observation epoch 2009.32 would be subject to all three gridshift steps in the pipeline. A coordinate with observation epoch 2014.12 would only by offset by the last step in the pipeline.

7.3.9.2 Parameters

Required

+grids=<list>

Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will the not complain if the grid is not available.

Grids are expected to be in CTable2, NTv1 or NTv2 format.

Optional

+t_epoch=<time>

Central epoch of the transformation.

New in version 5.1.0.

+t_final=<time>

Final epoch that the coordinate will be propagated to after transformation. The special epoch *now* can be used instead of writing a specific period in time. When *now* is used, it is replaced internally with the epoch of the transformation. This means that the resulting coordinate will be slightly different if carried out again at a later date.

New in version 5.1.0.

7.3.10 Triangulated Irregular Network based transformation

New in version 7.2.0.

Alias	tinshift
Input type	Projected or geographic coordinates (horizontal), meters (vertical)
Output type	Projected or geographic coordinates (horizontal), meters (vertical)
Domain	2D or 3D
Available forms	Forward and inverse

The `tinshift` transformation takes one mandatory argument, `file`, that points to a JSON file, which contains the triangulation and associated metadata. Input and output coordinates must be geographic or projected coordinates. Depending on the content of the JSON file, horizontal, vertical or both components of the coordinates may be transformed.

The transformation is invertible, with the same computational complexity than the forward transformation.

7.3.10.1 Parameters

Required

+file=<filename>

Filename to the JSON file for the TIN.

7.3.10.2 Example

Transforming a point with the Finland EPSG:2393 ("KKJ / Finland Uniform Coordinate System") projected CRS to EPSG:3067 ("ETRS89 / TM35FIN(E,N)")

```
$ echo 3210000.0000 6700000.0000 0 2020 | cct +proj=tinshift +file=./triangulation_kkj.
↪json

209948.3217     6697187.0009    0.0000     2020
```

Algorithm

Internally, `tinshift` ingest the whole file into memory. It is considered that triangulation should be small enough for that.

When a point is transformed, one must find the triangle into which it falls into. Instead of iterating over all triangles, we build a in-memory quadtree to speed-up the identification of candidates triangles.

To determine if a point falls into a triangle, one computes its 3 barycentric coordinates from its projected coordinates, λ_i for $i = 1, 2, 3$. They are real values (in the [0,1] range for a point inside the triangle), giving the weight of each of the 3 vertices of the triangles.

Once those weights are known, interpolating the target horizontal coordinate is a matter of doing the linear combination of those weights with the target horizontal coordinates at the 3 vertices of the triangle (Xt_i and Yt_i):

$$X_{target} = Xt_1 * \lambda_1 + Xt_2 * \lambda_2 + Xt_3 * \lambda_3$$
$$Y_{target} = Yt_1 * \lambda_1 + Yt_2 * \lambda_2 + Yt_3 * \lambda_3$$

This interpolation is exact at the vertices of the triangulation, and has linear properties inside each triangle. It is completely equivalent to other formulations of triangular interpolation, such as

$$X_{target} = A + X_{source} * B + Y_{source} * C$$
$$Y_{target} = D + X_{source} * E + Y_{source} * F$$

where the A, B, C, D, E, F constants (for a given triangle) are found by solving the 2 systems of 3 linear equations, constraint by the source and target coordinate pairs of the 3 vertices of the triangle:

$$Xt_i = A + Xs_i * B + Ys_i * C$$
$$Yt_i = D + Xs_i * E + Ys_i * F$$

Similarly for a vertical coordinate transformation, where $Zoff_i$ is the vertical offset at each vertex of the triangle:

$$Z_{target} = Z_{source} + Zoff_1 * \lambda_1 + Zoff_2 * \lambda_2 + Zoff_3 * \lambda_3$$

Constraints on the triangulation

No check is done on the consistence of the triangulation. It is highly recommended that triangles do not overlap each other (when considering the source coordinates or the forward transformation, or the target coordinates for the inverse transformation), otherwise which triangle will be selected is unspecified. Besides that, the triangulation does not need to have particular properties (like being a Delaunay triangulation)

File format

The triangulation is stored in a text-based format, using JSON as a serialization.

Below a minimal example, from the KKJ to ETRS89 transformation, with just a single triangle:

```json
{
  "file_type": "triangulation_file",
  "format_version": "1.0",
  "name": "Name",
  "version": "Version",
  "publication_date": "2018-07-01T00:00:00Z",
  "license": "Creative Commons Attribution 4.0 International",
```

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```
  "description": "Test triangulation",
  "authority": {
    "name": "Authority name",
    "url": "http://example.com",
    "address": "Adress",
    "email": "test@example.com"
  },
  "links": [
    {
      "href": "https://example.com/about.html",
      "rel": "about",
      "type": "text/html",
      "title": "About"
    },
    {
      "href": "https://example.com/download",
      "rel": "source",
      "type": "application/zip",
      "title": "Authoritative source"
    },
    {
      "href": "https://creativecommons.org/licenses/by/4.0/",
      "rel": "license",
      "type": "text/html",
      "title": "Creative Commons Attribution 4.0 International license"
    },
    {
      "href": "https://example.com/metadata.xml",
      "rel": "metadata",
      "type": "application/xml",
      "title": " ISO 19115 XML encoded metadata regarding the deformation model"
    }
  ],
  "transformed_components": [ "horizontal" ],
  "vertices_columns": [ "source_x", "source_y", "target_x", "target_y" ],
  "triangles_columns": [ "idx_vertex1", "idx_vertex2", "idx_vertex3" ],
  "vertices": [ [2,49,2.1,49.1], [3,50,3.1,50.1], [2, 50, 2.1,50.1] ],
  "triangles": [ [0, 1, 2] ]
}
```

So after the generic metadata, we define the input and output CRS (informative only), and that the transformation affects horizontal components of coordinates. We name the columns of the `vertices` and `triangles` arrays. We defined the source and target coordinates of each vertex, and define a triangle by referring to the index of its vertices in the `vertices` array.

More formally, the specific items for the triangulation file are:

input_crs
: String identifying the CRS of source coordinates in the vertices. Typically `EPSG:XXXX`. If the transformation is for vertical component, this should be the code for a compound CRS (can be EPSG:XXXX+YYYY where XXXX is the code of the horizontal CRS and YYYY the code of the vertical CRS). For example, for the KKJ->ETRS89 transformation, this is EPSG:2393 (`KKJ / Finland Uniform Coordinate System`). The input coordinates are assumed to be passed in the "normalized for visualisation" / "GIS friendly" order, that is longitude, latitude for geographic coordinates and easting, northing for projected coordinates.

output_crs
String identifying the CRS of target coordinates in the vertices. Typically `EPSG:XXXX`. If the transformation is for vertical component, this should be the code for a compound CRS (can be EPSG:XXXX+YYYY where XXXX is the code of the horizontal CRS and YYYY the code of the vertical CRS). For example, for the KKJ->ETRS89 transformation, this is EPSG:3067 ("ETRS89 / TM35FIN(E,N)"). The output coordinates will be returned in the "normalized for visualisation" / "GIS friendly" order, that is longitude, latitude for geographic coordinates and easting, northing for projected coordinates.

transformed_components
Array which may contain one or two strings: "horizontal" when horizontal components of the coordinates are transformed and/or "vertical" when the vertical component is transformed.

vertices_columns
Specify the name of the columns of the rows in the `vertices` array. There must be exactly as many elements in `vertices_columns` as in a row of `vertices`. The following names have a special meaning: `source_x`, `source_y`, `target_x`, `target_y`, `source_z`, `target_z` and `offset_z`. `source_x` and `source_y` are compulsory. `source_x` is for the source longitude (in degree) or easting. `source_y` is for the source latitude (in degree) or northing. `target_x` and `target_y` are compulsory when `horizontal` is specified in `transformed_components`. (`source_z` and `target_z`) or `offset_z` are compulsory when `vertical` is specified in `transformed_components`

triangles_columns
Specify the name of the columns of the rows in the `triangles` array. There must be exactly as many elements in `triangles_columns` as in a row of `triangles`. The following names have a special meaning: `idx_vertex1`, `idx_vertex2`, `idx_vertex3`. They are compulsory.

vertices
An array whose items are themselves arrays with as many columns as described in `vertices_columns`.

triangles
An array whose items are themselves arrays with as many columns as described in `triangles_columns`. The value of the `idx_vertexN` columns must be indices (between 0 and len(`vertices`-1) of items of the `vertices` array.

A JSON schema is available for this file format.

7.3.11 Vertical grid shift

New in version 5.0.0.

Change Vertical datum change by grid shift

Alias	vgridshift
Domain	3D and 4D
Input type	Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)
Output type	Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)

The vertical grid shift is done by offsetting the vertical input coordinates by a specific amount determined by the loaded grids. The simplest use case of the horizontal grid shift is applying a single grid. Here we change the vertical reference from the ellipsoid to the global geoid model, EGM96:

```
+proj=vgridshift +grids=egm96_15.gtx
```

More than one grid can be loaded at the same time, for instance in the case where a better geoid model than the global is available for a certain area. Here the gridshift is set up so that the local DVR90 geoid model takes precedence over the global model:

```
+proj=vgridshift +grids=@dvr90.gtx,egm96_15.gtx
```

The @ in the above example states that the grid is optional, in case the grid is not found in the PROJ search path. The list of grids is prioritized so that grids in the start of the list takes precedence over the grids in the back of the list.

PROJ supports the GTX file format for vertical grid corrections. Details about all the format can be found in the GDAL documentation. GDAL both reads and writes the format. Using GDAL for construction of new grids is recommended.

7.3.11.1 Temporal gridshifting

New in version 5.1.0.

By initializing the vertical gridshift operation with a central epoch, it can be used as a step function applying the grid offsets only if a coordinate is transformed from an epoch before grids central epoch to an epoch after. This is handy in transformations where it is necessary to handle deformations caused by seismic activity.

The central epoch of the grid is controlled with *+t_epoch* and the final epoch of the coordinate is set with *+t_final*. The observation epoch of the coordinate is part of the coordinate tuple.

Suppose we want to model the deformation of the 2008 earthquake in Iceland in a transformation of data from 2005 to 2009:

```
echo 63.992 -21.014 10.0 2005.0 | cct +proj=vgridshift +grids=iceland2008.gtx +t_
↪epoch=2008.4071 +t_final=2009.0
63.992 -21.014 10.11 2005.0
```

Note: The timestamp of the resulting coordinate is still 2005.0. The observation time is always kept unchanged as it would otherwise be impossible to do the inverse transformation.

Temporal gridshifting is especially powerful in transformation pipelines where several gridshifts can be chained together, effectively acting as a series of step functions that can be applied to a coordinate that is propagated through time. In the following example we establish a pipeline that allows transformation of coordinates from any given epoch up until the current date, applying only those gridshifts that have central epochs between the observation epoch and the final epoch:

```
+proj=pipeline +t_final=now
+step +proj=vgridshift +grids=earthquake_1.gtx +t_epoch=2010.421
+step +proj=vgridshift +grids=earthquake_2.gtx +t_epoch=2013.853
+step +proj=vgridshift +grids=earthquake_3.gtx +t_epoch=2017.713
```

Note: The special epoch *now* is used when specifying the final epoch with *+t_final*. This results in coordinates being transformed to the current date. Additionally, *+t_final* is used as a *global pipeline parameter*, which means that it is applied to all the steps in the pipeline.

In the above transformation, a coordinate with observation epoch 2009.32 would be subject to all three gridshift steps in the pipeline. A coordinate with observation epoch 2014.12 would only by offset by the last step in the pipeline.

7.3.11.2 Parameters

Required

+grids=<list>

Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will the not complain if the grid is not available.

Grids are expected to be in GTX format.

Optional

+t_epoch=<time>

Central epoch of the transformation.

New in version 5.1.0.

+t_final=<time>

Final epoch that the coordinate will be propagated to after transformation. The special epoch *now* can be used instead of writing a specific period in time. When *now* is used, it is replaced internally with the epoch of the transformation. This means that the resulting coordinate will be slightly different if carried out again at a later date.

New in version 5.1.0.

+multiplier=<value>

Specify the multiplier to apply to the grid value in the forward transformation direction, such that:

$$Z_{target} = Z_{source} + multiplier \times gridvalue \tag{7.11}$$

The multiplier can be used to control whether the gridvalue should be added or subtracted, and if unit conversion must be done (the multiplied gridvalue must be expressed in metre).

Note that the default is *-1.0* for historical reasons.

New in version 5.2.0.

7.3.12 Geocentric grid shift

New in version 7.0.0.

Geocentric translation using a grid shift

Alias	xyzgridshift
Domain	3D
Input type	Cartesian coordinates
Output type	Cartesian coordinates

Perform a geocentric translation by bilinear interpolation of dx, dy, dz translation values from a grid. The grid is referenced against either the 2D geographic CRS corresponding to the input (or sometimes output) CRS.

This method is described (in French) in [NTF_88] and as EPSG operation method code 9655 in [IOGP2018] (§2.4.4.1.1 France geocentric interpolation).

The translation in the grids are added to the input coordinates in the forward direction, and subtracted in the reverse direction. By default (if `grid_ref=input_crs`), in the forward direction, the input coordinates are converted to their geographic equivalent to directly read and interpolate from the grid. In the reverse direction, an iterative method is used to be able to find the grid locations to read. If `grid_ref=output_crs` is used, then the reverse strategy is applied: iterative method in the forward direction, and direct read in the reverse direction.

7.3.12.1 Example

NTF to RGF93 transformation using `gr3df97a.tif` grid

```
+proj=pipeline
    +step +proj=push +v_3
    +step +proj=cart +ellps=clrk80ign
    +step +proj=xyzgridshift +grids=gr3df97a.tif +grid_ref=output_crs +ellps=GRS80
    +step +proj=cart +ellps=GRS80 +inv
    +step +proj=pop +v_3
```

Parameters

The ellipsoid parameters should be the ones consistent with `grid_ref`. They are used to perform a geocentric to geographic conversion to find the translation parameters.

Required

+ellps=<value>

See *proj -le* for a list of available ellipsoids.

Defaults to "GRS80".

+grids=<list>

Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will the not complain if the grid is not available.

Grids are expected to be in GeoTIFF format. If no metadata is provided, the first, second and third samples are assumed to be the geocentric translation along X, Y and Z axis respectively, in metres.

Optional

+grid_ref=input_crs/output_crs

Specify in which CRS the grid is referenced to. The default value is input_crs. That is the grid is referenced in the geographic CRS corresponding to the input geocentric CRS.

If output_crs is specified, the grid is referenced in the geographic CRS corresponding to the output geocentric CRS. This is for example the case for the French `gr3df97a.tif` grid converting from NTF to RGF93, but referenced against RGF93. Thus in the forward direction (NTF->RGF93), an iterative method is used to find the appropriate shift.

+multiplier=<value>

Specify the multiplier to apply to the grid values. Defaults to 1.0

7.4 The pipeline operator

New in version 5.0.0.

Construct complex operations by daisy-chaining operations in a sequential pipeline.

Alias	pipeline
Domain	2D, 3D and 4D
Input type	Any
Output type	Any

Note: See the section on *Geodetic transformation* for a more thorough introduction to the concept of transformation pipelines in PROJ.

With the pipeline operation it is possible to perform several operations after each other on the same input data. This feature makes it possible to create transformations that are made up of more than one operation, e.g. performing a datum shift and then applying a suitable map projection. Theoretically any transformation between two coordinate reference systems is possible to perform using the pipeline operation, provided that the necessary coordinate operations in each step is available in PROJ.

A pipeline is made up of a number of steps, with each step being a coordinate operation in itself. By connecting these individual steps sequentially we end up with a concatenated coordinate operation. An example of this is a transformation from geodetic coordinates on the GRS80 ellipsoid to a projected system where the east-west and north-east axes has been swapped:

```
+proj=pipeline +ellps=GRS80 +step +proj=merc +step +proj=axisswap +order=2,1
```

Here the first step is applying the *Mercator* projection and the second step is applying the *Axis swap* conversion. Note that the *+ellps=GRS80* is specified before the first occurrence of *+step*. This means that the GRS80 ellipsoid is used in both steps, since any parameter stated before the first occurrence of *+step* is treated as a global parameter and is transferred to each individual steps.

7.4.1 Rules for pipelines

1. Pipelines must consist of at least one step.

```
+proj=pipeline
```

Will result in an error.

2. Pipelines can only be nested if the nested pipeline is defined in an init file.

```
+proj=pipeline
+step +proj=pipeline +step +proj=merc +step +proj=axisswap +order=2,1
+step +proj=unitconvert +xy_in=m +xy_out=us-ft
```

Results in an error, while

```
+proj=pipeline
+step +init=predefined_pipelines:projectandswap
+step +proj=unitconvert +xy_in=m +xy_out=us-ft
```

does not.

3. Pipelines without a forward path can't be constructed.

```
+proj=pipeline +step +inv +proj=urm5
```

Will result in an error since *Urmaev V* does not have an inverse operation defined.

4. Parameters added before the first `+step` are global and will be applied to all steps.

In the following the GRS80 ellipsoid will be applied to all steps.

```
+proj=pipeline +ellps=GRS80
+step +proj=cart
+step +proj=helmert +x=10 +y=3 +z=1
+step +proj=cart +inv
+step +proj=merc
```

5. Units of operations must match between steps.

New in version 5.1.0.

The output units of step *n* must match the expected input unit of step *n+1*. E.g., you can't pass an operation that outputs projected coordinates to an operation that expects angular units (degrees). An example of such a unit mismatch is displayed below.

```
+proj=pipeline
+step +proj=merc  # Mercator outputs projected coordinates
+step +proj=robin # The Robinson projection expects angular input
```

7.4.2 Parameters

7.4.2.1 Required

+step

Separate each step in a pipeline.

7.4.2.2 Optional

+inv

Invert a step in a pipeline.

+omit_fwd

New in version 6.3.0.

Skip a step of the pipeline when it is followed in the forward path.

The following example shows a combined use of *push* and *pop* operators, with `omit_fwd` and `omit_inv` options, to implement a vertical adjustment that must be done in a interpolation CRS that is different from the horizontal CRS used in input and output. +omit_fwd in the forward path avoid a useless inverse horizontal transformation and relies on the pop operator to restore initial horizontal coordinates. +omit_inv serves the similar purpose when the pipeline is executed in the reverse direction

```
+proj=pipeline
+step +proj=unitconvert +xy_in=deg +xy_out=rad
+step +proj=push +v_1 +v_2
+step +proj=hgridshift +grids=nvhpgn.gsb +omit_inv
+step +proj=vgridshift +grids=g1999u05.gtx +multiplier=1
+step +inv +proj=hgridshift +grids=nvhpgn.gsb +omit_fwd
+step +proj=pop +v_1 +v_2
+step +proj=unitconvert +xy_in=rad +xy_out=deg
```

+omit_inv

New in version 6.3.0.

Skip a step of the pipeline when it is followed in the reverse path.

7.5 Computation of coordinate operations between two CRS

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Last Updated
2021-02-10

7.5.1 Introduction

When using **projinfo -s {crs_def} -t {crs_def}**, **cs2cs {crs_def} {crs_def}** or the underlying *proj_create_crs_to_crs()* or *proj_create_operations()* functions, PROJ applies an algorithm to compute one or several candidate coordinate operations, that can be expressed as a PROJ *pipeline* to transform between the source and the target CRS. This document is about the description of this algorithm that finds the actual operations to apply to be able later to perform transform coordinates. So this is mostly about metadata management around coordinate operation methods, and not about the actual mathematics used to implement those methods. As a matter of fact with PROJ 6, there are about 60 000 lines of code dealing with "metadata" management (including conversions between PROJ strings, all CRS WKT variants), to be compared to 30 000 for the purely computation part.

This document is meant as a plain text explanation of the code for developers, but also as a in-depth examination of what happens under the hood for curious PROJ users. It is important to keep in mind that it is not meant to be the ultimate source of truth of how coordinate operations should be computed. There are clearly implementation choices and compromises that can be questioned.

Let us start with an example to research operations between the NAD27 and NAD83 geographic CRS:

```
$ projinfo -s NAD27 -t NAD83 --summary --spatial-test intersects --grid-check none

Candidate operations found: 10
DERIVED_FROM(EPSG):1312, NAD27 to NAD83 (3), 1.0 m, Canada
DERIVED_FROM(EPSG):1313, NAD27 to NAD83 (4), 1.5 m, Canada - NAD27, at least one grid␣
↪missing
DERIVED_FROM(EPSG):1241, NAD27 to NAD83 (1), 0.15 m, USA - CONUS including EEZ
DERIVED_FROM(EPSG):1243, NAD27 to NAD83 (2), 0.5 m, USA - Alaska including EEZ
DERIVED_FROM(EPSG):1573, NAD27 to NAD83 (6), 1.5 m, Canada - Quebec, at least one grid␣
↪missing
EPSG:1462, NAD27 to NAD83 (5), 1.0 m, Canada - Quebec, at least one grid missing
EPSG:9111, NAD27 to NAD83 (9), 1.5 m, Canada - Saskatchewan, at least one grid missing
```

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```
unknown id, Ballpark geographic offset from NAD27 to NAD83, unknown accuracy, World, has␣
↪ballpark transformation
EPSG:8555, NAD27 to NAD83 (7), 0.15 m, USA - CONUS and GoM, at least one grid missing
EPSG:8549, NAD27 to NAD83 (8), 0.5 m, USA - Alaska, at least one grid missing
```

The algorithm involves many cases, so we will progress in the explanation from the most simple case to more complex ones. We document here the working of this algorithm as implemented in PROJ 8.0.0. The results of some examples might also be quite sensitive to the content of the PROJ database and the PROJ version used.

From a code point of view, the entry point of the algorithm is the C++ `osgeo::proj::operation::CoordinateOperation::createOperations()` method.

It combines several strategies:

- look up in the PROJ database for available operations
- consider the pair (source CRS, target CRS) to synthetize operations depending on the nature of the source and target CRS.

7.5.2 Geographic CRS to Geographic CRS, with known identifiers

With the above example of two geographic CRS, that have an identified identifier, (**projinfo** internally resolves NAD27 to EPSG:4267 and NAD83 to EPSG:4269) the algorithm will first search in the coordinate operation related tables of the `proj.db` if there are records that list direct transformations between the source and the target CRS. The transformations typically involve *Helmert*-style operations or datum shift based on grids (more esoteric operations are possible).

A request similar to the following will be emitted:

```
$ sqlite3 proj.db "SELECT auth_name, code, name, method_name, accuracy FROM \
                   coordinate_operation_view WHERE \
                   source_crs_auth_name = 'EPSG' AND \
                   source_crs_code = '4267' AND \
                   target_crs_auth_name = 'EPSG' AND \
                   target_crs_code = '4269'"

EPSG|1241|NAD27 to NAD83 (1)|NADCON|0.15
EPSG|1243|NAD27 to NAD83 (2)|NADCON|0.5
EPSG|1312|NAD27 to NAD83 (3)|NTv1|1.0
EPSG|1313|NAD27 to NAD83 (4)|NTv2|1.5
EPSG|1462|NAD27 to NAD83 (5)|NTv1|1.0
EPSG|1573|NAD27 to NAD83 (6)|NTv2|1.5
EPSG|8549|NAD27 to NAD83 (8)|NADCON5 (2D)|0.5
EPSG|8555|NAD27 to NAD83 (7)|NADCON5 (2D)|0.15
EPSG|9111|NAD27 to NAD83 (9)|NTv2|1.5
ESRI|108003|NAD_1927_To_NAD_1983_PR_VI|NTv2|0.05
```

As we have found direct transformations, we will not attempt any more complicated research. One can note in the above result set that a ESRI:108003 operation was found, but as the source and target CRS are in the EPSG registry, and there are operations between those CRS in the EPSG registry itself, transformations from other authorities will be ignored (except if they are in the PROJ authority, which can be used as an override).

As those results all involve operations that does not have a perfect accuracy and that does not cover the area of use of the 2 CRSs, a 'Ballpark geographic offset from NAD27 to NAD83' operation is synthetized by PROJ (see *Ballpark transformation*)

7.5.3 Filtering and sorting of coordinate operations

The last step is to filter and sort results in order of relevance.

The filtering takes into account the following criteria to decide which operations must be retained or discarded:

- a minimum accuracy that the user might have expressed,
- an area of use on which the coordinate operation(s) must apply
- if the absence of grids needed by an operation must result in discarding it.

The sorting algorithm determines the order of relevance of the operations we got. A comparison function compares pair of operations to determine which of the two is the most relevant. This is implemented by the `operator ()` method of the SortFunction structure. When comparing two operations, the following criteria are used. The tests are performed in the order they are listed below:

1. consider as more relevant an operation that can be expressed as a PROJ operation string (the database might list operations whose method is not (yet) implemented by PROJ)
2. if both operations evaluate identically with respect to the above criterion, consider as more relevant an operation that does not include a synthetic ballpark vertical transformation (occurs when there is a geoid model).
3. if both operations evaluate identically with respect to the above criterion, consider as more relevant an operation that does not include a synthetic ballpark horizontal transformation.
4. consider as more relevant an operation that refers to shift grids that are locally available.
5. consider as more relevant an operation that refers to grids that are available in one of the proj-datumgrid packages, but not necessarily locally available
6. consider as more relevant an operation that has a known accuracy.
7. if two operations have unknown accuracy, consider as more relevant an operation that uses grid(s) if the other one does not (grid based operations are assumed to be more precise than operations relying on a few parameters)
8. consider as more relevant an operation whose area of use is larger (note: the computation of the are of use is approximate, based on a bounding box)
9. consider as more relevant an operation that has a better accuracy.
10. in case of same accuracy, consider as more relevant an operation that does not use grids (operations that use only parameters will be faster)
11. consider as more relevant an operation that involves less transformation steps (transformation steps considered are the ones listed in the WKT output, not PROJ pipeline steps)
12. and for completeness, if two operations are comparable given all the above criteria, consider as more relevant the one which has the shorter name, and if they have the same length, consider as more relevant the one whose name comes last in lexicographic order (e.g. “FOO to BAR (3)” will have higher precedence than “FOO to BAR (2)”)

7.5.4 Geodetic/geographic CRS to Geodetic/geographic CRS, without known identifiers

In a number of situations, the source and/or target CRS do not have an identifier (WKT without identifier, PROJ string, ..) The first step is to try to find in the `proj.db` a CRS of the same nature of the CRS to identify and whose name exactly matches the one provided to the `createOperations()` method. If there is exactly one match and that the CRS are "computationally" equivalent, then use the code of the CRS for further computations.

If this search did not succeed, or if the previous case with known CRS identifiers did not result in matches in the database, the search will be based on the datums. That is, a list of geographic CRS whose datum matches the datum of the source and target CRS is searched for in the database (by querying the *geodetic_crs* database table). If the datum has a known identifier, we will use it, otherwise we will look for an equivalent datum in the database based on the datum name.

Let's consider the case where the datum of the source CRS is EPSG:6171 "Reseau Geodesique Francais 1993" and the datum of the target CRS is EPSG:6258 "European Terrestrial Reference System 1989". For EPSG:6171, there are 10 matching (non-deprecated) geodetic CRSs:

- EPSG:4171, RGF93, geographic 2D
- EPSG:4964, RGF93, geocentric
- EPSG:4965, RGF93, geographic 3D
- EPSG:7042, RGF93 (lon-lat), geographic 3D
- EPSG:7084, RGF93 (lon-lat), geographic 2D
- IGNF:RGF93, RGF93 cartesiennes geocentriques, geocentric
- IGNF:RGF93GDD, RGF93 geographiques (dd),geographic 2D
- IGNF:RGF93GEODD, RGF93 geographiques (dd), geographic 3D
- IGNF:RGF93G, RGF93 geographiques (dms), geographic 2D
- IGNF:RGF93GEO, RGF93 geographiques (dms), geographic 3D

The first three entries from the EPSG dataset are typical: for each datum, one can define a geographic 2D CRS (latitude, longitude), a geographic 3D crs (latitude, longitude, ellipsoidal height) and a geocentric one. For that particular case, the EPSG dataset has also included two extra definitions corresponding to a longitude, latitude, [ellipsoidal height] coordinate system, as found in the official French IGNF registry. This IGNF registry has also definitions for a geographic 2D CRS (with an extra subtlety with an entry using decimal degree as unit and another one degree-minute-second), geographic 3D and geocentric.

For EPSG:6258, there are 7 matching (non-deprecated) geodetic CRSs:

- EPSG:4258, ETRS89, geographic 2D
- EPSG:4936, ETRS89, geocentric
- EPSG:4937, ETRS89, geographic 3D
- IGNF:ETRS89, ETRS89 cartesiennes geocentriques, geocentric
- IGNF:ETRS89G, ETRS89 geographiques (dms), geographic 2D
- IGNF:ETRS89GEO, ETRS89 geographiques (dms), geographic 3D
- ESRI:104129, GCS_EUREF_FIN, geographic 2D

So the 3 typical EPSG entries, 3 equivalent (with long, lat ordering for the geographic CRS) and one from the ESRI registry;

PROJ can now test 10 x 7 different combinations of source x target CRSs, using the database searching method explained in the previous section. As soon as one of this combination returns at least one non-ballpark combination, the result set coming from that combination is used. PROJ will then add before that transformation a conversion between the source CRS and the first intermediate CRS, and will add at the end a conversion between the second intermediate CRS and the target CRS. Those conversions are conversion between geographic 2D and geographic 3D CRS or geographic 2D/3D and geocentric CRS.

This is done by the `createOperationsWithDatumPivot()` method.

So if transforming between EPSG:7042, RGF93 (lon-lat), geographic 3D and EPSG:4936, ETRS89, geocentric, one get the following concatenated operation, chaining an axis order change, the null geocentric translation between RGF93 and ETRS89 (EPSG:1591), and a conversion between geographic and geocentric coordinates. This concatenated operation is assumed to have a perfect accuracy as both the initial and final operations are conversions, and the middle transformation accounts for the fact that the RGF93 datum is one realization of ETRS89, so they are equivalent for most purposes.

```
$ projinfo -s EPSG:7042 -t EPSG:4936

Candidate operations found: 1
-------------------------------------
Operation No. 1:

unknown id, axis order change (geographic3D horizontal) + RGF93 to ETRS89 (1) +␣
↪Conversion from ETRS89 (geog2D) to ETRS89 (geocentric), 0 m, France

PROJ string:
+proj=pipeline +step +proj=unitconvert +xy_in=deg +xy_out=rad +step +proj=cart␣
↪+ellps=GRS80

WKT2:2019 string:
CONCATENATEDOPERATION["axis order change (geographic3D horizontal) + RGF93 to ETRS89 (1)␣
↪+ Conversion from ETRS89 (geog2D) to ETRS89 (geocentric)",
    SOURCECRS[
        GEOGCRS["RGF93 (lon-lat)",
            [...]
            ID["EPSG",7042]]],
    TARGETCRS[
        GEODCRS["ETRS89",
            [...]
            ID["EPSG",4936]]],
    STEP[
        CONVERSION["axis order change (geographic3D horizontal)",
            METHOD["Axis Order Reversal (Geographic3D horizontal)",
                ID["EPSG",9844]],
            ID["EPSG",15499]]],
    STEP[
        COORDINATEOPERATION["RGF93 to ETRS89 (1)",
            [...]
            METHOD["Geocentric translations (geog2D domain)",
                ID["EPSG",9603]],
            PARAMETER["X-axis translation",0,
                LENGTHUNIT["metre",1],
                ID["EPSG",8605]],
            PARAMETER["Y-axis translation",0,
```

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```
                LENGTHUNIT["metre",1],
                ID["EPSG",8606]],
            PARAMETER["Z-axis translation",0,
                LENGTHUNIT["metre",1],
                ID["EPSG",8607]],
            OPERATIONACCURACY[0.0],
            ID["EPSG",1591],
            REMARK["May be taken as approximate transformation RGF93 to WGS 84 - see␣
↪code 1671."]]],
    STEP[
        CONVERSION["Conversion from ETRS89 (geog2D) to ETRS89 (geocentric)",
            METHOD["Geographic/geocentric conversions",
                ID["EPSG",9602]]]]],
    USAGE[
        SCOPE["unknown"],
        AREA["France"],
        BBOX[41.15,-9.86,51.56,10.38]]]
```

7.5.5 Geodetic/geographic CRS to Geodetic/geographic CRS, without direct transformation

Still considering transformations between geodetic/geographic CRS, but let's consider that the lookup in the database for a transformation between the source and target CRS (possibly going through the "equivalent" CRS based on the same datum as detailed in the previous section) leads to an empty set.

Of course, as most operations are invertible, one first tries to do a lookup switching the source and target CRS, and inverting the resulting operation(s):

```
$ projinfo -s NAD83 -t NAD27 --spatial-test intersects --summary

Candidate operations found: 10
INVERSE(DERIVED_FROM(EPSG)):1312, Inverse of NAD27 to NAD83 (3), 2.0 m, Canada
INVERSE(DERIVED_FROM(EPSG)):1313, Inverse of NAD27 to NAD83 (4), 1.5 m, Canada - NAD27
INVERSE(DERIVED_FROM(EPSG)):1241, Inverse of NAD27 to NAD83 (1), 0.15 m, USA - CONUS␣
↪including EEZ
INVERSE(DERIVED_FROM(EPSG)):1243, Inverse of NAD27 to NAD83 (2), 0.5 m, USA - Alaska␣
↪including EEZ
INVERSE(DERIVED_FROM(EPSG)):1573, Inverse of NAD27 to NAD83 (6), 1.5 m, Canada - Quebec,␣
↪at least one grid missing
INVERSE(EPSG):1462, Inverse of NAD27 to NAD83 (5), 2.0 m, Canada - Quebec, at least one␣
↪grid missing
INVERSE(EPSG):9111, Inverse of NAD27 to NAD83 (9), 1.5 m, Canada - Saskatchewan, at␣
↪least one grid missing
unknown id, Ballpark geographic offset from NAD83 to NAD27, unknown accuracy, World, has␣
↪ballpark transformation
INVERSE(EPSG):8555, Inverse of NAD27 to NAD83 (7), 0.15 m, USA - CONUS and GoM, at least␣
↪one grid missing
INVERSE(EPSG):8549, Inverse of NAD27 to NAD83 (8), 0.5 m, USA - Alaska, at least one␣
↪grid missing
```

That was an easy case. Now let's consider the transformation between the Australian CRS AGD84 and GDA2020. There is no direct transformation from AGD84 to GDA2020, or in the reverse direction, even when considering alternative geodetic CRS based on the underlying datums. PROJ will then do a cross-join in the coordinate_operation_view table to find the tuples (op1, op2) of coordinate operations such that:

- SOURCE_CRS = op1.source_crs AND op1.target_crs = op2.source_crs AND op2.target_crs = TARGET_CRS or
- SOURCE_CRS = op1.source_crs AND op1.target_crs = op2.target_crs AND op2.source_crs = TARGET_CRS or
- SOURCE_CRS = op1.target_crs AND op1.source_crs = op2.source_crs AND op2.target_crs = TARGET_CRS or
- SOURCE_CRS = op1.target_crs AND op1.source_crs = op2.target_crs AND op2.source_crs = TARGET_CRS

Depending on which case is selected, op1 and op2 should be reversed, before being concatenated.

This logic is implement by the `findsOpsInRegistryWithIntermediate()` method.

Assuming that the proj-datumgrid-oceania package is installed, we get the following results for the AGD84 to GDA2020 coordinate operations lookup:

```
$ projinfo -s AGD84 -t GDA2020 --spatial-test intersects -o PROJ

Candidate operations found: 4
-------------------------------------
Operation No. 1:

unknown id, AGD84 to GDA94 (5) + GDA94 to GDA2020 (1), 0.11 m, Australia - AGD84

PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1 \
               +step +proj=unitconvert +xy_in=deg +xy_out=rad \
               +step +proj=hgridshift +grids=National_84_02_07_01.gsb \
               +step +proj=push +v_3 \
               +step +proj=cart +ellps=GRS80 \
               +step +proj=helmert +x=0.06155 +y=-0.01087 +z=-0.04019 \
                                   +rx=-0.0394924 +ry=-0.0327221 +rz=-0.0328979 \
                                   +s=-0.009994 +convention=coordinate_frame \
               +step +inv +proj=cart +ellps=GRS80 \
               +step +proj=pop +v_3 \
               +step +proj=unitconvert +xy_in=rad +xy_out=deg \
               +step +proj=axisswap +order=2,1

-------------------------------------
Operation No. 2:

unknown id, AGD84 to GDA94 (2) + GDA94 to GDA2020 (1), 1.01 m, Australia - AGD84

PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1 \
               +step +proj=unitconvert +xy_in=deg +xy_out=rad \
               +step +proj=push +v_3 \
               +step +proj=cart +ellps=aust_SA \
               +step +proj=helmert +x=-117.763 +y=-51.51 +z=139.061 \
                                   +rx=-0.292 +ry=-0.443 +rz=-0.277 +s=-0.191 \
                                   +convention=coordinate_frame \
               +step +proj=helmert +x=0.06155 +y=-0.01087 +z=-0.04019 \
```

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```
                                   +rx=-0.0394924 +ry=-0.0327221 +rz=-0.0328979 \
                                   +s=-0.009994 +convention=coordinate_frame \
               +step +inv +proj=cart +ellps=GRS80 \
               +step +proj=pop +v_3 \
               +step +proj=unitconvert +xy_in=rad +xy_out=deg \
               +step +proj=axisswap +order=2,1

-------------------------------------
Operation No. 3:

unknown id, AGD84 to GDA94 (5) + GDA94 to GDA2020 (2), 0.15 m, unknown domain of validity

PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1 \
               +step +proj=unitconvert +xy_in=deg +xy_out=rad \
               +step +proj=hgridshift +grids=National_84_02_07_01.gsb \
               +step +proj=hgridshift +grids=GDA94_GDA2020_conformal_and_distortion.gsb \
               +step +proj=unitconvert +xy_in=rad +xy_out=deg \
               +step +proj=axisswap +order=2,1

-------------------------------------
Operation No. 4:

unknown id, AGD84 to GDA94 (5) + GDA94 to GDA2020 (3), 0.15 m, unknown domain of validity

PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1 \
               +step +proj=unitconvert +xy_in=deg +xy_out=rad \
               +step +proj=hgridshift +grids=National_84_02_07_01.gsb \
               +step +proj=hgridshift +grids=GDA94_GDA2020_conformal.gsb \
               +step +proj=unitconvert +xy_in=rad +xy_out=deg \
               +step +proj=axisswap +order=2,1
```

One can see that the selected intermediate CRS that has been used is GDA94. This is a completely novel behavior of PROJ 6 as opposed to the logic of PROJ.4 where datum transformations implied using EPSG:4326 / WGS 84 has the mandatory datum hub. PROJ 6 no longer hardcodes it as the mandatory datum hub, and relies on the database to find the appropriate hub(s). Actually, WGS 84 has been considered during the above lookup, because there are transformations between AGD84 and WGS 84 and WGS 84 and GDA2020. However those have been discarded in a step which we did not mention previously: just after the initial filtering of results and their sorting, there is a final filtering that is done. In the list of sorted results, given two operations A and B that have the same area of use, if B has an accuracy lower than A, and A does not use grids, or all the needed grids are available, then B is discarded.

If one forces the datum hub to be considered to be EPSG:4326, ones gets:

```
$ projinfo -s AGD84 -t GDA2020 --spatial-test intersects --pivot-crs EPSG:4326 -o PROJ

Candidate operations found: 2
-------------------------------------
Operation No. 1:

unknown id, AGD84 to WGS 84 (7) + Inverse of GDA2020 to WGS 84 (2), 4 m, Australia -␣
↪AGD84
```

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```
PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1 \
               +step +proj=unitconvert +xy_in=deg +xy_out=rad \
               +step +proj=push +v_3 \
               +step +proj=cart +ellps=aust_SA \
               +step +proj=helmert +x=-117.763 +y=-51.51 +z=139.061 \
                                   +rx=-0.292 +ry=-0.443 +rz=-0.277 \
                                   +s=-0.191 +convention=coordinate_frame \
               +step +inv +proj=cart +ellps=GRS80 \
               +step +proj=pop +v_3 \
               +step +proj=unitconvert +xy_in=rad +xy_out=deg \
               +step +proj=axisswap +order=2,1

-------------------------------------
Operation No. 2:

unknown id, AGD84 to WGS 84 (9) + Inverse of GDA2020 to WGS 84 (2), 4 m, Australia -␣
↪AGD84

PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1 \
               +step +proj=unitconvert +xy_in=deg +xy_out=rad \
               +step +proj=hgridshift +grids=National_84_02_07_01.gsb \
               +step +proj=unitconvert +xy_in=rad +xy_out=deg \
               +step +proj=axisswap +order=2,1
```

Those operations are less accurate, since WGS 84 is assumed to be equivalent to GDA2020 with an accuracy of 4 metre. This is an instance demonstrating that using WGS 84 as a hub systematically can be sub-optimal.

There are still situations where the attempt to find a hub CRS does not work, because there is no such hub. This can occur for example when transforming from GDA94 to the latest realization at time of writing of WGS 84, WGS 84 (G1762). There are transformations between WGS 84 (G1762). Using the above described techniques, we would only find one non-ballpark operation taking the route: 1. Conversion from GDA94 (geog2D) to GDA94 (geocentric): synthetized by PROJ 2. Inverse of ITRF2008 to GDA94 (1): from EPSG 3. Inverse of WGS 84 (G1762) to ITRF2008 (1): from EPSG 4. Conversion from WGS 84 (G1762) (geocentric) to WGS 84 (G1762): synthetized by PROJ

This is not bad, but the global validity area of use is "Australia - onshore and EEZ", whereas GDA94 has a larger area of use. There is another road that can be taken by going through GDA2020 instead of ITRF2008. The GDA94 to GDA2020 transformations operate on the respective geographic CRS, whereas GDA2020 to WGS 84 (G1762) operate on the geocentric CRS. Consequently, GDA2020 cannot be identifier as a hub by a "simple" self-join SQL request on the coordinate operation table. This requires to do the join based on the datum referenced by the source and target CRS of each operation rather than the source and target CRS themselves. When there is a match, PROJ inserts the required conversions between geographic and geocentric CRS to have a consistent concatenated operation, like the following: 1. GDA94 to GDA2020 (1): from EPSG 2. Conversion from GDA2020 (geog2D) to GDA2020 (geocentric): synthetized by PROJ 3. GDA2020 to WGS 84 (G1762) (1): from EPSG 4. Conversion from WGS 84 (G1762) (geocentric) to WGS 84 (G1762) (geog2D): synthetized by PROJ

7.5.6 Projected CRS to any target CRS

This actually extends to any Derived CRS, whose Projected CRS is a well-known particular case. Such transformations are done in 2 steps:

1. Use the inverse conversion of the derived CRS to its base CRS, typically an inverse map projection.
2. Find transformations from this base CRS to the target CRS. If the base CRS is the target CRS, this step can be skipped.

```
$ projinfo -s EPSG:32631 -t RGF93

Candidate operations found: 1
-------------------------------------
Operation No. 1:

unknown id, Inverse of UTM zone 31N + Inverse of RGF93 to WGS 84 (1), 1 m, France

PROJ string:
+proj=pipeline +step +inv +proj=utm +zone=31 +ellps=WGS84 +step +proj=unitconvert +xy_
↪in=rad +xy_out=deg +step +proj=axisswap +order=2,1
```

This is implemented by the `createOperationsDerivedTo` method

For the symmetric case, source CRS to a derived CRS, the above algorithm is applied by switching the source and target CRS, and then inverting the resulting operation(s). This is mostly a matter of avoiding to write very similar code twice. This logic is also applied to all below cases when considering the transformation between 2 different types of objects.

7.5.7 Vertical CRS to a Geographic CRS

Such transformation is normally not meant as being used as standalone by PROJ users, but as an internal computation step of a Compound CRS to a target CRS.

In cases where we are lucky, the PROJ database will have a transformation registered between those:

```
$ projinfo -s "NAVD88 height" -t "NAD83(2011)" -o PROJ --spatial-test intersects
Candidate operations found: 11
-------------------------------------
Operation No. 1:

INVERSE(DERIVED_FROM(EPSG)):9229, Inverse of NAD83(2011) to NAVD88 height (3), 0.015 m,␣
↪USA - CONUS - onshore

PROJ string:
+proj=vgridshift +grids=g2018u0.gtx +multiplier=1
```

But in cases where there is no match, the `createOperationsVertToGeog` method will be used to synthetize a ballpark vertical transformation, just taking care of unit changes, and axis reversal in case the vertical CRS was a depth rather than a height. Of course the results of such an operation are questionable, hence the ballpark qualifier and a unknown accuracy advertized for such an operation.

7.5.8 Vertical CRS to a Vertical CRS

Overall logic is similar to the above case. There might be direct operations in the PROJ database, involving grid transformations or simple offsets. The fallback case is to synthetize a ballpark transformation.

This is implemented by the `createOperationsVertToVert` method

```
$ projinfo -s "NGVD29 depth (ftUS)" -t "NAVD88 height" --spatial-test intersects -o PROJ

Candidate operations found: 3
-------------------------------------
Operation No. 1:

unknown id, Inverse of NGVD29 height (ftUS) to NGVD29 depth (ftUS) + NGVD29 height␣
↪(ftUS) to NGVD29 height (m) + NGVD29 height (m) to NAVD88 height (3), 0.02 m, USA -␣
↪CONUS east of 89°W - onshore

PROJ string:
+proj=pipeline +step +proj=axisswap +order=1,2,-3 +step +proj=unitconvert +z_in=us-ft +z_
↪out=m +step +proj=vgridshift +grids=vertcone.gtx +multiplier=0.001

-------------------------------------
Operation No. 2:

unknown id, Inverse of NGVD29 height (ftUS) to NGVD29 depth (ftUS) + NGVD29 height␣
↪(ftUS) to NGVD29 height (m) + NGVD29 height (m) to NAVD88 height (2), 0.02 m, USA -␣
↪CONUS 89°W-107°W - onshore

PROJ string:
+proj=pipeline +step +proj=axisswap +order=1,2,-3 +step +proj=unitconvert +z_in=us-ft +z_
↪out=m +step +proj=vgridshift +grids=vertconc.gtx +multiplier=0.001

-------------------------------------
Operation No. 3:

unknown id, Inverse of NGVD29 height (ftUS) to NGVD29 depth (ftUS) + NGVD29 height␣
↪(ftUS) to NGVD29 height (m) + NGVD29 height (m) to NAVD88 height (1), 0.02 m, USA -␣
↪CONUS west of 107°W - onshore

PROJ string:
+proj=pipeline +step +proj=axisswap +order=1,2,-3 +step +proj=unitconvert +z_in=us-ft +z_
↪out=m +step +proj=vgridshift +grids=vertconw.gtx +multiplier=0.001
```

7.5.9 Compound CRS to a Geographic CRS

A typical example of a Compound CRS is a CRS made of a geographic or projected CRS as the horizontal component, and a vertical CRS. E.g. "NAD83 + NAVD88 height"

When the horizontal component of the compound source CRS is a projected CRS, we first look for the operation from this source CRS to another compound CRS made of the geographic CRS base of the projected CRS, like "NAD83 / California zone 1 (ftUS) + NAVD88 height" to "NAD83 + NAVD88 height", which ultimately goes to one of the above described case. Then we can consider the transformation from a compound CRS made of a geographic CRS to another geographic CRS.

It first starts by the vertical transformations from the vertical CRS of the source compound CRS to the target geographic CRS, using the strategy detailed in *Vertical CRS to a Geographic CRS*

What we did not mention is that when there is not a transformation registered between the vertical CRS and the target geographic CRS, PROJ attempts to find transformations between that vertical CRS and any other geographic CRS. This is clearly an approximation. If the research of the vertical CRS to the target geographic CRS resulted in operations that use grids that are not available, as another approximation, we research operations from the vertical CRS to the source geographic CRS for the vertical component.

Once we got those more or less accurate vertical transformations, we must consider the horizontal transformation(s). The algorithm iterates over all found vertical transformations and look for their target geographic CRS. This will be used as the interpolation CRS for horizontal transformations. PROJ will then look for available transformations from the source geographic CRS to the interpolation CRS and from the interpolation CRS to the target geographic CRS. There is then a 3-level loop to create the final set of operations chaining together:

- the horizontal transformation from the source geographic CRS to the interpolation CRS
- the vertical transformation from the source vertical CRS to the interpolation CRS
- the horizontal transformation from the interpolation CRS to the target geographic CRS.

This is implemented by the `createOperationsCompoundToGeog` method

Example:

```
$ projinfo -s "NAD83(NSRS2007) + NAVD88 height" -t "WGS 84 (G1762)" --spatial-test␣
↪intersects --summary

Candidate operations found: 21
unknown id, Inverse of NAD83(NSRS2007) to NAVD88 height (1) + NAD83(NSRS2007) to WGS 84␣
↪(1) + WGS 84 to WGS 84 (G1762), 3.05 m, USA - CONUS - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (7) + NAD83(HARN) to WGS 84 (1) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS south of 41°N, 95°W to 78°W - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (7) + NAD83(HARN) to WGS 84 (3) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS south of 41°N, 95°W to 78°W - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (6) + NAD83(HARN) to WGS 84 (1) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS south of 41°N, 112°W to 95°W - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (6) + NAD83(HARN) to WGS 84 (3) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS south of 41°N, 112°W to 95°W - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (2) + NAD83(HARN) to WGS 84 (1) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS north of 41°N, 112°W to 95°W
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (2) + NAD83(HARN) to WGS 84 (3) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS north of 41°N, 112°W to 95°W
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (3) + NAD83(HARN) to WGS 84 (1) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS north of 41°N, 95°W to 78°W
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (3) + NAD83(HARN) to WGS 84 (3) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS north of 41°N, 95°W to 78°W
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (5) + NAD83(HARN) to WGS 84 (1) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
```

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```
↪ CONUS south of 41°N, west of 112°W - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (5) + NAD83(HARN) to WGS 84 (3) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS south of 41°N, west of 112°W - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (1) + NAD83(HARN) to WGS 84 (1) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS north of 41°N, west of 112°W - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (1) + NAD83(HARN) to WGS 84 (3) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS north of 41°N, west of 112°W - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (4) + NAD83(HARN) to WGS 84 (1) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS north of 41°N, east of 78°W - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (4) + NAD83(HARN) to WGS 84 (3) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS north of 41°N, east of 78°W - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (8) + NAD83(HARN) to WGS 84 (1) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS south of 41°N, east of 78°W - onshore
unknown id, Inverse of NAD83(HARN) to NAD83(NSRS2007) (1) + Inverse of NAD83(HARN) to␣
↪NAVD88 height (8) + NAD83(HARN) to WGS 84 (3) + WGS 84 to WGS 84 (G1762), 3.15 m, USA -
↪ CONUS south of 41°N, east of 78°W - onshore
unknown id, Ballpark geographic offset from NAD83(NSRS2007) to NAD83(FBN) + Inverse of␣
↪NAD83(FBN) to NAVD88 height (1) + Ballpark geographic offset from NAD83(FBN) to WGS 84␣
↪(G1762), unknown accuracy, USA - CONUS - onshore, has ballpark transformation
unknown id, Ballpark geographic offset from NAD83(NSRS2007) to NAD83(2011) + Inverse of␣
↪NAD83(2011) to NAVD88 height (3) + Ballpark geographic offset from NAD83(2011) to WGS␣
↪84 (G1762), unknown accuracy, USA - CONUS - onshore, has ballpark transformation
unknown id, Ballpark geographic offset from NAD83(NSRS2007) to NAD83(2011) + Inverse of␣
↪NAD83(2011) to NAVD88 height (3) + Conversion from NAD83(2011) (geog2D) to NAD83(2011)␣
↪(geocentric) + Inverse of ITRF2008 to NAD83(2011) (1) + Inverse of WGS 84 (G1762) to␣
↪ITRF2008 (1) + Conversion from WGS 84 (G1762) (geocentric) to WGS 84 (G1762) (geog2D),␣
↪unknown accuracy, USA - CONUS - onshore, has ballpark transformation
unknown id, NAD83(NSRS2007) to WGS 84 (1) + WGS 84 to WGS 84 (G1762) + Transformation␣
↪from NAVD88 height to WGS 84 (G1762) (ballpark vertical transformation, without␣
↪ellipsoid height to vertical height correction), unknown accuracy, USA - CONUS and␣
↪Alaska; PRVI, has ballpark transformation
```

7.5.10 CompoundCRS to CompoundCRS

There is some similarity with the previous paragraph. We first research the vertical transformations between the two vertical CRS.

1. If there is such a transformation, be it direct, or if both vertical CRS relate to a common intermediate CRS. If it has a registered interpolation geographic CRS, then it is used. Otherwise we fallback to the geographic CRS of the source CRS.

   Finally, a 3-level loop to create the final set of operations chaining together:

   - the horizontal transformation from the source CRS to the interpolation CRS
   - the vertical transformation
   - the horizontal transformation from the interpolation CRS to the target CRS.

Example:

```
$ projinfo -s "NAD27 + NGVD29 height (ftUS)" -t "NAD83 + NAVD88 height" --
↪spatial-test intersects --summary

Candidate operations found: 20
unknown id, NGVD29 height (ftUS) to NAVD88 height (3) + NAD27 to NAD83 (1),␣
↪0.17 m, USA - CONUS east of 89°W - onshore
unknown id, NGVD29 height (ftUS) to NAVD88 height (2) + NAD27 to NAD83 (1),␣
↪0.17 m, USA - CONUS 89°W-107°W - onshore
unknown id, NGVD29 height (ftUS) to NAVD88 height (1) + NAD27 to NAD83 (1),␣
↪0.17 m, USA - CONUS west of 107°W - onshore
unknown id, NGVD29 height (ftUS) to NAVD88 height (3) + NAD27 to NAD83 (3),␣
↪1.02 m, unknown domain of validity
unknown id, NGVD29 height (ftUS) to NAVD88 height (2) + NAD27 to NAD83 (3),␣
↪1.02 m, unknown domain of validity
unknown id, NGVD29 height (ftUS) to NAVD88 height (1) + NAD27 to NAD83 (3),␣
↪1.02 m, unknown domain of validity
unknown id, NGVD29 height (ftUS) to NAVD88 height (3) + NAD27 to NAD83 (5),␣
↪1.02 m, unknown domain of validity, at least one grid missing
unknown id, NGVD29 height (ftUS) to NAVD88 height (3) + NAD27 to NAD83 (6),␣
↪1.52 m, unknown domain of validity, at least one grid missing
unknown id, NGVD29 height (ftUS) to NAVD88 height (2) + NAD27 to NAD83 (9),␣
↪1.52 m, unknown domain of validity, at least one grid missing
unknown id, NGVD29 height (ftUS) to NAVD88 height (1) + NAD27 to NAD83 (9),␣
↪1.52 m, unknown domain of validity, at least one grid missing
unknown id, NGVD29 height (ftUS) to NAVD88 height (3) + Ballpark geographic␣
↪offset from NAD27 to NAD83, unknown accuracy, USA - CONUS east of 89°W -␣
↪onshore, has ballpark transformation
unknown id, NGVD29 height (ftUS) to NAVD88 height (2) + Ballpark geographic␣
↪offset from NAD27 to NAD83, unknown accuracy, USA - CONUS 89°W-107°W -␣
↪onshore, has ballpark transformation
unknown id, NGVD29 height (ftUS) to NAVD88 height (1) + Ballpark geographic␣
↪offset from NAD27 to NAD83, unknown accuracy, USA - CONUS west of 107°W -␣
↪onshore, has ballpark transformation
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height␣
↪(ballpark vertical transformation) + NAD27 to NAD83 (1), unknown accuracy,
↪ USA - CONUS including EEZ, has ballpark transformation
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height␣
↪(ballpark vertical transformation) + NAD27 to NAD83 (3), unknown accuracy,
↪ Canada, has ballpark transformation
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height␣
↪(ballpark vertical transformation) + NAD27 to NAD83 (4), unknown accuracy,
↪ Canada - NAD27, has ballpark transformation
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height␣
↪(ballpark vertical transformation) + NAD27 to NAD83 (5), unknown accuracy,
↪ Canada - Quebec, has ballpark transformation, at least one grid missing
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height␣
↪(ballpark vertical transformation) + NAD27 to NAD83 (6), unknown accuracy,
↪ Canada - Quebec, has ballpark transformation, at least one grid missing
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height␣
↪(ballpark vertical transformation) + NAD27 to NAD83 (9), unknown accuracy,
↪ Canada - Saskatchewan, has ballpark transformation, at least one grid␣
```

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```
↪missing
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height␣
↪(ballpark vertical transformation) + Ballpark geographic offset from␣
↪NAD27 to NAD83, unknown accuracy, World, has ballpark transformation
```

2. Otherwise, when there is no such transformation, we decompose into 3 steps:

   - transform from the source CRS to the geographic 3D CRS corresponding to it
   - transform from the geographic 3D CRS corresponding to the source CRS to the geographic 3D CRS corresponding to the target CRS
   - transform from the geographic 3D CRS corresponding to the target CRS to the target CRS.

   Example:

```
$  projinfo -s "WGS 84 + EGM96 height" -t "ETRS89 + Belfast height" --
↪spatial-test intersects --summary

Candidate operations found: 7
unknown id, Inverse of WGS 84 to EGM96 height (1) + Inverse of ETRS89 to␣
↪WGS 84 (1) + ETRS89 to Belfast height (2), 2.014 m, UK - Northern Ireland␣
↪- onshore
unknown id, Inverse of WGS 84 to EGM96 height (1) + Inverse of ETRS89 to␣
↪WGS 84 (1) + ETRS89 to Belfast height (1), 2.03 m, UK - Northern Ireland -
↪ onshore, at least one grid missing
unknown id, Inverse of WGS 84 to EGM96 height (1) + Null geographic offset␣
↪from WGS 84 (geog3D) to WGS 84 (geog2D) + Inverse of OSGB 1936 to WGS 84␣
↪(4) + OSGB 1936 to ETRS89 (2) + Null geographic offset from ETRS89␣
↪(geog2D) to ETRS89 (geog3D) + ETRS89 to Belfast height (2), 19.044 m,␣
↪unknown domain of validity
unknown id, Inverse of WGS 84 to EGM96 height (1) + Null geographic offset␣
↪from WGS 84 (geog3D) to WGS 84 (geog2D) + Inverse of OSGB 1936 to WGS 84␣
↪(2) + OSGB 1936 to ETRS89 (2) + Null geographic offset from ETRS89␣
↪(geog2D) to ETRS89 (geog3D) + ETRS89 to Belfast height (2), 11.044 m,␣
↪unknown domain of validity
unknown id, Inverse of WGS 84 to EGM96 height (1) + Null geographic offset␣
↪from WGS 84 (geog3D) to WGS 84 (geog2D) + Inverse of TM75 to WGS 84 (2) +␣
↪TM75 to ETRS89 (3) + Null geographic offset from ETRS89 (geog2D) to␣
↪ETRS89 (geog3D) + ETRS89 to Belfast height (2), 2.424 m, UK - Northern␣
↪Ireland - onshore, at least one grid missing
unknown id, Inverse of WGS 84 to EGM96 height (1) + Null geographic offset␣
↪from WGS 84 (geog3D) to WGS 84 (geog2D) + Inverse of TM75 to WGS 84 (2) +␣
↪TM75 to ETRS89 (3) + Null geographic offset from ETRS89 (geog2D) to␣
↪ETRS89 (geog3D) + ETRS89 to Belfast height (1), 2.44 m, UK - Northern␣
↪Ireland - onshore, at least one grid missing
unknown id, Inverse of WGS 84 to EGM96 height (1) + Null geographic offset␣
↪from WGS 84 (geog3D) to WGS 84 (geog2D) + Inverse of OSGB 1936 to WGS 84␣
↪(4) + OSGB 1936 to ETRS89 (2) + Null geographic offset from ETRS89␣
↪(geog2D) to ETRS89 (geog3D) + ETRS89 to Belfast height (1), 19.06 m,␣
↪unknown domain of validity, at least one grid missing
```

This is implemented by the `createOperationsCompoundToCompound` method

7.5.11 When the source or target CRS is a BoundCRS

The BoundCRS concept is an hybrid concept where a CRS is linked to a transformation from it to a hub CRS, typically WGS 84. This is a long-time practice in PROJ.4 strings with the `+towgs84`, `+nadgrids` and `+geoidgrids` keywords, or the `TOWGS84[]` node of WKT 1. When encountering those attributes when parsing a CRS string, PROJ will create a BoundCRS object capturing this transformation. A BoundCRS object can also be provided with a WKT2 string, and in that case with a hub CRS being potentially different from WGS 84.

Let's consider the case of a transformation between a BoundCRS ("+proj=tmerc +lat_0=49 +lon_0=-2 +k=0.9996012717 +x_0=400000 +y_0=-100000 +ellps=airy +towgs84=446.448,-125.157,542.06,0.15,0.247,0.842,-20.489 +units=m" which used to be the PROJ.4 definition of "OSGB 1936 / British National Grid") and a target Geographic CRS, ETRS89.

We apply the following steps:

- transform from the base of the source CRS (that is the CRS wrapped by BoundCRS, here a ProjectedCRS) to the geographic CRS of this base CRS
- apply the transformation of the BoundCRS to go from the geographic CRS of this base CRS to the hub CRS of the BoundCRS, in that instance WGS 84.
- apply a transformation from the hub CRS to the target CRS.

This is implemented by the `createOperationsBoundToGeog` method

Example:

```
$ projinfo -s "+proj=tmerc +lat_0=49 +lon_0=-2 +k=0.9996012717 +x_0=400000 +y_0=-100000␣
↪+ellps=airy +towgs84=446.448,-125.157,542.06,0.15,0.247,0.842,-20.489 +units=m␣
↪+type=crs" -t ETRS89 -o PROJ

Candidate operations found: 1
-------------------------------------
Operation No. 1:

unknown id, Inverse of unknown + Transformation from unknown to WGS84 + Inverse of␣
↪ETRS89 to WGS 84 (1), unknown accuracy, Europe - ETRS89

PROJ string:
+proj=pipeline +step +inv +proj=tmerc +lat_0=49 +lon_0=-2 +k=0.9996012717 +x_0=400000 +y_
↪0=-100000 +ellps=airy +step +proj=push +v_3 +step +proj=cart +ellps=airy +step␣
↪+proj=helmert +x=446.448 +y=-125.157 +z=542.06 +rx=0.15 +ry=0.247 +rz=0.842 +s=-20.489␣
↪+convention=position_vector +step +inv +proj=cart +ellps=GRS80 +step +proj=pop +v_3␣
↪+step +proj=unitconvert +xy_in=rad +xy_out=deg +step +proj=axisswap +order=2,1
```

There are other situations with BoundCRS, involving vertical transformations, or transforming to other objects than a geographic CRS, but the curious reader will have to inspect the code for the actual gory details.

CHAPTER

EIGHT

RESOURCE FILES

A number of files containing preconfigured transformations and default parameters for certain projections are bundled with the PROJ distribution. Init files contain preconfigured proj-strings for various coordinate reference systems and the *defaults* file contains default values for parameters of select projections.

In addition to the bundled init files the PROJ project also distributes a number of packages containing transformation grids and additional init files not included in the main PROJ package.

8.1 Where are PROJ resource files looked for ?

PROJ will attempt to locate its resource files - database, transformation grids or init files - from several directories. The following paths are checked in order:

- For resource files that have an explicit relative or absolute path, the directory specified in the filename.
- Path resolved by the callback function set with the `proj_context_set_file_finder()`. If it is set, the next tests will not be run.
- Path(s) set with the `proj_context_set_search_paths()`. If set, the next tests will not be run.
- New in version 7.0.

  The PROJ user writable directory, which is :

  – on Windows, `${LOCALAPPDATA}/proj`

  – on macOS, `${HOME}/Library/Application Support/proj`

  – on other platforms (Linux), `${XDG_DATA_HOME}/proj` if `XDG_DATA_HOME` is defined. Else `${HOME}/.local/share/proj`
- Path(s) set with by the environment variable *PROJ_LIB*. On Linux/macOS/Unix, use `:` to separate paths. On Windows, `;`
- New in version 7.0.

  The `../share/proj/` and its contents are found automatically at run-time if the installation respects the build structure. That is, the binaries and `proj.dll/libproj.so` are installed under `../bin/` or `../lib/`, and resource files are in `../share/proj/`.
- A path built into PROJ as its resource installation directory (whose value is `$(pkgdatadir)` for builds using the Makefile build system or `${CMAKE_INSTALL_PREFIX}/${DATADIR}` for CMake builds). Note, however, that since this is a hard-wired path setting, it only works if the whole PROJ installation is not moved somewhere else.

Note: if PROJ is built with the `PROJ_LIB_ENV_VAR_TRIED_LAST` CMake option / `--enable-proj-lib-env-var-tried-last` configure switch, then this hard-wired path will be tried before looking at the environment variable *PROJ_LIB*.

- The current directory

When networking capabilities are enabled, either by API with the `proj_context_set_enable_network()` function or when the *PROJ_NETWORK* environment variable is set to `ON`, PROJ will attempt to use remote grids stored on CDN (Content Delivery Network) storage.

8.2 proj.db

A proj installation includes a SQLite database of transformation information that must be accessible for the library to work properly. The library will print an error if the database can't be found.

8.3 proj.ini

New in version 7.0.

`proj.ini` is a text configuration file, mostly dedicated at setting up network related parameters.

Its default content is:

```
[general]
; Lines starting by ; are commented lines.
;

; Network capabilities disabled by default.
; Can be overridden with the PROJ_NETWORK=ON environment variable.
; network = on

; Can be overridden with the PROJ_NETWORK_ENDPOINT environment variable.
cdn_endpoint = https://cdn.proj.org

cache_enabled = on

cache_size_MB = 300

cache_ttl_sec = 86400

; Transverse Mercator (and UTM) default algorithm: auto, evenden_snyder or poder_engsager
; * evenden_snyder is the fastest, but less accurate far from central meridian
; * poder_engsager is slower, but more accurate far from central meridian
; * default will auto-select between the two above depending on the coordinate
;   to transform and will use evenden_snyder if the error in doing so is below
;   0.1 mm (for an ellipsoid of the size of Earth)
tmerc_default_algo = poder_engsager
```

8.4 Transformation grids

Grid files are important for shifting and transforming between datums.

PROJ supports CTable2, NTv1 and NTv2 files for horizontal grid corrections and the GTX file format for vertical corrections. Details about the formats can be found in the GDAL documentation. GDAL reads and writes all formats. Using GDAL for construction of new grids is recommended.

8.5 External resources and packaged grids

8.5.1 proj-data

The `proj-data` package is a collection of all the resource files that are freely available for use with PROJ. The package is maintained on GitHub and the contents of the package are show-cased on the PROJ CDN. The contents of the package can be installed using the **projsync** package or by downloading the zip archive of the package and unpacking in the *PROJ_LIB* directory.

8.5.2 proj-datumgrid

Note: The packages described below can be used with PROJ 7 and later but are primarily meant to be used with PROJ 6 and earlier versions. The `proj-datumgrid` series of packages are not maintained anymore and are only kept available for legacy purposes.

For a functioning build of PROJ prior to version 7, installation of the proj-datumgrid is needed. If you have installed PROJ from a package system chances are that this will already be done for you. The *proj-datumgrid* package provides transformation grids that are essential for many of the predefined transformations in PROJ. Which grids are included in the package can be seen on the proj-datumgrid repository as well as descriptions of those grids. This is the main grid package and the only one that is required. It includes various older grids that is mostly needed for legacy reasons. Without this package, the test suite fails miserably.

8.5.3 Regional packages

In addition to the default `proj-datumgrid` package regional packages are also distributed. These include grids and init files that are valid within the given region. The packages are divided into geographical regions in order to keep the needed disk space by PROJ at a minimum. Some users may have a use for resource files covering several regions in which case they can download more than one.

At the moment three regional resource file packages are distributed:

- Europe
- Oceania
- North America

If someone supplies grids relevant for Africa, South-America, Asia or Antarctica we will create new regional packages.

Click the links to jump to the relevant README files for each package. Details on the content of the packages maintained there.

Tip: To download the various datumgrid packages head to the *download section*.

8.5.4 World package

The world package includes grids that have global extent, e.g. the global geoid model EGM08.

8.5.5 -latest packages

All packages above come in different versions, e.g., `proj-datumgrid-1.8` or `proj-datumgrid-europe-1.4`. The `-latest` packages are symbolic links to the latest version of a given package. That means that the link https://download.osgeo.org/proj/proj-datumgrid-north-america-latest.zip is equivalent to https://download.osgeo.org/proj/proj-datumgrid-north-america-1.2.zip (as of the time of writing this).

8.6 Other transformation grids

Below is a list of grid resources for various countries which are not included in the grid distributions mentioned above.

8.6.1 Free grids

The following is a list of grids distributed under a free and open license.

8.6.1.1 Hungary

Hungarian grid ETRS89 - HD72/EOV (epsg:23700), both horizontal and elevation grids

8.6.2 Non-Free Grids

Not all grid shift files have licensing that allows them to be freely distributed, but can be obtained by users through free and legal methods.

8.6.2.1 Austria

Overview of Austrian grids and other resources related to the local geodetic reference.

8.6.2.2 Brazil

Brazilian grids for datums Corrego Alegre 1961, Corrego Alegre 1970-72, SAD69 and SAD69(96)

8.6.2.3 Netherlands

Dutch grid (Registration required before download)

8.6.2.4 Portugal

Portuguese grids for ED50, Lisbon 1890, Lisbon 1937 and Datum 73

8.6.2.5 South Africa

South African grid (Cape to Hartebeesthoek94 or WGS84)

8.6.2.6 Spain

Spanish grids for ED50.

8.6.3 HTDP

This section describes the use of the `crs2crs2grid.py` script and the HTDP (Horizontal Time Dependent Positioning) grid shift modelling program from NGS/NOAA to produce PROJ compatible grid shift files for fine grade conversions between various NAD83 epochs and WGS84. Traditionally PROJ has treated NAD83 and WGS84 as equivalent and failed to distinguish between different epochs or realizations of those datums. At the scales of much mapping this is adequate but as interest grows in high resolution imagery and other high resolution mapping this is inadequate. Also, as the North American crust drifts over time the displacement between NAD83 and WGS84 grows (more than one foot over the last two decades).

8.6.3.1 Getting and building HTDP

The HTDP modelling program is written in FORTRAN. The source and documentation can be found on the HTDP page at http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml

On Linux systems it will be necessary to install GFortran or some Fortran compiler. For Ubuntu something like the following should work.

```
apt-get install gfortran
```

To compile the program do something like the following to produce the binary **`htdp`** from the source code.

```
gfortran htdp.for -o htdp
```

8.6.3.2 Getting `crs2crs2grid.py`

The `crs2crs2grid.py` script can be found at https://github.com/OSGeo/gdal/tree/master/gdal/swig/python/samples/crs2crs2grid.py

The script depends on having the GDAL Python bindings operational; if they are not you will get an error such as:

```
Traceback (most recent call last):
  File "./crs2crs2grid.py", line 37, in <module>
    from osgeo import gdal, gdal_array, osr
ImportError: No module named osgeo
```

8.6.3.3 Usage

```
crs2crs2grid.py
        <src_crs_id> <src_crs_date> <dst_crs_id> <dst_crs_year>
        [-griddef <ul_lon> <ul_lat> <ll_lon> <ll_lat> <lon_count> <lat_count>]
        [-htdp <path_to_exe>] [-wrkdir <dirpath>] [-kwf]
        -o <output_grid_name>

 -griddef: by default the following values for roughly the continental USA
           at a six minute step size are used:
           -127 50 -66 25 251 611
 -kwf: keep working files in the working directory for review.
```

```
crs2crs2grid.py 29 2002.0 8 2002.0 -o nad83_2002.ct2
```

The goal of `crs2crs2grid.py` is to produce a grid shift file for a designated region. The region is defined using the `-griddef` switch. When missing a continental US region is used. The script creates a set of sample points for the grid definition, runs **htdp** against it and then parses the resulting points and computes a point by point shift to encode into the final grid shift file. By default it is assumed that **htdp** is in the executable path. If not, please provide the path to the executable using the `-htdp` switch.

The **htdp** program supports transformations between many CRSes and for each (or most?) of them you need to provide a date at which the CRS is fixed. The full set of CRS Ids available in the HTDP program are:

```
 1...NAD_83(2011) (North America tectonic plate fixed)
 29...NAD_83(CORS96)  (NAD_83(2011) will be used)
 30...NAD_83(2007)    (NAD_83(2011) will be used)
 2...NAD_83(PA11) (Pacific tectonic plate fixed)
 31...NAD_83(PACP00)  (NAD 83(PA11) will be used)
 3...NAD_83(MA11) (Mariana tectonic plate fixed)
 32...NAD_83(MARP00)  (NAD_83(MA11) will be used)

 4...WGS_72                             16...ITRF92
 5...WGS_84(transit) = NAD_83(2011)     17...ITRF93
 6...WGS_84(G730) = ITRF92              18...ITRF94 = ITRF96
 7...WGS_84(G873) = ITRF96              19...ITRF96
 8...WGS_84(G1150) = ITRF2000           20...ITRF97
 9...PNEOS_90 = ITRF90                  21...IGS97 = ITRF97
10...NEOS_90 = ITRF90                   22...ITRF2000
11...SIO/MIT_92 = ITRF91                23...IGS00 = ITRF2000
12...ITRF88                             24...IGb00 = ITRF2000
13...ITRF89                             25...ITRF2005
14...ITRF90                             26...IGS05 = ITRF2005
15...ITRF91                             27...ITRF2008
                                        28...IGS08 = ITRF2008
```

The typical use case is mapping from NAD83 on a particular date to WGS84 on some date. In this case the source CRS Id “29” (NAD_83(CORS96)) and the destination CRS Id is “8 (WGS_84(G1150)). It is also necessary to select the source and destination date (epoch). For example:

```
crs2crs2grid.py 29 2002.0 8 2002.0 -o nad83_2002.ct2
```

The output is a CTable2 format grid shift file suitable for use with PROJ (4.8.0 or newer). It might be utilized something like:

```
cs2cs +proj=latlong +ellps=GRS80 +nadgrids=./nad83_2002.ct2 +to +proj=latlong␣
↪+datum=WGS84
```

8.6.3.4 See Also

- http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml - NGS/NOAA page about the HTDP model and program. Source for the HTDP program can be downloaded from here.

8.7 Init files

Init files are used for preconfiguring proj-strings for often used transformations, such as those found in the EPSG database. Most init files contain transformations from a given coordinate reference system to WGS84. This makes it easy to transform between any two coordinate reference systems with **cs2cs**. Init files can however contain any proj-string and don't necessarily have to follow the *cs2cs* paradigm where WGS84 is used as a pivot datum. The ITRF init file is a good example of that.

A number of init files come pre-bundled with PROJ but it is also possible to add your own custom init files. PROJ looks for the init files in the directory listed in the *PROJ_LIB* environment variable.

The format of init files is an identifier in angled brackets and a proj-string:

```
<3819> +proj=longlat +ellps=bessel
       +towgs84=595.48,121.69,515.35,4.115,-2.9383,0.853,-3.408 +no_defs <>
```

The above example is the first entry from the `epsg` init file. So, this is the coordinate reference system with ID 3819 in the EPSG database. Comments can be inserted by prefixing them with a "#". With version 4.10.0 a new special metadata entry is now accepted in init files. It can be parsed with a function from the public API. The metadata entry in the epsg init file looks like this at the time of writing:

```
<metadata> +version=9.0.0 +origin=EPSG +lastupdate=2017-01-10
```

Pre-configured proj-strings from init files are used in the following way:

```
$ cs2cs -v +proj=latlong +to +init=epsg:3819
# ---- From Coordinate System ----
#Lat/long (Geodetic alias)
#
# +proj=latlong +ellps=WGS84
# ---- To Coordinate System ----
#Lat/long (Geodetic alias)
#
# +init=epsg:3819 +proj=longlat +ellps=bessel
# +towgs84=595.48,121.69,515.35,4.115,-2.9383,0.853,-3.408 +no_defs
```

It is possible to override parameters when using `+init`. Just add the parameter to the proj-string alongside the `+init` parameter. For instance by overriding the ellipsoid as in the following example

```
+init=epsg:25832 +ellps=intl
```

where the Hayford ellipsoid is used instead of the predefined GRS80 ellipsoid. It is also possible to add additional parameters not specified in the init file, for instance by adding an observation epoch when transforming from ITRF2000 to ITRF2005:

```
+init=ITRF2000:ITRF2005 +t_obs=2010.5
```

which then expands to

```
+proj=helmert +x=-0.0001 +y=0.0008 +z=0.0058 +s=-0.0004
+dx=0.0002 +dy=-0.0001 +dz=0.0018 +ds=-0.000008
+t_epoch=2000.0 +convention=position_vector
+t_obs=2010.5
```

Below is a list of the init files that are packaged with PROJ.

Name	Description
GL27	Great Lakes Grids
ITRF2000	Full set of transformation parameters between ITRF2000 and other ITRF's
ITRF2008	Full set of transformation parameters between ITRF2008 and other ITRF's
ITRF2014	Full set of transformation parameters between ITRF2014 and other ITRF's
nad27	State plane coordinate systems, North American Datum 1927
nad83	State plane coordinate systems, North American Datum 1983

CHAPTER

NINE

GEODESIC CALCULATIONS

9.1 Introduction

Consider an ellipsoid of revolution with equatorial radius a, polar semi-axis b, and flattening $f = (a - b)/a$. Points on the surface of the ellipsoid are characterized by their latitude ϕ and longitude λ. (Note that latitude here means the *geographical latitude*, the angle between the normal to the ellipsoid and the equatorial plane).

The shortest path between two points on the ellipsoid at (ϕ_1, λ_1) and (ϕ_2, λ_2) is called the geodesic. Its length is s_{12} and the geodesic from point 1 to point 2 has forward azimuths α_1 and α_2 at the two end points. In this figure, we have $\lambda_{12} = \lambda_2 - \lambda_1$.

A geodesic can be extended indefinitely by requiring that any sufficiently small segment is a shortest path; geodesics are also the straightest curves on the surface.

9.2 Solution of geodesic problems

Traditionally two geodesic problems are considered:

- the direct problem — given ϕ_1, λ_1, α_1, s_{12}, determine ϕ_2, λ_2, α_2.
- the inverse problem — given ϕ_1, λ_1, ϕ_2, λ_2, determine s_{12}, α_1, α_2.

PROJ incorporates C library for Geodesics from GeographicLib. This library provides routines to solve the direct and inverse geodesic problems. Full double precision accuracy is maintained provided that $|f| < \frac{1}{50}$. Refer to the application programming interface for full documentation. A brief summary of the routines is given in geodesic(3).

The interface to the geodesic routines differ in two respects from the rest of PROJ:

- angles (latitudes, longitudes, and azimuths) are in degrees (instead of in radians);
- the shape of ellipsoid is specified by the flattening f; this can be negative to denote a prolate ellipsoid; setting $f = 0$ corresponds to a sphere, in which case the geodesic becomes a great circle.

PROJ also includes a command line tool, *geod*(1), for performing simple geodesic calculations.

9.3 Additional properties

The routines also calculate several other quantities of interest

- S_{12} is the area between the geodesic from point 1 to point 2 and the equator; i.e., it is the area, measured counter-clockwise, of the quadrilateral with corners (ϕ_1, λ_1), $(0, \lambda_1)$, $(0, \lambda_2)$, and (ϕ_2, λ_2). It is given in meters^2.
- m_{12}, the reduced length of the geodesic is defined such that if the initial azimuth is perturbed by $d\alpha_1$ (radians) then the second point is displaced by $m_{12}\, d\alpha_1$ in the direction perpendicular to the geodesic. m_{12} is given in meters. On a curved surface the reduced length obeys a symmetry relation, $m_{12} + m_{21} = 0$. On a flat surface, we have $m_{12} = s_{12}$.
- M_{12} and M_{21} are geodesic scales. If two geodesics are parallel at point 1 and separated by a small distance dt, then they are separated by a distance $M_{12}\, dt$ at point 2. M_{21} is defined similarly (with the geodesics being parallel to one another at point 2). M_{12} and M_{21} are dimensionless quantities. On a flat surface, we have $M_{12} = M_{21} = 1$.
- σ_{12} is the arc length on the auxiliary sphere. This is a construct for converting the problem to one in spherical trigonometry. The spherical arc length from one equator crossing to the next is always $180°$.

If points 1, 2, and 3 lie on a single geodesic, then the following addition rules hold:

- $s_{13} = s_{12} + s_{23}$,
- $\sigma_{13} = \sigma_{12} + \sigma_{23}$,
- $S_{13} = S_{12} + S_{23}$,
- $m_{13} = m_{12} M_{23} + m_{23} M_{21}$,
- $M_{13} = M_{12} M_{23} - (1 - M_{12} M_{21}) m_{23}/m_{12}$,
- $M_{31} = M_{32} M_{21} - (1 - M_{23} M_{32}) m_{12}/m_{23}$.

9.4 Multiple shortest geodesics

The shortest distance found by solving the inverse problem is (obviously) uniquely defined. However, in a few special cases there are multiple azimuths which yield the same shortest distance. Here is a catalog of those cases:

- $\phi_1 = -\phi_2$ (with neither point at a pole). If $\alpha_1 = \alpha_2$, the geodesic is unique. Otherwise there are two geodesics and the second one is obtained by setting $[\alpha_1, \alpha_2] \leftarrow [\alpha_2, \alpha_1]$, $[M_{12}, M_{21}] \leftarrow [M_{21}, M_{12}]$, $S_{12} \leftarrow -S_{12}$. (This occurs when the longitude difference is near $\pm 180°$ for oblate ellipsoids.)
- $\lambda_2 = \lambda_1 \pm 180°$ (with neither point at a pole). If $\alpha_1 = 0°$ or $\pm 180°$, the geodesic is unique. Otherwise there are two geodesics and the second one is obtained by setting $[\alpha_1, \alpha_2] \leftarrow [-\alpha_1, -\alpha_2]$, $S_{12} \leftarrow -S_{12}$. (This occurs when ϕ_2 is near $-\phi_1$ for prolate ellipsoids.)
- Points 1 and 2 at opposite poles. There are infinitely many geodesics which can be generated by setting $[\alpha_1, \alpha_2] \leftarrow [\alpha_1, \alpha_2] + [\delta, -\delta]$, for arbitrary δ. (For spheres, this prescription applies when points 1 and 2 are antipodal.)
- $s_{12} = 0$ (coincident points). There are infinitely many geodesics which can be generated by setting $[\alpha_1, \alpha_2] \leftarrow [\alpha_1, \alpha_2] + [\delta, \delta]$, for arbitrary δ.

9.5 Background

The algorithms implemented by this package are given in [Karney2013] (addenda) and are based on [Bessel1825] and [Helmert1880]; the algorithm for areas is based on [Danielsen1989]. These improve on the work of [Vincenty1975] in the following respects:

- The results are accurate to round-off for terrestrial ellipsoids (the error in the distance is less than 15 nanometers, compared to 0.1 mm for Vincenty).
- The solution of the inverse problem is always found. (Vincenty's method fails to converge for nearly antipodal points.)
- The routines calculate differential and integral properties of a geodesic. This allows, for example, the area of a geodesic polygon to be computed.

Additional background material is provided in GeographicLib's geodesic bibliography, Wikipedia's article "Geodesics on an ellipsoid", and [Karney2011] (errata).

CHAPTER

TEN

DEVELOPMENT

These pages are primarily focused towards developers either contributing to the PROJ project or using the library in their own software.

10.1 Quick start

This is a short introduction to the PROJ API. In the following section we create a simple program that transforms a geodetic coordinate to UTM and back again. The program is explained a few lines at a time. The complete program can be seen at the end of the section.

See the following sections for more in-depth descriptions of different parts of the PROJ API or consult the *API reference* for specifics.

Before the PROJ API can be used it is necessary to include the `proj.h` header file. Here `stdio.h` is also included so we can print some text to the screen:

```
#include <stdio.h>
#include <proj.h>
```

Let's declare a few variables that'll be used later in the program. Each variable will be discussed below. See the *reference for more info on data types*.

```
PJ_CONTEXT *C;
PJ *P;
PJ* P_for_GIS;
PJ_COORD a, b;
```

For use in multi-threaded programs the `PJ_CONTEXT` threading-context is used. In this particular example it is not needed, but for the sake of completeness it created here. The section on *threads* discusses this in detail.

```
C = proj_context_create();
```

Next we create the `PJ` transformation object `P` with the function `proj_create_crs_to_crs()`. `proj_create_crs_to_crs()` takes the threading context `C` created above, a string that describes the source coordinate reference system (CRS), a string that describes the target CRS and an optional description of the area of use. The strings for the source or target CRS may be PROJ strings (`+proj=longlat +datum=WGS84`), CRS identified by their code (`EPSG:4326` or `urn:ogc:def:crs:EPSG::4326`) or by a well-known text (WKT) string:

```
GEOGCRS["WGS 84",
    DATUM["World Geodetic System 1984",
        ELLIPSOID["WGS 84",6378137,298.257223563,
```

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```
            LENGTHUNIT["metre",1]]],
    PRIMEM["Greenwich",0,
        ANGLEUNIT["degree",0.0174532925199433]],
    CS[ellipsoidal,2],
        AXIS["geodetic latitude (Lat)",north,
            ORDER[1],
            ANGLEUNIT["degree",0.0174532925199433]],
        AXIS["geodetic longitude (Lon)",east,
            ORDER[2],
            ANGLEUNIT["degree",0.0174532925199433]],
    USAGE[
        SCOPE["unknown"],
        AREA["World"],
        BBOX[-90,-180,90,180]],
    ID["EPSG",4326]]
```

The use of PROJ strings to describe a CRS is considered as legacy (one of the main weakness of PROJ strings is their inability to describe a geodetic datum, other than the few ones hardcoded in the `+datum` parameter). Here we transform from geographic coordinates to UTM zone 32N. It is recommended to create one threading-context per thread used by the program. This ensures that all *PJ* objects created in the same context will be sharing resources such as error-numbers and loaded grids. In case the creation of the *PJ* object fails an error message is displayed and the program returns. See *Error handling* for further details.

```
P = proj_create_crs_to_crs (C,
                            "EPSG:4326",
                            "+proj=utm +zone=32 +datum=WGS84", /* or EPSG:32632 */
                            NULL);

if (0==P) {
    fprintf(stderr, "Oops\n");
    return 1;
}
```

proj_create_crs_to_crs() creates a transformation object, which accepts coordinates expressed in the units and axis order of the definition of the source CRS, and return transformed coordinates in the units and axis order of the definition of the target CRS. For almost most geographic CRS, the units will be in most cases degrees (in rare cases, such as EPSG:4807 / NTF (Paris), this can be grads). For geographic CRS defined by the EPSG authority, the order of coordinates is latitude first, longitude second. When using a PROJ string, on contrary the order will be longitude first, latitude second. For projected CRS, the units may vary (metre, us-foot, etc..). For projected CRS defined by the EPSG authority, and with EAST / NORTH directions, the order might be easting first, northing second, or the reverse. When using a PROJ string, the order will be easting first, northing second, except if the `+axis` parameter modifies it.

If for the needs of your software, you want a uniform axis order (and thus do not care about axis order mandated by the authority defining the CRS), the `proj_normalize_for_visualization()` function can be used to modify the PJ* object returned by *proj_create_crs_to_crs()* so that it accepts as input and returns as output coordinates using the traditional GIS order, that is longitude, latitude (followed by elevation, time) for geographic CRS and easting, northing for most projected CRS.

```
P_for_GIS = proj_normalize_for_visualization(C, P);
if( 0 == P_for_GIS )  {
    fprintf(stderr, "Oops\n");
    return 1;
}
```

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```
proj_destroy(P);
P = P_for_GIS;
```

PROJ uses its own data structures for handling coordinates. Here we use a *PJ_COORD* which is easily assigned with the function *proj_coord()*. When using `+proj=longlat`, the order of coordinates is longitude, latitude, and values are expressed in degrees. If you used instead a EPSG geographic CRS, like EPSG:4326 (WGS84), it would be latitude, longitude.

```
a = proj_coord (12, 55, 0, 0);
```

The coordinate defined above is transformed with *proj_trans()*. For this a *PJ* object, a transformation direction (either forward or inverse) and the coordinate is needed. The transformed coordinate is returned in `b`. Here the forward (`PJ_FWD`) transformation from geographic to UTM is made.

```
b = proj_trans (P, PJ_FWD, a);
printf ("easting: %.3f, northing: %.3f\n", b.enu.e, b.enu.n);
```

The inverse transformation (UTM to geographic) is done similar to above, this time using `PJ_INV` as the direction.

```
b = proj_trans (P, PJ_INV, b);
printf ("longitude: %g, latitude: %g\n", b.lp.lam, b.lp.phi);
```

Before ending the program the allocated memory needs to be released again:

```
proj_destroy (P);
proj_context_destroy (C); /* may be omitted in the single threaded case */
```

A complete compilable version of the above can be seen here:

```
#include <stdio.h>
#include <proj.h>

int main (void) {
    PJ_CONTEXT *C;
    PJ *P;
    PJ* P_for_GIS;
    PJ_COORD a, b;

    /* or you may set C=PJ_DEFAULT_CTX if you are sure you will     */
    /* use PJ objects from only one thread                          */
    C = proj_context_create();

    P = proj_create_crs_to_crs (C,
                                "EPSG:4326",
                                "+proj=utm +zone=32 +datum=WGS84", /* or EPSG:32632 */
                                NULL);

    if (0==P) {
        fprintf(stderr, "Oops\n");
        return 1;
    }

    /* This will ensure that the order of coordinates for the input CRS */
```

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```
    /* will be longitude, latitude, whereas EPSG:4326 mandates latitude, */
    /* longitude */
    P_for_GIS = proj_normalize_for_visualization(C, P);
    if( 0 == P_for_GIS )  {
        fprintf(stderr, "Oops\n");
        return 1;
    }
    proj_destroy(P);
    P = P_for_GIS;

    /* a coordinate union representing Copenhagen: 55d N, 12d E    */
    /* Given that we have used proj_normalize_for_visualization(), the order of
    /* coordinates is longitude, latitude, and values are expressed in degrees. */
    a = proj_coord (12, 55, 0, 0);

    /* transform to UTM zone 32, then back to geographical */
    b = proj_trans (P, PJ_FWD, a);
    printf ("easting: %.3f, northing: %.3f\n", b.enu.e, b.enu.n);
    b = proj_trans (P, PJ_INV, b);
    printf ("longitude: %g, latitude: %g\n", b.lp.lam, b.lp.phi);

    /* Clean up */
    proj_destroy (P);
    proj_context_destroy (C); /* may be omitted in the single threaded case */
    return 0;
}
```

10.2 Transformations

10.3 Error handling

10.4 Threads

This page is about efforts to make PROJ thread safe.

10.4.1 Key Thread Safety Issues

- the global pj_errno variable is shared between threads and makes it essentially impossible to handle errors safely. Being addressed with the introduction of the projCtx execution context.
- the datum shift using grid files uses globally shared lists of loaded grid information. Access to this has been made safe in 4.7.0 with the introduction of a PROJ mutex used to protect access to these memory structures (see pj_mutex.c).

10.4.2 projCtx

Primarily in order to avoid having pj_errno as a global variable, a "thread context" structure has been introduced into a variation of the PROJ API for the 4.8.0 release. The pj_init() and pj_init_plus() functions now have context variations called pj_init_ctx() and pj_init_plus_ctx() which take a projections context.

The projections context can be created with pj_ctx_alloc(), and there is a global default context used when one is not provided by the application. There is a pj_ctx_ set of functions to create, manipulate, query, and destroy contexts. The contexts are also used now to handle setting debugging mode, and to hold an error reporting function for textual error and debug messages. The API looks like:

```
projPJ pj_init_ctx( projCtx, int, char ** );
projPJ pj_init_plus_ctx( projCtx, const char * );

projCtx pj_get_default_ctx(void);
projCtx pj_get_ctx( projPJ );
void pj_set_ctx( projPJ, projCtx );
projCtx pj_ctx_alloc(void);
void    pj_ctx_free( projCtx );
int pj_ctx_get_errno( projCtx );
void pj_ctx_set_errno( projCtx, int );
void pj_ctx_set_debug( projCtx, int );
void pj_ctx_set_logger( projCtx, void (*)(void *, int, const char *) );
void pj_ctx_set_app_data( projCtx, void * );
void *pj_ctx_get_app_data( projCtx );
```

Multithreaded applications are now expected to create a projCtx per thread using pj_ctx_alloc(). The context's error handlers, and app data may be modified if desired, but at the very least each context has an internal error value accessed with pj_ctx_get_errno() as opposed to looking at pj_errno.

Note that pj_errno continues to exist, and it is set by pj_ctx_set_errno() (as well as setting the context specific error number), but pj_errno still suffers from the global shared problem between threads and should not be used by multithreaded applications.

Note that pj_init_ctx(), and pj_init_plus_ctx() will assign the projCtx to the created projPJ object. Functions like pj_transform(), pj_fwd() and pj_inv() will use the context of the projPJ for error reporting.

10.4.3 src/multistresstest.c

A small multi-threaded test program has been written (src/multistresstest.c) for testing multithreaded use of PROJ. It performs a series of reprojections to setup a table expected results, and then it does them many times in several threads to confirm that the results are consistent. At this time this program is not part of the builds but it can be built on linux like:

```
gcc -g multistresstest.c .libs/libproj.so -lpthread -o multistresstest
./multistresstest
```

10.5 Reference

10.5.1 Macros

PROJ_VERSION_MAJOR

Major version number, e.g. 8 for PROJ 8.0.1

PROJ_VERSION_MINOR

Minor version number, e.g. 0 for PROJ 8.0.1

PROJ_VERSION_PATCH

Patch version number, e.g. 1 for PROJ 8.0.1

PROJ_COMPUTE_VERSION(maj, min, patch)

New in version 8.0.1.

Compute the version number from the major, minor and patch numbers.

PROJ_VERSION_NUMBER

New in version 8.0.1.

Total version number, equal to `PROJ_COMPUTE_VERSION(PROJ_VERSION_MAJOR, PROJ_VERSION_MINOR, PROJ_VERSION_PATCH)`

PROJ_AT_LEAST_VERSION(maj, min, patch)

New in version 8.0.1.

Macro that returns true if the current PROJ version is at least the version specified by (maj,min,patch)

Equivalent to `PROJ_VERSION_NUMBER >= PROJ_COMPUTE_VERSION(maj,min,patch)`

10.5.2 Data types

This section describes the numerous data types in use in PROJ.4. As a rule of thumb PROJ.4 data types are prefixed with `PJ_`, or in one particular case, is simply called *PJ*. A few notable exceptions can be traced back to the very early days of PROJ.4 when the `PJ_` prefix was not consistently used.

10.5.2.1 Transformation objects

type **PJ**

Object containing everything related to a given projection or transformation. As a user of the PROJ.4 library you are only exposed to pointers to this object and the contents is hidden behind the public API. *PJ* objects are created with *proj_create()* and destroyed with *proj_destroy()*.

type **PJ_DIRECTION**

Enumeration that is used to convey in which direction a given transformation should be performed. Used in transformation function call as described in the section on *transformation functions*.

Forward transformations are defined with the :c:

```
typedef enum proj_direction {
    PJ_FWD   =  1,   /* Forward    */
    PJ_IDENT =  0,   /* Do nothing */
    PJ_INV   = -1    /* Inverse    */
} PJ_DIRECTION;
```

enumerator **PJ_FWD**

Perform transformation in the forward direction.

enumerator **PJ_IDENT**

Identity. Do nothing.

enumerator **PJ_INV**

Perform transformation in the inverse direction.

type **PJ_CONTEXT**

Context objects enable safe multi-threaded usage of PROJ.4. Each *PJ* object is connected to a context (if not specified, the default context is used). All operations within a context should be performed in the same thread. *PJ_CONTEXT* objects are created with *proj_context_create()* and destroyed with *proj_context_destroy()*.

type **PJ_AREA**

New in version 6.0.0.

Opaque object describing an area in which a transformation is performed.

It is used with *proj_create_crs_to_crs()* to select the best transformation between the two input coordinate reference systems.

10.5.2.2 2 dimensional coordinates

Various 2-dimensional coordinate data types.

type **PJ_LP**

Geodetic coordinate, latitude and longitude. Usually in radians.

```
typedef struct { double lam, phi; } PJ_LP;
```

double PJ_LP.**lam**

Longitude. Lambda.

double PJ_LP.**phi**

Latitude. Phi.

type **PJ_XY**

2-dimensional cartesian coordinate.

```
typedef struct { double x, y; } PJ_XY;
```

double PJ_XY.**x**

Easting.

double PJ_XY.**y**

Northing.

type **PJ_UV**

2-dimensional generic coordinate. Usually used when contents can be either a *PJ_XY* or *PJ_LP*.

```
typedef struct {double u, v; } PJ_UV;
```

double PJ_UV.**u**

Longitude or easting, depending on use.

double PJ_UV.**v**

Latitude or northing, depending on use.

10.5.2.3 3 dimensional coordinates

The following data types are the 3-dimensional equivalents to the data types above.

type **PJ_LPZ**

3-dimensional version of *PJ_LP*. Holds longitude, latitude and a vertical component.

```
typedef struct { double lam, phi, z; } PJ_LPZ;
```

double PJ_LPZ.**lam**

Longitude. Lambda.

double PJ_LPZ.**phi**

Latitude. Phi.

double PJ_LPZ.**z**

Vertical component.

type **PJ_XYZ**

Cartesian coordinate in 3 dimensions. Extension of *PJ_XY*.

```
typedef struct { double x, y, z; } PJ_XYZ;
```

double PJ_XYZ.**x**

Easting or the X component of a 3D cartesian system.

double PJ_XYZ.**y**

Northing or the Y component of a 3D cartesian system.

double PJ_XYZ.**z**

Vertical component or the Z component of a 3D cartesian system.

type **PJ_UVW**

3-dimensional extension of *PJ_UV*.

```
typedef struct {double u, v, w; } PJ_UVW;
```

double PJ_UVW.**u**

Longitude or easting, depending on use.

double PJ_UVW.**v**

Latitude or northing, depending on use.

double PJ_UVW.**w**

Vertical component.

10.5.2.4 Spatiotemporal coordinate types

The following data types are extensions of the triplets above into the time domain.

type **PJ_LPZT**

Spatiotemporal version of *PJ_LPZ*.

```
typedef struct {
    double lam;
    double phi;
    double z;
    double t;
} PJ_LPZT;
```

double PJ_LPZT.**lam**

Longitude.

double PJ_LPZT.**phi**

Latitude

double PJ_LPZT.**z**

Vertical component.

double PJ_LPZT.**t**

Time component.

type **PJ_XYZT**

Generic spatiotemporal coordinate. Useful for e.g. cartesian coordinates with an attached time-stamp.

```
typedef struct {
    double x;
    double y;
    double z;
    double t;
} PJ_XYZT;
```

double PJ_XYZT.**x**

Easting or the X component of a 3D cartesian system.

double PJ_XYZT.**y**

Northing or the Y component of a 3D cartesian system.

double PJ_XYZT.**z**

Vertical or the Z component of a 3D cartesian system.

double PJ_XYZT.**t**

Time component.

type **PJ_UVWT**

Spatiotemporal version of *PJ_UVW*.

```
typedef struct { double u, v, w, t; } PJ_UVWT;
```

double PJ_UVWT.**e**

First horizontal component.

double PJ_UVWT.**n**

Second horizontal component.

double PJ_UVWT.**w**

Vertical component.

double PJ_UVWT.**t**

Temporal component.

10.5.2.5 Ancillary types for geodetic computations

type **PJ_OPK**

Rotations, for instance three euler angles.

```
typedef struct { double o, p, k; } PJ_OPK;
```

double PJ_OPK.**o**

First rotation angle, omega.

double PJ_OPK.**p**

Second rotation angle, phi.

double PJ_OPK.**k**

Third rotation angle, kappa.

type **PJ_ENU**

East, north and up components.

```
typedef struct { double e, n, u; }          PJ_ENU;
```

double PJ_ENU.**e**

East component.

double PJ_ENU.**n**

North component.

double PJ_ENU.**u**

Up component.

type **PJ_GEOD**

Geodesic length, forward and reverse azimuths.

```
typedef struct { double s, a1, a2; }        PJ_GEOD;
```

double PJ_GEOD.**s**

Geodesic length.

double PJ_GEOD.**a1**

Forward azimuth.

double PJ_GEOD.**a2**

Reverse azimuth.

10.5.2.6 Complex coordinate types

type **PJ_COORD**

General purpose coordinate union type, applicable in two, three and four dimensions. This is the default coordinate datatype used in PROJ.

```
typedef union {
    double v[4];
    PJ_XYZT xyzt;
    PJ_UVWT uvwt;
    PJ_LPZT lpzt;
    PJ_GEOD geod;
    PJ_OPK opk;
    PJ_ENU enu;
    PJ_XYZ  xyz;
    PJ_UVW  uvw;
    PJ_LPZ  lpz;
    PJ_XY   xy;
    PJ_UV   uv;
    PJ_LP   lp;
} PJ_COORD ;
```

double **v**[4]

Generic four-dimensional vector.

PJ_XYZT PJ_COORD.**xyzt**

Spatiotemporal cartesian coordinate.

PJ_UVWT PJ_COORD.**uvwt**

Spatiotemporal generic coordinate.

PJ_LPZT PJ_COORD.**lpzt**

Longitude, latitude, vertical and time components.

PJ_GEOD PJ_COORD.**geod**

Geodesic length, forward and reverse azimuths.

PJ_OPK PJ_COORD.**opk**

Rotations, for instance three euler angles.

PJ_ENU PJ_COORD.**enu**

East, north and up components.

PJ_XYZ PJ_COORD.**xyz**

3-dimensional cartesian coordinate.

PJ_UVW PJ_COORD.**uvw**

3-dimensional generic coordinate.

PJ_LPZ PJ_COORD.**lpz**

Longitude, latitude and vertical component.

PJ_XY PJ_COORD.**xy**

2-dimensional cartesian coordinate.

PJ_UV PJ_COORD.**uv**

2-dimensional generic coordinate.

PJ_LP PJ_COORD.**lp**

Longitude and latitude.

10.5.2.7 Projection derivatives

type **PJ_FACTORS**

Various cartographic properties, such as scale factors, angular distortion and meridian convergence. Calculated with *proj_factors()*.

```
typedef struct {
    double meridional_scale;
    double parallel_scale;
    double areal_scale;

    double angular_distortion;
    double meridian_parallel_angle;
    double meridian_convergence;

    double tissot_semimajor;
    double tissot_semiminor;

    double dx_dlam;
    double dx_dphi;
    double dy_dlam;
    double dy_dphi;
} PJ_FACTORS;
```

double PJ_FACTORS.**meridional_scale**

Meridional scale at coordinate (λ, ϕ).

double PJ_FACTORS.**parallel_scale**

Parallel scale at coordinate (λ, ϕ).

double PJ_FACTORS.**areal_scale**

Areal scale factor at coordinate (λ, ϕ).

double PJ_FACTORS.**angular_distortion**

Angular distortion at coordinate (λ, ϕ).

double PJ_FACTORS.**meridian_parallel_angle**

Meridian/parallel angle, θ', at coordinate (λ, ϕ).

double PJ_FACTORS.**meridian_convergence**

Meridian convergence at coordinate (λ, ϕ). Sometimes also described as *grid declination*.

double PJ_FACTORS.**tissot_semimajor**

Maximum scale factor.

double PJ_FACTORS.**tissot_semiminor**

Minimum scale factor.

double PJ_FACTORS.**dx_dlam**

Partial derivative $\frac{\partial x}{\partial \lambda}$ of coordinate (λ, ϕ).

double PJ_FACTORS.**dy_dlam**

Partial derivative $\frac{\partial y}{\partial \lambda}$ of coordinate (λ, ϕ).

double PJ_FACTORS.**dx_dphi**

Partial derivative $\frac{\partial x}{\partial \phi}$ of coordinate (λ, ϕ).

double PJ_FACTORS.**dy_dphi**

Partial derivative $\frac{\partial y}{\partial \phi}$ of coordinate (λ, ϕ).

10.5.2.8 List structures

type **PJ_OPERATIONS**

Description a PROJ.4 operation

```
struct PJ_OPERATIONS {
    const char  *id;            /* operation keyword */
    PJ *(*proj)(PJ *);          /* operation  entry point */
    char    * const *descr;     /* description text */
};
```

const char ***id**

Operation keyword.

PJ *(***op**)(*PJ**)

Operation entry point.

char *const ***descr**

Description of operation.

type **PJ_ELLPS**

Description of ellipsoids defined in PROJ.4

```
struct PJ_ELLPS {
    const char  *id;
    const char  *major;
    const char  *ell;
    const char  *name;
};
```

const char ***id**

Keyword name of the ellipsoid.

const char ***major**

Semi-major axis of the ellipsoid, or radius in case of a sphere.

const char ***ell**

Elliptical parameter, e.g. `rf=298.257` or `b=6356772.2`.

const char ***name**

Name of the ellipsoid

type **PJ_UNITS**

Distance units defined in PROJ.

```
struct PJ_UNITS {
    const char  *id;        /* units keyword */
    const char  *to_meter;  /* multiply by value to get meters */
    const char  *name;      /* comments */
    double      factor;     /* to_meter factor in actual numbers */
};
```

const char ***id**

Keyword for the unit.

const char ***to_meter**

Text representation of the factor that converts a given unit to meters

const char ***name**

Name of the unit.

double **factor**

Conversion factor that converts the unit to meters.

type **PJ_PRIME_MERIDIANS**

Prime meridians defined in PROJ.

```
struct PJ_PRIME_MERIDIANS {
    const char  *id;
    const char  *defn;
};
```

const char ***id**

Keyword for the prime meridian

const char ***def**

Offset from Greenwich in DMS format.

10.5.2.9 Info structures

type **PJ_INFO**

Struct holding information about the current instance of PROJ. Struct is populated by *proj_info()*.

```
typedef struct {
    int           major;
    int           minor;
    int           patch;
    const char   *release;
    const char   *version;
    const char   *searchpath;
} PJ_INFO;
```

const char *PJ_INFO.**release**

Release info. Version number and release date, e.g. “Rel. 4.9.3, 15 August 2016”.

const char *`PJ_INFO.version`

Text representation of the full version number, e.g. "4.9.3".

int `PJ_INFO.major`

Major version number.

int `PJ_INFO.minor`

Minor version number.

int `PJ_INFO.patch`

Patch level of release.

const char `PJ_INFO.searchpath`

Search path for PROJ. List of directories separated by semicolons (Windows) or colons (non-Windows), e.g. `C:\\Users\\doctorwho;C:\\OSGeo4W64\\share\\proj`. Grids and *init files* are looked for in directories in the search path.

type **PJ_PROJ_INFO**

Struct holding information about a *PJ* object. Populated by *proj_pj_info()*. The *PJ_PROJ_INFO* object provides a view into the internals of a *PJ*, so once the *PJ* is destroyed or otherwise becomes invalid, so does the *PJ_PROJ_INFO*

```
typedef struct {
    const char  *id;
    const char  *description;
    const char  *definition;
    int          has_inverse;
    double       accuracy;
} PJ_PROJ_INFO;
```

const char *`PJ_PROJ_INFO.id`

Short ID of the operation the *PJ* object is based on, that is, what comes after the `+proj=` in a proj-string, e.g. "*merc*".

const char *`PJ_PROJ_INFO.description`

Long describes of the operation the *PJ* object is based on, e.g. "*Mercator Cyl, Sph&Ell lat_ts=*".

const char *`PJ_PROJ_INFO.definition`

The proj-string that was used to create the *PJ* object with, e.g. "*+proj=merc +lat_0=24 +lon_0=53 +ellps=WGS84*".

int `PJ_PROJ_INFO.has_inverse`

1 if an inverse mapping of the defined operation exists, otherwise 0.

double `PJ_PROJ_INFO.accuracy`

Expected accuracy of the transformation. -1 if unknown.

type **PJ_GRID_INFO**

Struct holding information about a specific grid in the search path of PROJ. Populated with the function *proj_grid_info()*.

```
typedef struct {
    char        gridname[32];
    char        filename[260];
    char        format[8];
    LP          lowerleft;
```

(continues on next page)

(continued from previous page)

```
    LP          upperright;
    int         n_lon, n_lat;
    double      cs_lon, cs_lat;
} PJ_GRID_INFO;
```

char *PJ_GRID_INFO*.**gridname**[32]

Name of grid, e.g. "*BETA2007.gsb*".

char **PJ_GRID_INFO**

Full path of grid file, e.g. *"C:\OSGeo4W64\share\proj\BETA2007.gsb"*

char *PJ_GRID_INFO*.**format**[8]

File format of grid file, e.g. "*ntv2*"

LP *PJ_GRID_INFO*.**lowerleft**

Geodetic coordinate of lower left corner of grid.

LP *PJ_GRID_INFO*.**upperright**

Geodetic coordinate of upper right corner of grid.

int *PJ_GRID_INFO*.**n_lon**

Number of grid cells in the longitudinal direction.

int *PJ_GRID_INFO*.**n_lat**

Number of grid cells in the latitudinal direction.

double *PJ_GRID_INFO*.**cs_lon**

Cell size in the longitudinal direction. In radians.

double *PJ_GRID_INFO*.**cs_lat**

Cell size in the latitudinal direction. In radians.

type **PJ_INIT_INFO**

Struct holding information about a specific init file in the search path of PROJ. Populated with the function *proj_init_info()*.

```
typedef struct {
    char        name[32];
    char        filename[260];
    char        version[32];
    char        origin[32];
    char        lastupdate[16];
} PJ_INIT_INFO;
```

char PJ_INIT_INFO.**name**[32]

Name of init file, e.g. "*epsg*".

char PJ_INIT_INFO.**filename**[260]

Full path of init file, e.g. "*C:\OSGeo4W64\share\proj\epsg*"

char PJ_INIT_INFO.**version**[32]

Version number of init file, e.g. "*9.0.0*"

char PJ_INIT_INFO.**origin**[32]

Originating entity of the init file, e.g. "*EPSG*" char PJ_INIT_INFO.**lastupdate**

Date of last update of the init file.

10.5.2.10 Error codes

New in version 8.0.0.

Three classes of errors are defined below. The belonging of a given error code to a class can bit tested with a binary and test. The error class itself can be used as an error value in some rare cases where the error does not fit into a more precise error value.

Those error codes are still quite generic for a number of them. Details on the actual errors will be typically logged with the PJ_LOG_ERROR level.

Errors in class PROJ_ERR_INVALID_OP

PROJ_ERR_INVALID_OP

Class of error codes typically related to coordinate operation initialization, typically when creating a PJ* object from a PROJ string.

Note: some of them can also be emitted during coordinate transformation, like PROJ_ERR_INVALID_OP_FILE_NOT_FOUND_OR_INVALID in case the resource loading is deferred until it is really needed.

PROJ_ERR_INVALID_OP_WRONG_SYNTAX

Invalid pipeline structure, missing +proj argument, etc.

PROJ_ERR_INVALID_OP_MISSING_ARG

Missing required operation parameter

PROJ_ERR_INVALID_OP_ILLEGAL_ARG_VALUE

One of the operation parameter has an illegal value.

PROJ_ERR_INVALID_OP_MUTUALLY_EXCLUSIVE_ARGS

Mutually exclusive arguments

PROJ_ERR_INVALID_OP_FILE_NOT_FOUND_OR_INVALID

File not found or with invalid content (particular case of PROJ_ERR_INVALID_OP_ILLEGAL_ARG_VALUE)

Errors in class PROJ_ERR_COORD_TRANSFM

PROJ_ERR_COORD_TRANSFM

Class of error codes related to transformation on a specific coordinate.

PROJ_ERR_COORD_TRANSFM_INVALID_COORD

Invalid input coordinate. e.g. a latitude > 90°.

PROJ_ERR_COORD_TRANSFM_OUTSIDE_PROJECTION_DOMAIN

Coordinate is outside of the projection domain. e.g. approximate mercator with |longitude - lon_0| > 90°, or iterative convergence method failed.

PROJ_ERR_COORD_TRANSFM_NO_OPERATION
No operation found, e.g. if no match the required accuracy, or if ballpark transformations were asked to not be used and they would be only such candidate.

PROJ_ERR_COORD_TRANSFM_OUTSIDE_GRID
Point to transform falls outside grid/subgrid/TIN.

PROJ_ERR_COORD_TRANSFM_GRID_AT_NODATA
Point to transform falls in a grid cell that evaluates to nodata.

Errors in class PROJ_ERR_OTHER

PROJ_ERR_OTHER
Class of error codes that do not fit into one of the above class.

PROJ_ERR_OTHER_API_MISUSE
Error related to a misuse of PROJ API.

PROJ_ERR_OTHER_NO_INVERSE_OP
No inverse method available

PROJ_ERR_OTHER_NETWORK_ERROR
Failure when accessing a network resource.

10.5.2.11 Logging

type **PJ_LOG_LEVEL**
Enum of logging levels in PROJ. Used to set the logging level in PROJ. Usually using *proj_log_level()*.

enumerator **PJ_LOG_NONE**
Don't log anything.

enumerator **PJ_LOG_ERROR**
Log only errors.

enumerator **PJ_LOG_DEBUG**
Log errors and additional debug information.

enumerator **PJ_LOG_TRACE**
Highest logging level. Log everything including very detailed debug information.

enumerator **PJ_LOG_TELL**
Special logging level that when used in *proj_log_level()* will return the current logging level set in PROJ.

New in version 5.1.0.

type **PJ_LOG_FUNC**
Function prototype for the logging function used by PROJ. Defined as

```
typedef void (*PJ_LOG_FUNCTION)(void *, int, const char *);
```

where the first argument (void pointer) references a data structure used by the calling application, the second argument (int type) is used to set the logging level and the third argument (const char pointer) is the string that will be logged by the function.

New in version 5.1.0.

10.5.2.12 Setting custom I/O functions

New in version 7.0.0.

struct **PROJ_FILE_API**

File API callbacks

Public Members

int **version**

Version of this structure. Should be set to 1 currently.

PROJ_FILE_HANDLE *(***open_cbk**)(PJ_CONTEXT *ctx, const char *filename, *PROJ_OPEN_ACCESS* access, void *user_data)

Open file. Return NULL if error

size_t (***read_cbk**)(PJ_CONTEXT *ctx, *PROJ_FILE_HANDLE**, void *buffer, size_t sizeBytes, void *user_data)

Read sizeBytes into buffer from current position and return number of bytes read

size_t (***write_cbk**)(PJ_CONTEXT *ctx, *PROJ_FILE_HANDLE**, const void *buffer, size_t sizeBytes, void *user_data)

Write sizeBytes into buffer from current position and return number of bytes written

int (***seek_cbk**)(PJ_CONTEXT *ctx, *PROJ_FILE_HANDLE**, long long offset, int whence, void *user_data)

Seek to offset using whence=SEEK_SET/SEEK_CUR/SEEK_END. Return TRUE in case of success

unsigned long long (***tell_cbk**)(PJ_CONTEXT *ctx, *PROJ_FILE_HANDLE**, void *user_data)

Return current file position

void (***close_cbk**)(PJ_CONTEXT *ctx, *PROJ_FILE_HANDLE**, void *user_data)

Close file

int (***exists_cbk**)(PJ_CONTEXT *ctx, const char *filename, void *user_data)

Return TRUE if a file exists

int (***mkdir_cbk**)(PJ_CONTEXT *ctx, const char *filename, void *user_data)

Return TRUE if directory exists or could be created

int (***unlink_cbk**)(PJ_CONTEXT *ctx, const char *filename, void *user_data)

Return TRUE if file could be removed

int (***rename_cbk**)(PJ_CONTEXT *ctx, const char *oldPath, const char *newPath, void *user_data)

Return TRUE if file could be renamed

typedef struct *PROJ_FILE_HANDLE* **PROJ_FILE_HANDLE**

Opaque structure for PROJ for a file handle. Implementations might cast it to their structure/class of choice.

enum **PROJ_OPEN_ACCESS**

Open access / mode

Values:

enumerator **PROJ_OPEN_ACCESS_READ_ONLY**

Read-only access. Equivalent to "rb"

enumerator **PROJ_OPEN_ACCESS_READ_UPDATE**

Read-update access. File should be created if not existing. Equivalent to "r+b"

enumerator **PROJ_OPEN_ACCESS_CREATE**

Create access. File should be truncated to 0-byte if already existing. Equivalent to "w+b"

10.5.2.13 Network related functionality

New in version 7.0.0.

typedef struct *PROJ_NETWORK_HANDLE* **PROJ_NETWORK_HANDLE**

Opaque structure for PROJ for a network handle. Implementations might cast it to their structure/class of choice.

typedef *PROJ_NETWORK_HANDLE* *(***proj_network_open_cbk_type**)(PJ_CONTEXT *ctx, const char *url, unsigned long long offset, size_t size_to_read, void *buffer, size_t *out_size_read, size_t error_string_max_size, char *out_error_string, void *user_data)

Network access: open callback

Should try to read the size_to_read first bytes at the specified offset of the file given by URL url, and write them to buffer. *out_size_read should be updated with the actual amount of bytes read (== size_to_read if the file is larger than size_to_read). During this read, the implementation should make sure to store the HTTP headers from the server response to be able to respond to proj_network_get_header_value_cbk_type callback.

error_string_max_size should be the maximum size that can be written into the out_error_string buffer (including terminating nul character).

Return

a non-NULL opaque handle in case of success.

typedef void (***proj_network_close_cbk_type**)(PJ_CONTEXT *ctx, *PROJ_NETWORK_HANDLE* *handle, void *user_data)

Network access: close callback

typedef const char *(***proj_network_get_header_value_cbk_type**)(PJ_CONTEXT *ctx, *PROJ_NETWORK_HANDLE* *handle, const char *header_name, void *user_data)

Network access: get HTTP headers

typedef size_t (***proj_network_read_range_type**)(PJ_CONTEXT *ctx, *PROJ_NETWORK_HANDLE* *handle, unsigned long long offset, size_t size_to_read, void *buffer, size_t error_string_max_size, char *out_error_string, void *user_data)

Network access: read range

Read size_to_read bytes from handle, starting at offset, into buffer. During this read, the implementation should make sure to store the HTTP headers from the server response to be able to respond to proj_network_get_header_value_cbk_type callback.

error_string_max_size should be the maximum size that can be written into the out_error_string buffer (including terminating nul character).

Return
the number of bytes actually read (0 in case of error)

10.5.2.14 C API for ISO-19111 functionality

enum **PJ_GUESSED_WKT_DIALECT**

Guessed WKT "dialect".

Values:

enumerator **PJ_GUESSED_WKT2_2019**

WKT2:2019

enumerator **PJ_GUESSED_WKT2_2018**

Deprecated alias for PJ_GUESSED_WKT2_2019

enumerator **PJ_GUESSED_WKT2_2015**

WKT2:2015

enumerator **PJ_GUESSED_WKT1_GDAL**

WKT1 specification

enumerator **PJ_GUESSED_WKT1_ESRI**

ESRI variant of WKT1

enumerator **PJ_GUESSED_NOT_WKT**

Not WKT / unrecognized

enum **PJ_CATEGORY**

Object category.

Values:

enumerator **PJ_CATEGORY_ELLIPSOID**

enumerator **PJ_CATEGORY_PRIME_MERIDIAN**

enumerator **PJ_CATEGORY_DATUM**

enumerator **PJ_CATEGORY_CRS**

enumerator **PJ_CATEGORY_COORDINATE_OPERATION**

enumerator **PJ_CATEGORY_DATUM_ENSEMBLE**

enum **PJ_TYPE**

Object type.

Values:

enumerator **PJ_TYPE_UNKNOWN**

enumerator **PJ_TYPE_ELLIPSOID**

enumerator **PJ_TYPE_PRIME_MERIDIAN**

enumerator **PJ_TYPE_GEODETIC_REFERENCE_FRAME**

enumerator **PJ_TYPE_DYNAMIC_GEODETIC_REFERENCE_FRAME**

enumerator **PJ_TYPE_VERTICAL_REFERENCE_FRAME**

enumerator **PJ_TYPE_DYNAMIC_VERTICAL_REFERENCE_FRAME**

enumerator **PJ_TYPE_DATUM_ENSEMBLE**

enumerator **PJ_TYPE_CRS**

Abstract type, not returned by *proj_get_type()*

enumerator **PJ_TYPE_GEODETIC_CRS**

enumerator **PJ_TYPE_GEOCENTRIC_CRS**

enumerator **PJ_TYPE_GEOGRAPHIC_CRS**

proj_get_type() will never return that type, but PJ_TYPE_GEOGRAPHIC_2D_CRS or PJ_TYPE_GEOGRAPHIC_3D_CRS.

enumerator **PJ_TYPE_GEOGRAPHIC_2D_CRS**

enumerator **PJ_TYPE_GEOGRAPHIC_3D_CRS**

enumerator **PJ_TYPE_VERTICAL_CRS**

enumerator **PJ_TYPE_PROJECTED_CRS**

enumerator **PJ_TYPE_COMPOUND_CRS**

enumerator **PJ_TYPE_TEMPORAL_CRS**

enumerator **PJ_TYPE_ENGINEERING_CRS**

enumerator **PJ_TYPE_BOUND_CRS**

enumerator **PJ_TYPE_OTHER_CRS**

enumerator **PJ_TYPE_CONVERSION**

enumerator **PJ_TYPE_TRANSFORMATION**

enumerator **PJ_TYPE_CONCATENATED_OPERATION**

enumerator **PJ_TYPE_OTHER_COORDINATE_OPERATION**

enumerator **PJ_TYPE_TEMPORAL_DATUM**

enumerator **PJ_TYPE_ENGINEERING_DATUM**

enumerator **PJ_TYPE_PARAMETRIC_DATUM**

enum **PJ_COMPARISON_CRITERION**

Comparison criterion.

Values:

enumerator **PJ_COMP_STRICT**

All properties are identical.

enumerator **PJ_COMP_EQUIVALENT**

The objects are equivalent for the purpose of coordinate operations. They can differ by the name of their objects, identifiers, other metadata. Parameters may be expressed in different units, provided that the value is (with some tolerance) the same once expressed in a common unit.

enumerator **PJ_COMP_EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS**

Same as EQUIVALENT, relaxed with an exception that the axis order of the base CRS of a DerivedCRS/ProjectedCRS or the axis order of a GeographicCRS is ignored. Only to be used with DerivedCRS/ProjectedCRS/GeographicCRS enum **PJ_WKT_TYPE**

WKT version.

Values:

enumerator **PJ_WKT2_2015**

cf *osgeo::proj::io::WKTFormatter::Convention::WKT2*

enumerator **PJ_WKT2_2015_SIMPLIFIED**

cf *osgeo::proj::io::WKTFormatter::Convention::WKT2_SIMPLIFIED*

enumerator **PJ_WKT2_2019**

cf *osgeo::proj::io::WKTFormatter::Convention::WKT2_2019*

enumerator **PJ_WKT2_2018**

Deprecated alias for PJ_WKT2_2019

enumerator **PJ_WKT2_2019_SIMPLIFIED**

cf *osgeo::proj::io::WKTFormatter::Convention::WKT2_2019_SIMPLIFIED*

enumerator **PJ_WKT2_2018_SIMPLIFIED**

Deprecated alias for PJ_WKT2_2019

enumerator **PJ_WKT1_GDAL**

cf *osgeo::proj::io::WKTFormatter::Convention::WKT1_GDAL*

enumerator **PJ_WKT1_ESRI**

cf *osgeo::proj::io::WKTFormatter::Convention::WKT1_ESRI*

enum **PROJ_CRS_EXTENT_USE**

Specify how source and target CRS extent should be used to restrict candidate operations (only taken into account if no explicit area of interest is specified.

Values:

enumerator **PJ_CRS_EXTENT_NONE**

Ignore CRS extent

enumerator **PJ_CRS_EXTENT_BOTH**

Test coordinate operation extent against both CRS extent.

enumerator **PJ_CRS_EXTENT_INTERSECTION**

Test coordinate operation extent against the intersection of both CRS extent.

enumerator **PJ_CRS_EXTENT_SMALLEST**

Test coordinate operation against the smallest of both CRS extent.

enum **PROJ_GRID_AVAILABILITY_USE**

Describe how grid availability is used.

Values:

enumerator **PROJ_GRID_AVAILABILITY_USED_FOR_SORTING**

Grid availability is only used for sorting results. Operations where some grids are missing will be sorted last.

enumerator **PROJ_GRID_AVAILABILITY_DISCARD_OPERATION_IF_MISSING_GRID**

Completely discard an operation if a required grid is missing.

enumerator **PROJ_GRID_AVAILABILITY_IGNORED**

Ignore grid availability at all. Results will be presented as if all grids were available.

enumerator **PROJ_GRID_AVAILABILITY_KNOWN_AVAILABLE**

Results will be presented as if grids known to PROJ (that is registered in the grid_alternatives table of its database) were available. Used typically when networking is enabled.

enum **PJ_PROJ_STRING_TYPE**

PROJ string version.

Values:

enumerator **PJ_PROJ_5**

cf *osgeo::proj::io::PROJStringFormatter::Convention::PROJ_5*

enumerator **PJ_PROJ_4**

cf *osgeo::proj::io::PROJStringFormatter::Convention::PROJ_4*

enum **PROJ_SPATIAL_CRITERION**

Spatial criterion to restrict candidate operations.

Values:

enumerator **PROJ_SPATIAL_CRITERION_STRICT_CONTAINMENT**

The area of validity of transforms should strictly contain the are of interest.

enumerator **PROJ_SPATIAL_CRITERION_PARTIAL_INTERSECTION**

The area of validity of transforms should at least intersect the area of interest.

enum **PROJ_INTERMEDIATE_CRS_USE**

Describe if and how intermediate CRS should be used

Values:

enumerator **PROJ_INTERMEDIATE_CRS_USE_ALWAYS**

Always search for intermediate CRS.

enumerator **PROJ_INTERMEDIATE_CRS_USE_IF_NO_DIRECT_TRANSFORMATION**

Only attempt looking for intermediate CRS if there is no direct transformation available.

enumerator **PROJ_INTERMEDIATE_CRS_USE_NEVER**

enum **PJ_COORDINATE_SYSTEM_TYPE**

Type of coordinate system.

Values:

enumerator **PJ_CS_TYPE_UNKNOWN**

enumerator **PJ_CS_TYPE_CARTESIAN**

enumerator **PJ_CS_TYPE_ELLIPSOIDAL**

enumerator **PJ_CS_TYPE_VERTICAL**

enumerator **PJ_CS_TYPE_SPHERICAL**

enumerator **PJ_CS_TYPE_ORDINAL**

enumerator **PJ_CS_TYPE_PARAMETRIC**

enumerator **PJ_CS_TYPE_DATETIMETEMPORAL**

enumerator **PJ_CS_TYPE_TEMPORALCOUNT**

enumerator **PJ_CS_TYPE_TEMPORALMEASURE**

typedef char ****PROJ_STRING_LIST**

Type representing a NULL terminated list of NULL-terminate strings.

struct **PROJ_CRS_INFO**

#include <proj.h> Structure given overall description of a CRS.

This structure may grow over time, and should not be directly allocated by client code.

Public Members

char ***auth_name**

Authority name.

char ***code**

Object code.

char ***name**

Object name.

PJ_TYPE **type**

Object type.

int **deprecated**

Whether the object is deprecated

int **bbox_valid**

Whereas the west_lon_degree, south_lat_degree, east_lon_degree and north_lat_degree fields are valid.

double **west_lon_degree**

Western-most longitude of the area of use, in degrees.

double **south_lat_degree**

Southern-most latitude of the area of use, in degrees.

double **east_lon_degree**

Eastern-most longitude of the area of use, in degrees.

double **north_lat_degree**

Northern-most latitude of the area of use, in degrees.

char ***area_name**

Name of the area of use.

char ***projection_method_name**

Name of the projection method for a projected CRS. Might be NULL even for projected CRS in some cases.

struct **PROJ_CRS_LIST_PARAMETERS**

#include <proj.h> Structure describing optional parameters for proj_get_crs_list();.

This structure may grow over time, and should not be directly allocated by client code.

Public Members

const *PJ_TYPE* ***types***

Array of allowed object types. Should be NULL if all types are allowed

size_t **typesCount**

Size of types. Should be 0 if all types are allowed

int **crs_area_of_use_contains_bbox**

If TRUE and bbox_valid == TRUE, then only CRS whose area of use entirely contains the specified bounding box will be returned. If FALSE and bbox_valid == TRUE, then only CRS whose area of use intersects the specified bounding box will be returned.

int **bbox_valid**

To set to TRUE so that west_lon_degree, south_lat_degree, east_lon_degree and north_lat_degree fields are taken into account.

double **west_lon_degree**

Western-most longitude of the area of use, in degrees.

double **south_lat_degree**

Southern-most latitude of the area of use, in degrees.

double **east_lon_degree**

Eastern-most longitude of the area of use, in degrees.

double **north_lat_degree**

Northern-most latitude of the area of use, in degrees.

int **allow_deprecated**

Whether deprecated objects are allowed. Default to FALSE.

struct **PROJ_UNIT_INFO**

#include <proj.h> Structure given description of a unit.

This structure may grow over time, and should not be directly allocated by client code.

Since

7.1

Public Members

char *`auth_name`

Authority name.

char *`code`

Object code.

char *`name`

Object name. For example "metre", "US survey foot", etc.

char *`category`

Category of the unit: one of "linear", "linear_per_time", "angular", "angular_per_time", "scale", "scale_per_time" or "time"

double `conv_factor`

Conversion factor to apply to transform from that unit to the corresponding SI unit (metre for "linear", radian for "angular", etc.). It might be 0 in some cases to indicate no known conversion factor.

char *`proj_short_name`

PROJ short name, like "m", "ft", "us-ft", etc... Might be NULL

int `deprecated`

Whether the object is deprecated

10.5.3 Functions

10.5.3.1 Threading contexts

PJ_CONTEXT *`proj_context_create`(void)

Create a new threading-context.

Returns

a new context

PJ_CONTEXT *`proj_context_clone`(*PJ_CONTEXT* *ctx)

New in version 7.2.

Create a new threading-context based on an existing context.

Returns

a new context

void `proj_context_destroy`(*PJ_CONTEXT* *ctx)

Deallocate a threading-context.

Parameters

- `ctx` (*PJ_CONTEXT* *) – Threading context.

10.5.3.2 Transformation setup

The objects returned by the functions defined in this section have minimal interaction with the functions of the *C API for ISO-19111 functionality*, and vice versa. See its introduction paragraph for more details.

PJ ***proj_create**(*PJ_CONTEXT* *ctx, const char *definition)

Create a transformation object, or a CRS object, from:

- a proj-string,
- a WKT string,
- an object code (like "EPSG:4326", "urn:ogc:def:crs:EPSG::4326", "urn:ogc:def:coordinateOperation:EPSG::1671"),
- an Object name. e.g "WGS 84", "WGS 84 / UTM zone 31N". In that case as uniqueness is not guaranteed, heuristics are applied to determine the appropriate best match.
- a OGC URN combining references for compound coordinate reference systems (e.g "urn:ogc:def:crs,crs:EPSG::2393,crs:EPSG::5717" or custom abbreviated syntax "EPSG:2393+5717"),
- a OGC URN combining references for concatenated operations (e.g. "urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618")
- a PROJJSON string. The jsonschema is at https://proj.org/schemas/v0.2/projjson.schema.json (*added in 6.2*)
- a compound CRS made from two object names separated with " + ". e.g. "WGS 84 + EGM96 height" (*added in 7.1*)

Example call:

```
PJ *P = proj_create(0, "+proj=etmerc +lat_0=38 +lon_0=125 +ellps=bessel");
```

If a proj-string contains a +type=crs option, then it is interpreted as a CRS definition. In particular geographic CRS are assumed to have axis in the longitude, latitude order and with degree angular unit. The use of proj-string to describe a CRS is discouraged. It is a legacy means of conveying CRS descriptions: use of object codes (EPSG:XXXX typically) or WKT description is recommended for better expressivity.

If a proj-string does not contain +type=crs, then it is interpreted as a coordination operation / transformation.

If creation of the transformation object fails, the function returns *0* and the PROJ error number is updated. The error number can be read with `proj_errno()` or `proj_context_errno()`.

The returned *PJ*-pointer should be deallocated with `proj_destroy()`.

Parameters

- **ctx** (*PJ_CONTEXT* *) – Threading context.
- **definition** (*const char**) – Proj-string of the desired transformation.

PJ ***proj_create_argv**(*PJ_CONTEXT* *ctx, int argc, char **argv)

Create a transformation object, or a CRS object, with argc/argv-style initialization. For this application each parameter in the defining proj-string is an entry in `argv`.

Example call:

```
char *args[3] = {"proj=utm", "zone=32", "ellps=GRS80"};
PJ* P = proj_create_argv(0, 3, args);
```

If there is a type=crs argument, then the arguments are interpreted as a CRS definition. In particular geographic CRS are assumed to have axis in the longitude, latitude order and with degree angular unit.

If there is no type=crs argument, then it is interpreted as a coordination operation / transformation.

If creation of the transformation object fails, the function returns *0* and the PROJ error number is updated. The error number can be read with `proj_errno()` or `proj_context_errno()`.

The returned `PJ`-pointer should be deallocated with `proj_destroy()`.

Parameters

- **ctx** (*PJ_CONTEXT* *) – Threading context.
- **argc** (*int*) – Count of arguments in `argv`
- **argv** (*char* **) – Array of strings with proj-string parameters, e.g. `+proj=merc`

Returns
PJ *

PJ ***proj_create_crs_to_crs**(*PJ_CONTEXT* *ctx, const char *source_crs, const char *target_crs, *PJ_AREA* *area)

Create a transformation object that is a pipeline between two known coordinate reference systems.

source_crs and target_crs can be :

- a "AUTHORITY:CODE", like EPSG:25832. When using that syntax for a source CRS, the created pipeline will expect that the values passed to `proj_trans()` respect the axis order and axis unit of the official definition (so for example, for EPSG:4326, with latitude first and longitude next, in degrees). Similarly, when using that syntax for a target CRS, output values will be emitted according to the official definition of this CRS.
- a PROJ string, like "+proj=longlat +datum=WGS84". When using that syntax, the axis order and unit for geographic CRS will be longitude, latitude, and the unit degrees.
- the name of a CRS as found in the PROJ database, e.g "WGS84", "NAD27", etc.
- more generally any string accepted by `proj_create()` representing a CRS

An "area of use" can be specified in area. When it is supplied, the more accurate transformation between two given systems can be chosen.

When no area of use is specific and several coordinate operations are possible depending on the area of use, this function will internally store those candidate coordinate operations in the return PJ object. Each subsequent coordinate transformation done with `proj_trans()` will then select the appropriate coordinate operation by comparing the input coordinates with the area of use of the candidate coordinate operations.

Example call:

```
PJ *P = proj_create_crs_to_crs(0, "EPSG:25832", "EPSG:25833", 0);
```

If creation of the transformation object fails, the function returns *0* and the PROJ error number is updated. The error number can be read with `proj_errno()` or `proj_context_errno()`.

The returned `PJ`-pointer should be deallocated with `proj_destroy()`.

Parameters

- **ctx** (*PJ_CONTEXT* *) – Threading context.
- **source_crs** (*const char**) – Source CRS.
- **target_crs** (*const char**) – Destination SRS.

- **area** (*PJ_AREA* *) – Descriptor of the desired area for the transformation.

Returns
PJ *

PJ ***proj_create_crs_to_crs_from_pj**(*PJ_CONTEXT* *ctx, *PJ* *source_crs, *PJ* *target_crs, *PJ_AREA* *area, const char *const *options)

New in version 6.2.0.

Create a transformation object that is a pipeline between two known coordinate reference systems.

This is the same as *proj_create_crs_to_crs()* except that the source and target CRS are passed as PJ* objects which must be of the CRS variety.

Parameters

- **options** – a list of NUL terminated options, or NULL.

The list of supported options is:

- AUTHORITY=name: to restrict the authority of coordinate operations looked up in the database. When not specified, coordinate `operations from any authority` will be searched, with the restrictions set in the authority_to_authority_preference database table related to the authority of the source/target CRS themselves. If authority is set to "any", then coordinate operations from any authority will be searched If authority is a non-empty string different of `any`, then coordinate operations will be searched only in that authority namespace (e.g `EPSG`).
- ACCURACY=value: to set the minimum desired accuracy (in metres) of the candidate coordinate operations.
- ALLOW_BALLPARK=YES/NO: can be set to NO to disallow the use of *Ballpark transformation* in the candidate coordinate operations.

PJ ***proj_normalize_for_visualization**(PJ_CONTEXT *ctx, const PJ *obj)

Returns a PJ* object whose axis order is the one expected for visualization purposes.

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The input object must be either:

- a coordinate operation, that has been created with proj_create_crs_to_crs(). If the axis order of its source or target CRS is northing,easting, then an axis swap operation will be inserted.
- or a CRS. The axis order of geographic CRS will be longitude, latitude [,height], and the one of projected CRS will be easting, northing [, height]

Parameters

- **ctx** – PROJ context, or NULL for default context
- **obj** – Object of type CRS, or CoordinateOperation created with proj_create_crs_to_crs() (must not be NULL)

Returns
a new PJ* object to free with proj_destroy() in case of success, or nullptr in case of error

PJ ***proj_destroy**(*PJ* *P)

Deallocate a *PJ* transformation object.

Parameters

- **P** (const *PJ* *) – Transformation object

Returns
PJ *

10.5.3.3 Area of interest

New in version 6.0.0.

PJ_AREA ***proj_area_create***(void)

Create an area of use.

Such an area of use is to be passed to *proj_create_crs_to_crs()* to specify the area of use for the choice of relevant coordinate operations.

Returns
PJ_AREA * to be deallocated with *proj_area_destroy()*

void **proj_area_set_bbox**(*PJ_AREA* *area, double west_lon_degree, double south_lat_degree, double east_lon_degree, double north_lat_degree)

Set the bounding box of the area of use

Such an area of use is to be passed to *proj_create_crs_to_crs()* to specify the area of use for the choice of relevant coordinate operations.

In the case of an area of use crossing the antimeridian (longitude +/- 180 degrees), *west_lon_degree* will be greater than *east_lon_degree*.

Parameters

- **area** – Pointer to an object returned by *proj_area_create()*.
- **west_lon_degree** – West longitude, in degrees. In [-180,180] range.
- **south_lat_degree** – South latitude, in degrees. In [-90,90] range.
- **east_lon_degree** – East longitude, in degrees. In [-180,180] range.
- **north_lat_degree** – North latitude, in degrees. In [-90,90] range.

void **proj_area_destroy**(*PJ_AREA* *area)

Deallocate a *PJ_AREA* object.

:param PJ_AREA* area

10.5.3.4 Coordinate transformation

PJ_COORD **proj_trans**(*PJ* *P, *PJ_DIRECTION* direction, *PJ_COORD* coord)

Transform a single *PJ_COORD* coordinate.

Parameters

- **P** (*PJ* *) – Transformation object
- **direction** (*PJ_DIRECTION*) – Transformation direction.
- **coord** (*PJ_COORD*) – Coordinate that will be transformed.

Returns
PJ_COORD

size_t **proj_trans_generic**(*PJ* *P, *PJ_DIRECTION* direction, double *x, size_t sx, size_t nx, double *y, size_t sy, size_t ny, double *z, size_t sz, size_t nz, double *t, size_t st, size_t nt)

Transform a series of coordinates, where the individual coordinate dimension may be represented by an array that is either

1. fully populated
2. a null pointer and/or a length of zero, which will be treated as a fully populated array of zeroes
3. of length one, i.e. a constant, which will be treated as a fully populated array of that constant value

Note: Even though the coordinate components are named `x`, `y`, `z` and `t`, axis ordering of the to and from CRS is respected. Transformations exhibit the same behavior as if they were gathered in a `PJ_COORD` struct.

The strides, `sx`, `sy`, `sz`, `st`, represent the step length, in bytes, between consecutive elements of the corresponding array. This makes it possible for `proj_trans_generic()` to handle transformation of a large class of application specific data structures, without necessarily understanding the data structure format, as in:

```
typedef struct {
    double x, y;
    int quality_level;
    char surveyor_name[134];
} XYQS;

XYQS survey[345];
double height = 23.45;
size_t stride = sizeof (XYQS);

...

proj_trans_generic (
    P, PJ_INV,
    &(survey[0].x), stride, 345,  /*  We have 345 eastings  */
    &(survey[0].y), stride, 345,  /*  ...and 345 northings. */
    &height, sizeof(double), 1,   /*  The height is the constant  23.45 m */
    0, 0, 0                       /*  and the time is the constant 0.00 s */
);
```

This is similar to the inner workings of the deprecated `pj_transform()` function, but the stride functionality has been generalized to work for any size of basic unit, not just a fixed number of doubles.

In most cases, the stride will be identical for x, y, z, and t, since they will typically be either individual arrays (`stride = sizeof(double)`), or strided views into an array of application specific data structures (`stride = sizeof (...)`).

But in order to support cases where `x`, `y`, `z`, and `t` come from heterogeneous sources, individual strides, `sx`, `sy`, `sz`, `st`, are used.

Note: Since `proj_trans_generic()` does its work *in place*, this means that even the supposedly constants (i.e. length 1 arrays) will return from the call in altered state. Hence, remember to reinitialize between repeated calls.

Parameters

- **P** (*PJ* *) – Transformation object
- **direction** (*PJ_DIRECTION*) – Transformation direction.
- **x** (*double* *) – Array of x-coordinates
- **sx** (*size_t*) – Step length, in bytes, between consecutive elements of the corresponding array
- **nx** (*size_t*) – Number of elements in the corresponding array
- **y** (*double* *) – Array of y-coordinates
- **sy** (*size_t*) – Step length, in bytes, between consecutive elements of the corresponding array
- **ny** (*size_t*) – Number of elements in the corresponding array
- **z** (*double* *) – Array of z-coordinates
- **sz** (*size_t*) – Step length, in bytes, between consecutive elements of the corresponding array
- **nz** (*size_t*) – Number of elements in the corresponding array
- **t** (*double* *) – Array of t-coordinates
- **st** (*size_t*) – Step length, in bytes, between consecutive elements of the corresponding array
- **nt** (*size_t*) – Number of elements in the corresponding array

Returns
Number of transformations successfully completed

int **proj_trans_array**(*PJ* *P, *PJ_DIRECTION* direction, size_t n, *PJ_COORD* *coord)

Batch transform an array of `PJ_COORD`.

Performs transformation on all points, even if errors occur on some points (new to 8.0. Previous versions would exit early in case of failure on a given point)

Individual points that fail to transform will have their components set to `HUGE_VAL`

Parameters

- **P** (*PJ* *) – Transformation object
- **direction** (*PJ_DIRECTION*) – Transformation direction.
- **n** (*size_t*) – Number of coordinates in `coord`

Returns
int 0 if all observations are transformed without error, otherwise returns error number. This error number will be a precise error number if all coordinates that fail to transform for the same reason, or a generic error code if they fail for different reasons.

10.5.3.5 Error reporting

int **proj_errno**(*PJ* *P)

Get a reading of the current error-state of `P`. An non-zero error codes indicates an error either with the transformation setup or during a transformation. In cases `P` is *0* the error number of the default context is read. A text representation of the error number can be retrieved with `proj_errno_string()`.

Consult *Error codes* for the list of error codes (PROJ >= 8.0)

Parameters

- **P** (*PJ* *) – Transformation object

Returns
int

int **proj_context_errno**(*PJ_CONTEXT* *ctx)

Get a reading of the current error-state of `ctx`. An non-zero error codes indicates an error either with the transformation setup or during a transformation. A text representation of the error number can be retrieved with `proj_errno_string()`.

Consult *Error codes* for the list of error codes (PROJ >= 8.0)

Parameters

- **ctx** (*PJ_CONTEXT* *) – threading context.

Returns
int

void **proj_errno_set**(*PJ* *P, int err)

Change the error-state of `P` to *err*.

Parameters

- **P** (*PJ* *) – Transformation object
- **err** (*int*) – Error number.

int **proj_errno_reset**(*PJ* *P)

Clears the error number in `P`, and bubbles it up to the context.

Example:

```
void foo (PJ *P) {
    int last_errno = proj_errno_reset (P);

    do_something_with_P (P);

    /* failure - keep latest error status */
    if (proj_errno(P))
        return;
    /* success - restore previous error status */
    proj_errno_restore (P, last_errno);
    return;
}
```

Parameters

- **P** (*PJ* *) – Transformation object

Returns
int Returns the previous value of the errno, for convenient reset/restore operations.

void **proj_errno_restore**(*PJ* *P, int err)

Reduce some mental impedance in the canonical reset/restore use case: Basically, `proj_errno_restore()` is a synonym for `proj_errno_set()`, but the use cases are very different: *set* indicate an error to higher level user code, *restore* passes previously set error indicators in case of no errors at this level.

Hence, although the inner working is identical, we provide both options, to avoid some rather confusing real world code.

See usage example under `proj_errno_reset()`

Parameters

- **P** (*PJ* *) – Transformation object
- **err** (*int*) – Error number.

const char ***proj_errno_string**(int err)

New in version 5.1.0.

Get a text representation of an error number.

Deprecated since version This: function is potentially thread-unsafe, replaced by *proj_context_errno_string()*.

Parameters

- **err** (*int*) – Error number.

Returns
*const char** String with description of error.

const char ***proj_context_errno_string**(*PJ_CONTEXT* *ctx, int err)

New in version 8.0.0.

Get a text representation of an error number.

Parameters

- **ctx** (*PJ_CONTEXT* *) – threading context.
- **err** (*int*) – Error number.

Returns
*const char** String with description of error.

10.5.3.6 Logging

PJ_LOG_LEVEL **proj_log_level**(*PJ_CONTEXT* *ctx, *PJ_LOG_LEVEL* level)

Get and set logging level for a given context. Changes the log level to `level` and returns the previous logging level. If called with `level` set to `PJ_LOG_TELL` the function returns the current logging level without changing it.

Parameters

- **ctx** (*PJ_CONTEXT* *) – Threading context.
- **level** (*PJ_LOG_LEVEL*) – New logging level.

Returns
PJ_LOG_LEVEL

New in version 5.1.0.

void **proj_log_func**(*PJ_CONTEXT* *ctx, void *app_data, PJ_LOG_FUNCTION logf)

Override the internal log function of PROJ.

Parameters

- **ctx** (*PJ_CONTEXT* *) – Threading context.
- **app_data** (*void* *) – Pointer to data structure used by the calling application.
- **logf** (PJ_LOG_FUNCTION) – Log function that overrides the PROJ log function.

New in version 5.1.0.

10.5.3.7 Info functions

PJ_INFO **proj_info**(void)

Get information about the current instance of the PROJ library.

Returns
PJ_INFO

PJ_PROJ_INFO **proj_pj_info**(const *PJ* *P)

Get information about a specific transformation object, *P*.

Parameters

- **P** (const *PJ* *) – Transformation object

Returns
PJ_PROJ_INFO

PJ_GRID_INFO **proj_grid_info**(const char *gridname)

Get information about a specific grid.

Parameters

- **gridname** (*const char**) – Gridname in the PROJ searchpath

Returns
PJ_GRID_INFO

PJ_INIT_INFO **proj_init_info**(const char *initname)

Get information about a specific init file.

Parameters

- **initname** (*const char**) – Init file in the PROJ searchpath

Returns
PJ_INIT_INFO

10.5.3.8 Lists

const *PJ_OPERATIONS* ***proj_list_operations**(void)

Get a pointer to an array of all operations in PROJ. The last entry of the returned array is a NULL-entry. The array is statically allocated and does not need to be freed after use.

Print a list of all operations in PROJ:

```
PJ_OPERATIONS *ops;
for (ops = proj_list_operations(); ops->id; ++ops)
    printf("%s\n", ops->id);
```

Returns
const *PJ_OPERATIONS* *

const *PJ_ELLPS* ***proj_list_ellps**(void)

Get a pointer to an array of ellipsoids defined in PROJ. The last entry of the returned array is a NULL-entry. The array is statically allocated and does not need to be freed after use.

Returns
const *PJ_ELLPS* *

const *PJ_UNITS* ***proj_list_units**(void)

Get a pointer to an array of distance units defined in PROJ. The last entry of the returned array is a NULL-entry. The array is statically allocated and does not need to be freed after use.

Note: starting with PROJ 7.1, this function is deprecated by `proj_get_units_from_database()`

Returns

const `PJ_UNITS` *

const *PJ_PRIME_MERIDIANS* ***proj_list_prime_meridians**(void)

Get a pointer to an array of prime meridians defined in PROJ. The last entry of the returned array is a NULL-entry. The array is statically allocated and does not need to be freed after use.

Returns

const `PJ_PRIME_MERIDIANS` *

10.5.3.9 Distances

double **proj_lp_dist**(const *PJ* *P, *PJ_COORD* a, *PJ_COORD* b)

Calculate geodesic distance between two points in geodetic coordinates. The calculated distance is between the two points located on the ellipsoid.

The coordinates in `a` and `b` needs to be given as longitude and latitude in radians. Note that the axis order of the `P` object is not taken into account in this function, so even though a CRS object comes with axis ordering latitude/longitude coordinates used in this function should be reordered as longitude/latitude.

Parameters

- **P** (const `PJ` *) – Transformation or CRS object
- **a** (`PJ_COORD`) – Coordinate of first point
- **b** (`PJ_COORD`) – Coordinate of second point

Returns

double Distance between `a` and `b` in meters.

double **proj_lpz_dist**(const *PJ* *P, *PJ_COORD* a, *PJ_COORD* b)

Calculate geodesic distance between two points in geodetic coordinates. Similar to `proj_lp_dist()` but also takes the height above the ellipsoid into account.

The coordinates in `a` and `b` needs to be given as longitude and latitude in radians. Note that the axis order of the `P` object is not taken into account in this function, so even though a CRS object comes with axis ordering latitude/longitude coordinates used in this function should be reordered as longitude/latitude.

Parameters

- **P** (const `PJ` *) – Transformation or CRS object
- **a** (`PJ_COORD`) – Coordinate of first point
- **b** (`PJ_COORD`) – Coordinate of second point

Returns

double Distance between `a` and `b` in meters.

double **proj_xy_dist**(*PJ_COORD* a, *PJ_COORD* b)

Calculate 2-dimensional euclidean between two projected coordinates.

Parameters

- **a** (`PJ_COORD`) – First coordinate

- **b** (*PJ_COORD*) – Second coordinate

Returns
double Distance between *a* and *b* in meters.

double **proj_xyz_dist**(*PJ_COORD* a, *PJ_COORD* b)

Calculate 3-dimensional euclidean between two projected coordinates.

Parameters

- **a** (*PJ_COORD*) – First coordinate
- **b** (*PJ_COORD*) – Second coordinate

Returns
double Distance between *a* and *b* in meters.

PJ_COORD **proj_geod**(const *PJ* *P, *PJ_COORD* a, *PJ_COORD* b)

Calculate the geodesic distance as well as forward and reverse azimuth between two points on the ellipsoid.

The coordinates in *a* and *b* needs to be given as longitude and latitude in radians. Note that the axis order of the *P* object is not taken into account in this function, so even though a CRS object comes with axis ordering latitude/longitude coordinates used in this function should be reordered as longitude/latitude.

Parameters

- **P** (const *PJ* *) – Transformation or CRS object
- **a** (*PJ_COORD*) – Coordinate of first point
- **b** (*PJ_COORD*) – Coordinate of second point

Returns
PJ_COORD where the first value is the distance between *a* and *b* in meters, the second value is the forward azimuth and the third value is the reverse azimuth. The fourth coordinate value is unused.

10.5.3.10 Various

PJ_COORD **proj_coord**(double x, double y, double z, double t)

Initializer for the *PJ_COORD* union. The function is shorthand for the otherwise convoluted assignment. Equivalent to

```
PJ_COORD c = {{10.0, 20.0, 30.0, 40.0}};
```

or

```
PJ_COORD c;
// Assign using the PJ_XYZT struct in the union
c.xyzt.x = 10.0;
c.xyzt.y = 20.0;
c.xyzt.z = 30.0;
c.xyzt.t = 40.0;
```

Since *PJ_COORD* is a union of structs, the above assignment can also be expressed in terms of the other types in the union, e.g. *PJ_UVWT* or *PJ_LPZT*.

Parameters

- **x** (*double*) – 1st component in a *PJ_COORD*

- **y** (*double*) – 2nd component in a *PJ_COORD*
- **z** (*double*) – 3rd component in a *PJ_COORD*
- **t** (*double*) – 4th component in a *PJ_COORD*

Returns
PJ_COORD

double **proj_roundtrip**(*PJ* *P, *PJ_DIRECTION* direction, int n, *PJ_COORD* *coord)

Measure internal consistency of a given transformation. The function performs *n* round trip transformations starting in either the forward or reverse *direction*. Returns the euclidean distance of the starting point `coo` and the resulting coordinate after *n* iterations back and forth.

Parameters

- **P** (*PJ* *) – Transformation object
- **direction** (*PJ_DIRECTION*) – Starting direction of transformation
- **n** (*int*) – Number of roundtrip transformations
- **coord** (*PJ_COORD* *) – Input coordinate

Returns
double Distance between original coordinate and the resulting coordinate after *n* transformation iterations.

PJ_FACTORS **proj_factors**(*PJ* *P, *PJ_COORD* lp)

Calculate various cartographic properties, such as scale factors, angular distortion and meridian convergence. Depending on the underlying projection values will be calculated either numerically (default) or analytically.

The function also calculates the partial derivatives of the given coordinate.

Parameters

- **P** (*PJ* *) – Transformation object
- **lp** (*PJ_COORD*) – Geodetic coordinate

Returns
PJ_FACTORS

double **proj_torad**(double angle_in_degrees)

Convert degrees to radians.

Parameters

- **angle_in_degrees** (*double*) – Degrees

Returns
double Radians

double **proj_todeg**(double angle_in_radians)

Convert radians to degrees

Parameters

- **angle_in_radians** (*double*) – Radians

Returns
double Degrees

double **proj_dmstor**(const char *is, char **rs)

Convert string of degrees, minutes and seconds to radians. Works similarly to the C standard library function `strtod()`.

Parameters

- **is** (*const char**) – Value to be converted to radians
- **rs** – Reference to an already allocated char*, whose value is set by the function to the next character in *is* after the numerical value.

char ***proj_rtodms**(char *s, double r, int pos, int neg)

Convert radians to string representation of degrees, minutes and seconds.

Parameters

- **s** (*char **) – Buffer that holds the output string
- **r** (*double*) – Value to convert to dms-representation
- **pos** (*int*) – Character denoting positive direction, typically *'N'* or *'E'*.
- **neg** (*int*) – Character denoting negative direction, typically *'S'* or *'W'*.

Returns

*char** Pointer to output buffer (same as *s*)

int **proj_angular_input**(*PJ* *P, enum *PJ_DIRECTION* dir)

Check if an operation expects input in radians or not.

Parameters

- **P** (*PJ **) – Transformation object
- **direction** (*PJ_DIRECTION*) – Starting direction of transformation

Returns

int 1 if input units is expected in radians, otherwise 0

int **proj_angular_output**(*PJ* *P, enum *PJ_DIRECTION* dir)

Check if an operation returns output in radians or not.

Parameters

- **P** (*PJ **) – Transformation object
- **direction** (*PJ_DIRECTION*) – Starting direction of transformation

Returns

int 1 if output units is expected in radians, otherwise 0

int **proj_degree_input**(*PJ* *P, enum *PJ_DIRECTION* dir)

New in version 7.1.0.

Check if an operation expects input in degrees or not.

Parameters

- **P** (*PJ **) – Transformation object
- **direction** (*PJ_DIRECTION*) – Starting direction of transformation

Returns

int 1 if input units is expected in degrees, otherwise 0 int **proj_degree_output**(*PJ* *P, enum *PJ_DIRECTION* dir)

New in version 7.1.0.

Check if an operation returns output in degrees or not.

Parameters

- **P** (*PJ* *) – Transformation object
- **direction** (*PJ_DIRECTION*) – Starting direction of transformation

Returns

int 1 if output units is expected in degrees, otherwise 0

10.5.3.11 Setting custom I/O functions

New in version 7.0.0.

int **proj_context_set_fileapi**(PJ_CONTEXT *ctx, const *PROJ_FILE_API* *fileapi, void *user_data)

Set a file API

All callbacks should be provided (non NULL pointers). If read-only usage is intended, then the callbacks might have a dummy implementation.

Since

7.0

Note: Those callbacks will not be used for SQLite3 database access. If custom I/O is desired for that, then *proj_context_set_sqlite3_vfs_name()* should be used.

Parameters

- **ctx** – PROJ context, or NULL
- **fileapi** – Pointer to file API structure (content will be copied).
- **user_data** – Arbitrary pointer provided by the user, and passed to the above callbacks. May be NULL.

Returns

TRUE in case of success.

void **proj_context_set_sqlite3_vfs_name**(PJ_CONTEXT *ctx, const char *name)

Set the name of a custom SQLite3 VFS.

This should be a valid SQLite3 VFS name, such as the one passed to the sqlite3_vfs_register(). See https://www.sqlite.org/vfs.html

It will be used to read proj.db or create&access the cache.db file in the PROJ user writable directory.

Since

7.0

Parameters

- **ctx** – PROJ context, or NULL

- **name** – SQLite3 VFS name. If NULL is passed, default implementation by SQLite will be used.

10.5.3.12 Network related functionality

New in version 7.0.0.

int **proj_context_set_network_callbacks**(PJ_CONTEXT *ctx, *proj_network_open_cbk_type* open_cbk, *proj_network_close_cbk_type* close_cbk, *proj_network_get_header_value_cbk_type* get_header_value_cbk, *proj_network_read_range_type* read_range_cbk, void *user_data)

Define a custom set of callbacks for network access.

All callbacks should be provided (non NULL pointers).

Since
7.0

Parameters

- **ctx** – PROJ context, or NULL
- **open_cbk** – Callback to open a remote file given its URL
- **close_cbk** – Callback to close a remote file.
- **get_header_value_cbk** – Callback to get HTTP headers
- **read_range_cbk** – Callback to read a range of bytes inside a remote file.
- **user_data** – Arbitrary pointer provided by the user, and passed to the above callbacks. May be NULL.

Returns
TRUE in case of success.

int **proj_context_set_enable_network**(PJ_CONTEXT *ctx, int enabled)

Enable or disable network access.

This overrides the default endpoint in the PROJ configuration file or with the PROJ_NETWORK environment variable.

Since
7.0

Parameters

- **ctx** – PROJ context, or NULL
- **enable** – TRUE if network access is allowed.

Returns
TRUE if network access is possible. That is either libcurl is available, or an alternate interface has been set.

int **proj_context_is_network_enabled**(PJ_CONTEXT *ctx)

Return if network access is enabled.

Since
7.0

Parameters
ctx – PROJ context, or NULL

Returns
TRUE if network access has been enabled

void **proj_context_set_url_endpoint**(PJ_CONTEXT *ctx, const char *url)

Define the URL endpoint to query for remote grids.

This overrides the default endpoint in the PROJ configuration file or with the PROJ_NETWORK_ENDPOINT environment variable.

Since
7.0

Parameters

- **ctx** – PROJ context, or NULL
- **url** – Endpoint URL. Must NOT be NULL.

const char ***proj_context_get_url_endpoint**(PJ_CONTEXT *ctx)

Get the URL endpoint to query for remote grids.

Since
7.1

Parameters
ctx – PROJ context, or NULL

Returns
Endpoint URL. The returned pointer would be invalidated by a later call to *proj_context_set_url_endpoint()*

const char ***proj_context_get_user_writable_directory**(PJ_CONTEXT *ctx, int create)

Get the PROJ user writable directory for datumgrid files.

Since
7.1

Parameters

- **ctx** – PROJ context, or NULL
- **create** – If set to TRUE, create the directory if it does not exist already.

Returns
The path to the PROJ user writable directory.

void **proj_grid_cache_set_enable**(PJ_CONTEXT *ctx, int enabled)

Enable or disable the local cache of grid chunks

This overrides the setting in the PROJ configuration file.

Since
7.0

Parameters

- **ctx** – PROJ context, or NULL
- **enabled** – TRUE if the cache is enabled.

void **proj_grid_cache_set_filename**(PJ_CONTEXT *ctx, const char *fullname)

Override, for the considered context, the path and file of the local cache of grid chunks.

Since
7.0

Parameters

- **ctx** – PROJ context, or NULL
- **fullname** – Full name to the cache (encoded in UTF-8). If set to NULL, caching will be disabled.

void **proj_grid_cache_set_max_size**(PJ_CONTEXT *ctx, int max_size_MB)

Override, for the considered context, the maximum size of the local cache of grid chunks.

Since
7.0

Parameters

- **ctx** – PROJ context, or NULL
- **max_size_MB** – Maximum size, in mega-bytes (1024*1024 bytes), or negative value to set unlimited size.

void **proj_grid_cache_set_ttl**(PJ_CONTEXT *ctx, int ttl_seconds)

Override, for the considered context, the time-to-live delay for re-checking if the cached properties of files are still up-to-date.

Since
7.0

Parameters

- **ctx** – PROJ context, or NULL

- **ttl_seconds** – Delay in seconds. Use negative value for no expiration.

void **proj_grid_cache_clear**(PJ_CONTEXT *ctx)

Clear the local cache of grid chunks.

Since

7.0

Parameters

ctx – PROJ context, or NULL

int **proj_is_download_needed**(PJ_CONTEXT *ctx, const char *url_or_filename, int ignore_ttl_setting)

Return if a file must be downloaded or is already available in the PROJ user-writable directory.

The file will be determinted to have to be downloaded if it does not exist yet in the user-writable directory, or if it is determined that a more recent version exists. To determine if a more recent version exists, PROJ will use the "downloaded_file_properties" table of its grid cache database. Consequently files manually placed in the user-writable directory without using this function would be considered as non-existing/obsolete and would be unconditionally downloaded again.

This function can only be used if networking is enabled, and either the default curl network API or a custom one have been installed.

Since

7.0

Parameters

- **ctx** – PROJ context, or NULL
- **url_or_filename** – URL or filename (without directory component)
- **ignore_ttl_setting** – If set to FALSE, PROJ will only check the recentness of an already downloaded file, if the delay between the last time it has been verified and the current time exceeds the TTL setting. This can save network accesses. If set to TRUE, PROJ will unconditionnally check from the server the recentness of the file.

Returns

TRUE if the file must be downloaded with *proj_download_file()*

int **proj_download_file**(PJ_CONTEXT *ctx, const char *url_or_filename, int ignore_ttl_setting, int (*progress_cbk)(PJ_CONTEXT*, double pct, void *user_data), void *user_data)

Download a file in the PROJ user-writable directory.

The file will only be downloaded if it does not exist yet in the user-writable directory, or if it is determined that a more recent version exists. To determine if a more recent version exists, PROJ will use the "downloaded_file_properties" table of its grid cache database. Consequently files manually placed in the user-writable directory without using this function would be considered as non-existing/obsolete and would be unconditionally downloaded again.

This function can only be used if networking is enabled, and either the default curl network API or a custom one have been installed.

Since
7.0

Parameters

- **ctx** – PROJ context, or NULL
- **url_or_filename** – URL or filename (without directory component)
- **ignore_ttl_setting** – If set to FALSE, PROJ will only check the recentness of an already downloaded file, if the delay between the last time it has been verified and the current time exceeds the TTL setting. This can save network accesses. If set to TRUE, PROJ will unconditionnally check from the server the recentness of the file.
- **progress_cbk** – Progress callback, or NULL. The passed percentage is in the [0, 1] range. The progress callback must return TRUE if download must be continued.
- **user_data** – User data to provide to the progress callback, or NULL

Returns
TRUE if the download was successful (or not needed)

10.5.3.13 Cleanup

void **proj_cleanup**()

New in version 6.2.0.

This function frees global resources (grids, cache of +init files). It should be called typically before process termination, and *after* having freed PJ and PJ_CONTEXT objects.

10.5.3.14 C API for ISO-19111 functionality

New in version 6.0.0.

The PJ* objects returned by `proj_create_from_wkt()`, `proj_create_from_database()` and other functions in that section will have generally minimal interaction with the functions declared in the previous sections (calling those functions on those objects will either return an error or default/nonsensical values). The exception is for ISO19111 objects of type CoordinateOperation that can be exported as a valid PROJ pipeline. In this case, objects will work for example with *proj_trans_generic()*. Conversely, objects returned by *proj_create()* and *proj_create_argv()*, which are not of type CRS (can be tested with `proj_is_crs()`), will return an error when used with functions of this section.

void **proj_string_list_destroy**(*PROJ_STRING_LIST* list)

Free a list of NULL terminated strings.

void **proj_context_set_autoclose_database**(PJ_CONTEXT *ctx, int autoclose)

Set if the database must be closed after each C API call where it has been opened, and automatically re-opened when needed.

The default value is FALSE, that is the database remains open until the context is destroyed.

Since
6.2

Parameters

- **ctx** – PROJ context, or NULL for default context

- **autoclose** – Boolean parameter

int **proj_context_set_database_path**(PJ_CONTEXT *ctx, const char *dbPath, const char *const *auxDbPaths, const char *const *options)

Explicitly point to the main PROJ CRS and coordinate operation definition database ("proj.db"), and potentially auxiliary databases with same structure.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **dbPath** – Path to main database, or NULL for default.
- **auxDbPaths** – NULL-terminated list of auxiliary database filenames, or NULL.
- **options** – should be set to NULL for now

Returns
TRUE in case of success

const char ***proj_context_get_database_path**(PJ_CONTEXT *ctx)

Returns the path to the database.

The returned pointer remains valid while ctx is valid, and until *proj_context_set_database_path()* is called.

Parameters
ctx – PROJ context, or NULL for default context

Returns
path, or nullptr

const char ***proj_context_get_database_metadata**(PJ_CONTEXT *ctx, const char *key)

Return a metadata from the database.

The returned pointer remains valid while ctx is valid, and until *proj_context_get_database_metadata()* is called.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **key** – Metadata key. Must not be NULL

Returns
value, or nullptr

PJ_GUESSED_WKT_DIALECT **proj_context_guess_wkt_dialect**(PJ_CONTEXT *ctx, const char *wkt)

Guess the "dialect" of the WKT string.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **wkt** – String (must not be NULL)

PJ ***proj_create_from_wkt**(PJ_CONTEXT *ctx, const char *wkt, const char *const *options, *PROJ_STRING_LIST* *out_warnings, *PROJ_STRING_LIST* *out_grammar_errors)

Instantiate an object from a WKT string.

This function calls *osgeo::proj::io::WKTParser::createFromWKT()*

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **wkt** – WKT string (must not be NULL)
- **options** – null-terminated list of options, or NULL. Currently supported options are:
  - STRICT=YES/NO. Defaults to NO. When set to YES, strict validation will be enabled.
- **out_warnings** – Pointer to a PROJ_STRING_LIST object, or NULL. If provided, *out_warnings will contain a list of warnings, typically for non recognized projection method or parameters. It must be freed with *proj_string_list_destroy()*.
- **out_grammar_errors** – Pointer to a PROJ_STRING_LIST object, or NULL. If provided, *out_grammar_errors will contain a list of errors regarding the WKT grammar. It must be freed with *proj_string_list_destroy()*.

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error.

PJ ***proj_create_from_database**(PJ_CONTEXT *ctx, const char *auth_name, const char *code, *PJ_CATEGORY* category, int usePROJAlternativeGridNames, const char *const *options)

Instantiate an object from a database lookup.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **ctx** – Context, or NULL for default context.
- **auth_name** – Authority name (must not be NULL)
- **code** – Object code (must not be NULL)
- **category** – Object category
- **usePROJAlternativeGridNames** – Whether PROJ alternative grid names should be substituted to the official grid names. Only used on transformations
- **options** – should be set to NULL for now

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error.

int **proj_uom_get_info_from_database**(PJ_CONTEXT *ctx, const char *auth_name, const char *code, const char **out_name, double *out_conv_factor, const char **out_category)

Get information for a unit of measure from a database lookup.

Parameters

- **ctx** – Context, or NULL for default context.
- **auth_name** – Authority name (must not be NULL)
- **code** – Unit of measure code (must not be NULL)
- **out_name** – Pointer to a string value to store the parameter name. or NULL. This value remains valid until the next call to *proj_uom_get_info_from_database()* or the context destruction.
- **out_conv_factor** – Pointer to a value to store the conversion factor of the prime meridian longitude unit to radian. or NULL

- **out_category** – Pointer to a string value to store the parameter name. or NULL. This value might be "unknown", "none", "linear", "linear_per_time", "angular", "angular_per_time", "scale", "scale_per_time", "time", "parametric" or "parametric_per_time"

Returns
TRUE in case of success

int **proj_grid_get_info_from_database**(PJ_CONTEXT *ctx, const char *grid_name, const char **out_full_name, const char **out_package_name, const char **out_url, int *out_direct_download, int *out_open_license, int *out_available)

Get information for a grid from a database lookup.

Parameters

- **ctx** – Context, or NULL for default context.
- **grid_name** – Grid name (must not be NULL)
- **out_full_name** – Pointer to a string value to store the grid full filename. or NULL
- **out_package_name** – Pointer to a string value to store the package name where the grid might be found. or NULL
- **out_url** – Pointer to a string value to store the grid URL or the package URL where the grid might be found. or NULL
- **out_direct_download** – Pointer to a int (boolean) value to store whether *out_url can be downloaded directly. or NULL
- **out_open_license** – Pointer to a int (boolean) value to store whether the grid is released with an open license. or NULL
- **out_available** – Pointer to a int (boolean) value to store whether the grid is available at runtime. or NULL

Returns
TRUE in case of success.

PJ ***proj_clone**(PJ_CONTEXT *ctx, const PJ *obj)

"Clone" an object.

The object might be used independently of the original object, provided that the use of context is compatible. In particular if you intend to use a clone in a different thread than the original object, you should pass a context that is different from the one of the original object (or later assing a different context with proj_assign_context()).

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **obj** – Object to clone. Must not be NULL.

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error.

PJ_OBJ_LIST ***proj_create_from_name**(PJ_CONTEXT *ctx, const char *auth_name, const char *searchedName, const *PJ_TYPE* *types, size_t typesCount, int approximateMatch, size_t limitResultCount, const char *const *options)

Return a list of objects by their name.

Parameters

- **ctx** – Context, or NULL for default context.
- **auth_name** – Authority name, used to restrict the search. Or NULL for all authorities.
- **searchedName** – Searched name. Must be at least 2 character long.
- **types** – List of object types into which to search. If NULL, all object types will be searched.
- **typesCount** – Number of elements in types, or 0 if types is NULL
- **approximateMatch** – Whether approximate name identification is allowed.
- **limitResultCount** – Maximum number of results to return. Or 0 for unlimited.
- **options** – should be set to NULL for now

Returns
a result set that must be unreferenced with *proj_list_destroy()*, or NULL in case of error.

PJ_TYPE **proj_get_type**(const PJ *obj)

Return the type of an object.

Parameters
obj – Object (must not be NULL)

Returns
its type.

int **proj_is_deprecated**(const PJ *obj)

Return whether an object is deprecated.

Parameters
obj – Object (must not be NULL)

Returns
TRUE if it is deprecated, FALSE otherwise

PJ_OBJ_LIST ***proj_get_non_deprecated**(PJ_CONTEXT *ctx, const PJ *obj)

Return a list of non-deprecated objects related to the passed one.

Parameters

- **ctx** – Context, or NULL for default context.
- **obj** – Object (of type CRS for now) for which non-deprecated objects must be searched. Must not be NULL

Returns
a result set that must be unreferenced with *proj_list_destroy()*, or NULL in case of error.

int **proj_is_equivalent_to**(const PJ *obj, const PJ *other, *PJ_COMPARISON_CRITERION* criterion)

Return whether two objects are equivalent.

Use *proj_is_equivalent_to_with_ctx()* to be able to use database information.

Parameters

- **obj** – Object (must not be NULL)
- **other** – Other object (must not be NULL)
- **criterion** – Comparison criterion

Returns
TRUE if they are equivalent

int **proj_is_equivalent_to_with_ctx**(PJ_CONTEXT *ctx, const PJ *obj, const PJ *other, *PJ_COMPARISON_CRITERION* criterion)

Return whether two objects are equivalent.

Possibly using database to check for name aliases.

Since
6.3

Parameters

- **ctx** – PROJ context, or NULL for default context
- **obj** – Object (must not be NULL)
- **other** – Other object (must not be NULL)
- **criterion** – Comparison criterion

Returns
TRUE if they are equivalent

int **proj_is_crs**(const PJ *obj)

Return whether an object is a CRS.

Parameters
obj – Object (must not be NULL)

const char ***proj_get_name**(const PJ *obj)

Get the name of an object.

The lifetime of the returned string is the same as the input obj parameter.

Parameters
obj – Object (must not be NULL)

Returns
a string, or NULL in case of error or missing name.

const char ***proj_get_id_auth_name**(const PJ *obj, int index)

Get the authority name / codespace of an identifier of an object.

The lifetime of the returned string is the same as the input obj parameter.

Parameters

- **obj** – Object (must not be NULL)
- **index** – Index of the identifier. 0 = first identifier

Returns
a string, or NULL in case of error or missing name.

const char ***proj_get_id_code**(const PJ *obj, int index)

Get the code of an identifier of an object.

The lifetime of the returned string is the same as the input obj parameter.

Parameters

- **obj** – Object (must not be NULL)
- **index** – Index of the identifier. 0 = first identifier

Returns
a string, or NULL in case of error or missing name.

const char ***proj_get_remarks**(const PJ *obj)

Get the remarks of an object.

The lifetime of the returned string is the same as the input obj parameter.

Parameters
obj – Object (must not be NULL)

Returns
a string, or NULL in case of error.

const char ***proj_get_scope**(const PJ *obj)

Get the scope of an object.

In case of multiple usages, this will be the one of first usage.

The lifetime of the returned string is the same as the input obj parameter.

Parameters
obj – Object (must not be NULL)

Returns
a string, or NULL in case of error or missing scope.

int **proj_get_area_of_use**(PJ_CONTEXT *ctx, const PJ *obj, double *out_west_lon_degree, double *out_south_lat_degree, double *out_east_lon_degree, double *out_north_lat_degree, const char **out_area_name)

Return the area of use of an object.

In case of multiple usages, this will be the one of first usage.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **obj** – Object (must not be NULL)
- **out_west_lon_degree** – Pointer to a double to receive the west longitude (in degrees). Or NULL. If the returned value is -1000, the bounding box is unknown.
- **out_south_lat_degree** – Pointer to a double to receive the south latitude (in degrees). Or NULL. If the returned value is -1000, the bounding box is unknown.
- **out_east_lon_degree** – Pointer to a double to receive the east longitude (in degrees). Or NULL. If the returned value is -1000, the bounding box is unknown.
- **out_north_lat_degree** – Pointer to a double to receive the north latitude (in degrees). Or NULL. If the returned value is -1000, the bounding box is unknown.
- **out_area_name** – Pointer to a string to receive the name of the area of use. Or NULL. *p_area_name is valid while obj is valid itself.

Returns
TRUE in case of success, FALSE in case of error or if the area of use is unknown.

const char ***proj_as_wkt**(PJ_CONTEXT *ctx, const PJ *obj, *PJ_WKT_TYPE* type, const char *const *options)

Get a WKT representation of an object.

The returned string is valid while the input obj parameter is valid, and until a next call to *proj_as_wkt()* with the same input object.

This function calls *osgeo::proj::io::IWKTExportable::exportToWKT()*.

This function may return NULL if the object is not compatible with an export to the requested type.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `obj` – Object (must not be NULL)
- `type` – WKT version.
- `options` – null-terminated list of options, or NULL. Currently supported options are:
  - MULTILINE=YES/NO. Defaults to YES, except for WKT1_ESRI
  - INDENTATION_WIDTH=number. Defaults to 4 (when multiline output is on).
  - OUTPUT_AXIS=AUTO/YES/NO. In AUTO mode, axis will be output for WKT2 variants, for WKT1_GDAL for ProjectedCRS with easting/northing ordering (otherwise stripped), but not for WKT1_ESRI. Setting to YES will output them unconditionally, and to NO will omit them unconditionally.
  - STRICT=YES/NO. Default is YES. If NO, a Geographic 3D CRS can be for example exported as WKT1_GDAL with 3 axes, whereas this is normally not allowed.
  - ALLOW_ELLIPSOIDAL_HEIGHT_AS_VERTICAL_CRS=YES/NO. Default is NO. If set to YES and type == PJ_WKT1_GDAL, a Geographic 3D CRS or a Projected 3D CRS will be exported as a compound CRS whose vertical part represents an ellipsoidal height (for example for use with LAS 1.4 WKT1).

Returns

a string, or NULL in case of error.

const char ***proj_as_proj_string**(PJ_CONTEXT *ctx, const PJ *obj, *PJ_PROJ_STRING_TYPE* type, const char *const *options)

Get a PROJ string representation of an object.

The returned string is valid while the input obj parameter is valid, and until a next call to *proj_as_proj_string()* with the same input object.

This function calls *osgeo::proj::io::IPROJStringExportable::exportToPROJString()*.

This function may return NULL if the object is not compatible with an export to the requested type.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `obj` – Object (must not be NULL)
- `type` – PROJ String version.
- `options` – NULL-terminated list of strings with "KEY=VALUE" format. or NULL. Currently supported options are:
  - USE_APPROX_TMERC=YES to add the +approx flag to +proj=tmerc or +proj=utm.
  - MULTILINE=YES/NO. Defaults to NO
  - INDENTATION_WIDTH=number. Defaults to 2 (when multiline output is on).
  - MAX_LINE_LENGTH=number. Defaults to 80 (when multiline output is on).

Returns

a string, or NULL in case of error.

const char ***proj_as_projjson**(PJ_CONTEXT *ctx, const PJ *obj, const char *const *options)

Get a PROJJSON string representation of an object.

The returned string is valid while the input obj parameter is valid, and until a next call to *proj_as_proj_string()* with the same input object.

This function calls *osgeo::proj::io::IJSONExportable::exportToJSON()*.

This function may return NULL if the object is not compatible with an export to the requested type.

Since
6.2

Parameters

- **ctx** – PROJ context, or NULL for default context
- **obj** – Object (must not be NULL)
- **options** – NULL-terminated list of strings with "KEY=VALUE" format. or NULL. Currently supported options are:
  - MULTILINE=YES/NO. Defaults to YES
  - INDENTATION_WIDTH=number. Defaults to 2 (when multiline output is on).
  - SCHEMA=string. URL to PROJJSON schema. Can be set to empty string to disable it.

Returns
a string, or NULL in case of error.

PJ ***proj_get_source_crs**(PJ_CONTEXT *ctx, const PJ *obj)

Return the base CRS of a BoundCRS or a DerivedCRS/ProjectedCRS, or the source CRS of a CoordinateOperation.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **obj** – Object of type BoundCRS or CoordinateOperation (must not be NULL)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error, or missing source CRS.

PJ ***proj_get_target_crs**(PJ_CONTEXT *ctx, const PJ *obj)

Return the hub CRS of a BoundCRS or the target CRS of a CoordinateOperation.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **obj** – Object of type BoundCRS or CoordinateOperation (must not be NULL)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error, or missing target CRS.

PJ_OBJ_LIST ***proj_identify**(PJ_CONTEXT *ctx, const PJ *obj, const char *auth_name, const char *const *options, int **out_confidence)

Identify the CRS with reference CRSs.

The candidate CRSs are either hard-coded, or looked in the database when it is available.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference CRS, and the percentage (0-100) of confidence in the match. The list is sorted by decreasing confidence.

- 100% means that the name of the reference entry perfectly matches the CRS name, and both are equivalent. In which case a single result is returned. Note: in the case of a GeographicCRS whose axis order is implicit in the input definition (for example ESRI WKT), then axis order is ignored for the purpose of identification. That is the CRS built from GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]], PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]] will be identified to EPSG:4326, but will not pass a isEquivalentTo(EPSG_4326, util::IComparable::Criterion::EQUIVALENT) test, but rather isEquivalentTo(EPSG_4326, util::IComparable::Criterion::EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS)
- 90% means that CRS are equivalent, but the names are not exactly the same.
- 70% means that CRS are equivalent, but the names are not equivalent.
- 25% means that the CRS are not equivalent, but there is some similarity in the names.

Other confidence values may be returned by some specialized implementations.

This is implemented for GeodeticCRS, ProjectedCRS, VerticalCRS and CompoundCRS.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **obj** – Object of type CRS. Must not be NULL
- **auth_name** – Authority name, or NULL for all authorities
- **options** – Placeholder for future options. Should be set to NULL.
- **out_confidence** – Output parameter. Pointer to an array of integers that will be allocated by the function and filled with the confidence values (0-100). There are as many elements in this array as *proj_list_get_count()* returns on the return value of this function. *confidence should be released with *proj_int_list_destroy()*.

Returns
a list of matching reference CRS, or nullptr in case of error.

void **proj_int_list_destroy**(int *list)

Free an array of integer.

PROJ_STRING_LIST **proj_get_authorities_from_database**(PJ_CONTEXT *ctx)

Return the list of authorities used in the database.

The returned list is NULL terminated and must be freed with *proj_string_list_destroy()*.

Parameters
ctx – PROJ context, or NULL for default context

Returns
a NULL terminated list of NUL-terminated strings that must be freed with *proj_string_list_destroy()*, or NULL in case of error.

PROJ_STRING_LIST **proj_get_codes_from_database**(PJ_CONTEXT *ctx, const char *auth_name, *PJ_TYPE* type, int allow_deprecated)

Returns the set of authority codes of the given object type.

The returned list is NULL terminated and must be freed with *proj_string_list_destroy()*.

See also:

proj_get_crs_info_list_from_database()

Parameters

- **ctx** – PROJ context, or NULL for default context.
- **auth_name** – Authority name (must not be NULL)
- **type** – Object type.
- **allow_deprecated** – whether we should return deprecated objects as well.

Returns

a NULL terminated list of NUL-terminated strings that must be freed with *proj_string_list_destroy()*, or NULL in case of error.

PROJ_CRS_LIST_PARAMETERS ***proj_get_crs_list_parameters_create**(void)

Instantiate a default set of parameters to be used by proj_get_crs_list().

Returns

a new object to free with *proj_get_crs_list_parameters_destroy()*

void **proj_get_crs_list_parameters_destroy**(*PROJ_CRS_LIST_PARAMETERS* *params)

Destroy an object returned by *proj_get_crs_list_parameters_create()*

PROJ_CRS_INFO ****proj_get_crs_info_list_from_database**(PJ_CONTEXT *ctx, const char *auth_name, const *PROJ_CRS_LIST_PARAMETERS* *params, int *out_result_count)

Enumerate CRS objects from the database, taking into account various criteria.

The returned object is an array of PROJ_CRS_INFO* pointers, whose last entry is NULL. This array should be freed with *proj_crs_info_list_destroy()*

When no filter parameters are set, this is functionnaly equivalent to *proj_get_codes_from_database()*, instantiating a PJ* object for each of the codes with *proj_create_from_database()* and retrieving information with the various getters. However this function will be much faster.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **auth_name** – Authority name, used to restrict the search. Or NULL for all authorities.
- **params** – Additional criteria, or NULL. If not-NULL, params SHOULD have been allocated by *proj_get_crs_list_parameters_create()*, as the *PROJ_CRS_LIST_PARAMETERS* structure might grow over time.
- **out_result_count** – Output parameter pointing to an integer to receive the size of the result list. Might be NULL

Returns

an array of PROJ_CRS_INFO* pointers to be freed with *proj_crs_info_list_destroy()*, or NULL in case of error.

void **proj_crs_info_list_destroy**(*PROJ_CRS_INFO* **list)

Destroy the result returned by *proj_get_crs_info_list_from_database()*.

PROJ_UNIT_INFO ****proj_get_units_from_database**(PJ_CONTEXT *ctx, const char *auth_name, const char *category, int allow_deprecated, int *out_result_count)

Enumerate units from the database, taking into account various criteria.

The returned object is an array of PROJ_UNIT_INFO* pointers, whose last entry is NULL. This array should be freed with *proj_unit_list_destroy()*

Since
7.1

Parameters

- **ctx** – PROJ context, or NULL for default context
- **auth_name** – Authority name, used to restrict the search. Or NULL for all authorities.
- **category** – Filter by category, if this parameter is not NULL. Category is one of "linear", "linear_per_time", "angular", "angular_per_time", "scale", "scale_per_time" or "time"
- **allow_deprecated** – whether we should return deprecated objects as well.
- **out_result_count** – Output parameter pointing to an integer to receive the size of the result list. Might be NULL

Returns
an array of PROJ_UNIT_INFO* pointers to be freed with *proj_unit_list_destroy()*, or NULL in case of error.

void **proj_unit_list_destroy**(*PROJ_UNIT_INFO* **list)

Destroy the result returned by *proj_get_units_from_database()*.

Since
7.1

PJ_OPERATION_FACTORY_CONTEXT ***proj_create_operation_factory_context**(PJ_CONTEXT *ctx, const char *authority)

Instantiate a context for building coordinate operations between two CRS.

The returned object must be unreferenced with *proj_operation_factory_context_destroy()* after use.

If authority is NULL or the empty string, then coordinate operations from any authority will be searched, with the restrictions set in the authority_to_authority_preference database table. If authority is set to "any", then coordinate operations from any authority will be searched If authority is a non-empty string different of "any", then coordinate operations will be searched only in that authority namespace.

Parameters

- **ctx** – Context, or NULL for default context.
- **authority** – Name of authority to which to restrict the search of candidate operations.

Returns
Object that must be unreferenced with *proj_operation_factory_context_destroy()*, or NULL in case of error.

void **proj_operation_factory_context_destroy**(PJ_OPERATION_FACTORY_CONTEXT *ctx)

Drops a reference on an object.

This method should be called one and exactly one for each function returning a PJ_OPERATION_FACTORY_CONTEXT*

Parameters

ctx – Object, or NULL.

void **proj_operation_factory_context_set_desired_accuracy**(PJ_CONTEXT *ctx, PJ_OPERATION_FACTORY_CONTEXT *factory_ctx, double accuracy)

Set the desired accuracy of the resulting coordinate transformations.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **factory_ctx** – Operation factory context. must not be NULL
- **accuracy** – Accuracy in meter (or 0 to disable the filter).

void **proj_operation_factory_context_set_area_of_interest**(PJ_CONTEXT *ctx, PJ_OPERATION_FACTORY_CONTEXT *factory_ctx, double west_lon_degree, double south_lat_degree, double east_lon_degree, double north_lat_degree)

Set the desired area of interest for the resulting coordinate transformations.

For an area of interest crossing the anti-meridian, west_lon_degree will be greater than east_lon_degree.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **factory_ctx** – Operation factory context. must not be NULL
- **west_lon_degree** – West longitude (in degrees).
- **south_lat_degree** – South latitude (in degrees).
- **east_lon_degree** – East longitude (in degrees).
- **north_lat_degree** – North latitude (in degrees).

void **proj_operation_factory_context_set_crs_extent_use**(PJ_CONTEXT *ctx, PJ_OPERATION_FACTORY_CONTEXT *factory_ctx, *PROJ_CRS_EXTENT_USE* use)

Set how source and target CRS extent should be used when considering if a transformation can be used (only takes effect if no area of interest is explicitly defined).

The default is PJ_CRS_EXTENT_SMALLEST.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **factory_ctx** – Operation factory context. must not be NULL
- **use** – How source and target CRS extent should be used.

void **proj_operation_factory_context_set_spatial_criterion**(PJ_CONTEXT *ctx, PJ_OPERATION_FACTORY_CONTEXT *factory_ctx, *PROJ_SPATIAL_CRITERION* criterion)

Set the spatial criterion to use when comparing the area of validity of coordinate operations with the area of interest / area of validity of source and target CRS.

The default is PROJ_SPATIAL_CRITERION_STRICT_CONTAINMENT.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **factory_ctx** – Operation factory context. must not be NULL
- **criterion** – patial criterion to use

void **proj_operation_factory_context_set_grid_availability_use**(PJ_CONTEXT *ctx, PJ_OPERATION_FACTORY_CONTEXT *factory_ctx, *PROJ_GRID_AVAILABILITY_USE* use)

Set how grid availability is used.

The default is USE_FOR_SORTING.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **factory_ctx** – Operation factory context. must not be NULL
- **use** – how grid availability is used.

void **proj_operation_factory_context_set_use_proj_alternative_grid_names**(PJ_CONTEXT *ctx, PJ_OPERATION_FACTORY_CONTEXT *factory_ctx, int usePROJNames)

Set whether PROJ alternative grid names should be substituted to the official authority names.

The default is true.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **factory_ctx** – Operation factory context. must not be NULL
- **usePROJNames** – whether PROJ alternative grid names should be used

void **proj_operation_factory_context_set_allow_use_intermediate_crs**(PJ_CONTEXT *ctx, PJ_OPERATION_FACTORY_CONTEXT *factory_ctx, *PROJ_INTERMEDIATE_CRS_USE* use)

Set whether an intermediate pivot CRS can be used for researching coordinate operations between a source and target CRS.

Concretely if in the database there is an operation from A to C (or C to A), and another one from C to B (or B to C), but no direct operation between A and B, setting this parameter to true, allow chaining both operations.

The current implementation is limited to researching one intermediate step.

By default, with the IF_NO_DIRECT_TRANSFORMATION strategy, all potential C candidates will be used if there is no direct transformation.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `factory_ctx` – Operation factory context. must not be NULL
- `use` – whether and how intermediate CRS may be used.

void **proj_operation_factory_context_set_allowed_intermediate_crs**(PJ_CONTEXT *ctx, PJ_OPERATION_FACTORY_CONTEXT *factory_ctx, const char *const *list_of_auth_name_codes)

Restrict the potential pivot CRSs that can be used when trying to build a coordinate operation between two CRS that have no direct operation.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `factory_ctx` – Operation factory context. must not be NULL
- `list_of_auth_name_codes` – an array of strings NLL terminated, with the format { "auth_name1", "code1", "auth_name2", "code2", … NULL }

void **proj_operation_factory_context_set_discard_superseded**(PJ_CONTEXT *ctx, PJ_OPERATION_FACTORY_CONTEXT *factory_ctx, int discard)

Set whether transformations that are superseded (but not deprecated) should be discarded.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `factory_ctx` – Operation factory context. must not be NULL
- `discard` – superseded crs or not

void **proj_operation_factory_context_set_allow_ballpark_transformations**(PJ_CONTEXT *ctx, PJ_OPERATION_FACTORY_CONTEXT *factory_ctx, int allow)

Set whether ballpark transformations are allowed.

Since

7.1

Parameters

- `ctx` – PROJ context, or NULL for default context
- `factory_ctx` – Operation factory context. must not be NULL
- `allow` – set to TRUE to allow ballpark transformations.

PJ_OBJ_LIST ***proj_create_operations**(PJ_CONTEXT *ctx, const PJ *source_crs, const PJ *target_crs, const PJ_OPERATION_FACTORY_CONTEXT *operationContext)

Find a list of CoordinateOperation from source_crs to target_crs.

The operations are sorted with the most relevant ones first: by descending area (intersection of the transformation area with the area of interest, or intersection of the transformation with the area of use of the CRS), and by increasing accuracy. Operations with unknown accuracy are sorted last, whatever their area.

When one of the source or target CRS has a vertical component but not the other one, the one that has no vertical component is automatically promoted to a 3D version, where its vertical axis is the ellipsoidal height in metres, using the ellipsoid of the base geodetic CRS.

Parameters

- **`ctx`** – PROJ context, or NULL for default context
- **`source_crs`** – source CRS. Must not be NULL.
- **`target_crs`** – source CRS. Must not be NULL.
- **`operationContext`** – Search context. Must not be NULL.

Returns

a result set that must be unreferenced with *proj_list_destroy()*, or NULL in case of error.

int **`proj_list_get_count`**(const PJ_OBJ_LIST *result)

Return the number of objects in the result set.

Parameters

`result` – Object of type PJ_OBJ_LIST (must not be NULL)

PJ ***`proj_list_get`**(PJ_CONTEXT *ctx, const PJ_OBJ_LIST *result, int index)

Return an object from the result set.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **`ctx`** – PROJ context, or NULL for default context
- **`result`** – Object of type PJ_OBJ_LIST (must not be NULL)
- **`index`** – Index

Returns

a new object that must be unreferenced with proj_destroy(), or nullptr in case of error.

void **`proj_list_destroy`**(PJ_OBJ_LIST *result)

Drops a reference on the result set.

This method should be called one and exactly one for each function returning a PJ_OBJ_LIST*

Parameters

`result` – Object, or NULL.

int **`proj_get_suggested_operation`**(PJ_CONTEXT *ctx, PJ_OBJ_LIST *operations, PJ_DIRECTION direction, PJ_COORD coord)

Return the index of the operation that would be the most appropriate to transform the specified coordinates.

This operation may use resources that are not locally available, depending on the search criteria used by *proj_create_operations()*.

This could be done by using *proj_create_operations()* with a punctual bounding box, but this function is faster when one needs to evaluate on many points with the same (source_crs, target_crs) tuple.

Since
7.1

Parameters

- **ctx** – PROJ context, or NULL for default context
- **operations** – List of operations returned by *proj_create_operations()*
- **direction** – Direction into which to transform the point.
- **coord** – Coordinate to transform

Returns
the index in operations that would be used to transform coord. Or -1 in case of error, or no match.

int **proj_crs_is_derived**(PJ_CONTEXT *ctx, const PJ *crs)

Returns whether a CRS is a derived CRS.

Since
8.0

Parameters

- **ctx** – PROJ context, or NULL for default context
- **crs** – Object of type CRS (must not be NULL)

Returns
TRUE if the CRS is a derived CRS.

PJ ***proj_crs_get_geodetic_crs**(PJ_CONTEXT *ctx, const PJ *crs)

Get the geodeticCRS / geographicCRS from a CRS.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **crs** – Object of type CRS (must not be NULL)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error.

PJ ***proj_crs_get_horizontal_datum**(PJ_CONTEXT *ctx, const PJ *crs)

Get the horizontal datum from a CRS.

This function may return a Datum or DatumEnsemble object.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **crs** – Object of type CRS (must not be NULL)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error.

PJ ***proj_crs_get_sub_crs**(PJ_CONTEXT *ctx, const PJ *crs, int index)

Get a CRS component from a CompoundCRS.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **crs** – Object of type CRS (must not be NULL)
- **index** – Index of the CRS component (typically 0 = horizontal, 1 = vertical)

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error.

PJ ***proj_crs_get_datum**(PJ_CONTEXT *ctx, const PJ *crs)

Returns the datum of a SingleCRS.

If that function returns NULL,

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

See also:

proj_crs_get_datum_ensemble() to potentially get a DatumEnsemble instead.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **crs** – Object of type SingleCRS (must not be NULL)

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error (or if there is no datum)

PJ ***proj_crs_get_datum_ensemble**(PJ_CONTEXT *ctx, const PJ *crs)

Returns the datum ensemble of a SingleCRS.

If that function returns NULL,

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

See also:

proj_crs_get_datum() to potentially get a Datum instead.

Since

7.2

Parameters

- **ctx** – PROJ context, or NULL for default context
- **crs** – Object of type SingleCRS (must not be NULL)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error (or if there is no datum ensemble)

PJ ***proj_crs_get_datum_forced**(PJ_CONTEXT *ctx, const PJ *crs)

Returns a datum for a SingleCRS.

If the SingleCRS has a datum, then this datum is returned. Otherwise, the SingleCRS has a datum ensemble, and this datum ensemble is returned as a regular datum instead of a datum ensemble.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Since
7.2

Parameters

- `ctx` – PROJ context, or NULL for default context
- `crs` – Object of type SingleCRS (must not be NULL)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error (or if there is no datum)

int **proj_datum_ensemble_get_member_count**(PJ_CONTEXT *ctx, const PJ *datum_ensemble)

Returns the number of members of a datum ensemble.

Since
7.2

Parameters

- `ctx` – PROJ context, or NULL for default context
- `datum_ensemble` – Object of type DatumEnsemble (must not be NULL)

double **proj_datum_ensemble_get_accuracy**(PJ_CONTEXT *ctx, const PJ *datum_ensemble)

Returns the positional accuracy of the datum ensemble.

Since
7.2

Parameters

- `ctx` – PROJ context, or NULL for default context
- `datum_ensemble` – Object of type DatumEnsemble (must not be NULL)

Returns
the accuracy, or -1 in case of error.

PJ ***proj_datum_ensemble_get_member**(PJ_CONTEXT *ctx, const PJ *datum_ensemble, int member_index)

Returns a member from a datum ensemble.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Since

7.2

Parameters

- **ctx** – PROJ context, or NULL for default context
- **datum_ensemble** – Object of type DatumEnsemble (must not be NULL)
- **member_index** – Index of the datum member to extract (between 0 and *proj_datum_ensemble_get_member_count()*-1)

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error (or if there is no datum ensemble)

double **proj_dynamic_datum_get_frame_reference_epoch**(PJ_CONTEXT *ctx, const PJ *datum)

Returns the frame reference epoch of a dynamic geodetic or vertical reference frame.

Since

7.2

Parameters

- **ctx** – PROJ context, or NULL for default context
- **datum** – Object of type DynamicGeodeticReferenceFrame or DynamicVerticalReferenceFrame (must not be NULL)

Returns

the frame reference epoch as decimal year, or -1 in case of error.

PJ ***proj_crs_get_coordinate_system**(PJ_CONTEXT *ctx, const PJ *crs)

Returns the coordinate system of a SingleCRS.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **crs** – Object of type SingleCRS (must not be NULL)

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error.

PJ_COORDINATE_SYSTEM_TYPE **proj_cs_get_type**(PJ_CONTEXT *ctx, const PJ *cs)

Returns the type of the coordinate system.

Parameters

- **ctx** – PROJ context, or NULL for default context

- **cs** – Object of type CoordinateSystem (must not be NULL)

Returns
type, or PJ_CS_TYPE_UNKNOWN in case of error.

int **proj_cs_get_axis_count**(PJ_CONTEXT *ctx, const PJ *cs)

Returns the number of axis of the coordinate system.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **cs** – Object of type CoordinateSystem (must not be NULL)

Returns
number of axis, or -1 in case of error.

int **proj_cs_get_axis_info**(PJ_CONTEXT *ctx, const PJ *cs, int index, const char **out_name, const char **out_abbrev, const char **out_direction, double *out_unit_conv_factor, const char **out_unit_name, const char **out_unit_auth_name, const char **out_unit_code)

Returns information on an axis.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **cs** – Object of type CoordinateSystem (must not be NULL)
- **index** – Index of the coordinate system (between 0 and *proj_cs_get_axis_count()* - 1)
- **out_name** – Pointer to a string value to store the axis name. or NULL
- **out_abbrev** – Pointer to a string value to store the axis abbreviation. or NULL
- **out_direction** – Pointer to a string value to store the axis direction. or NULL
- **out_unit_conv_factor** – Pointer to a double value to store the axis unit conversion factor. or NULL
- **out_unit_name** – Pointer to a string value to store the axis unit name. or NULL
- **out_unit_auth_name** – Pointer to a string value to store the axis unit authority name. or NULL
- **out_unit_code** – Pointer to a string value to store the axis unit code. or NULL

Returns
TRUE in case of success

PJ ***proj_get_ellipsoid**(PJ_CONTEXT *ctx, const PJ *obj)

Get the ellipsoid from a CRS or a GeodeticReferenceFrame.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **obj** – Object of type CRS or GeodeticReferenceFrame (must not be NULL)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error.

int **proj_ellipsoid_get_parameters**(PJ_CONTEXT *ctx, const PJ *ellipsoid, double *out_semi_major_metre, double *out_semi_minor_metre, int *out_is_semi_minor_computed, double *out_inv_flattening)

Return ellipsoid parameters.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `ellipsoid` – Object of type Ellipsoid (must not be NULL)
- `out_semi_major_metre` – Pointer to a value to store the semi-major axis in metre. or NULL
- `out_semi_minor_metre` – Pointer to a value to store the semi-minor axis in metre. or NULL
- `out_is_semi_minor_computed` – Pointer to a boolean value to indicate if the semi-minor value was computed. If FALSE, its value comes from the definition. or NULL
- `out_inv_flattening` – Pointer to a value to store the inverse flattening. or NULL

Returns

TRUE in case of success.

PJ ***proj_get_prime_meridian**(PJ_CONTEXT *ctx, const PJ *obj)

Get the prime meridian of a CRS or a GeodeticReferenceFrame.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `obj` – Object of type CRS or GeodeticReferenceFrame (must not be NULL)

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error.

int **proj_prime_meridian_get_parameters**(PJ_CONTEXT *ctx, const PJ *prime_meridian, double *out_longitude, double *out_unit_conv_factor, const char **out_unit_name)

Return prime meridian parameters.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `prime_meridian` – Object of type PrimeMeridian (must not be NULL)
- `out_longitude` – Pointer to a value to store the longitude of the prime meridian, in its native unit. or NULL
- `out_unit_conv_factor` – Pointer to a value to store the conversion factor of the prime meridian longitude unit to radian. or NULL
- `out_unit_name` – Pointer to a string value to store the unit name. or NULL

Returns

TRUE in case of success.

PJ *`proj_crs_get_coordoperation`(PJ_CONTEXT *ctx, const PJ *crs)

Return the Conversion of a DerivedCRS (such as a ProjectedCRS), or the Transformation from the baseCRS to the hubCRS of a BoundCRS.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `crs` – Object of type DerivedCRS or BoundCRSs (must not be NULL)

Returns

Object of type SingleOperation that must be unreferenced with proj_destroy(), or NULL in case of error.

int `proj_coordoperation_get_method_info`(PJ_CONTEXT *ctx, const PJ *coordoperation, const char **out_method_name, const char **out_method_auth_name, const char **out_method_code)

Return information on the operation method of the SingleOperation.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `coordoperation` – Object of type SingleOperation (typically a Conversion or Transformation) (must not be NULL)
- `out_method_name` – Pointer to a string value to store the method (projection) name. or NULL
- `out_method_auth_name` – Pointer to a string value to store the method authority name. or NULL
- `out_method_code` – Pointer to a string value to store the method code. or NULL

Returns

TRUE in case of success.

int `proj_coordoperation_is_instantiable`(PJ_CONTEXT *ctx, const PJ *coordoperation)

Return whether a coordinate operation can be instantiated as a PROJ pipeline, checking in particular that referenced grids are available.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `coordoperation` – Object of type CoordinateOperation or derived classes (must not be NULL)

Returns

TRUE or FALSE.

int `proj_coordoperation_has_ballpark_transformation`(PJ_CONTEXT *ctx, const PJ *coordoperation)

Return whether a coordinate operation has a "ballpark" transformation, that is a very approximate one, due to lack of more accurate transformations.

Typically a null geographic offset between two horizontal datum, or a null vertical offset (or limited to unit changes) between two vertical datum. Errors of several tens to one hundred meters might be expected, compared to more accurate transformations.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **coordoperation** – Object of type CoordinateOperation or derived classes (must not be NULL)

Returns
TRUE or FALSE.

int **proj_coordoperation_get_param_count**(PJ_CONTEXT *ctx, const PJ *coordoperation)

Return the number of parameters of a SingleOperation.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **coordoperation** – Object of type SingleOperation or derived classes (must not be NULL)

int **proj_coordoperation_get_param_index**(PJ_CONTEXT *ctx, const PJ *coordoperation, const char *name)

Return the index of a parameter of a SingleOperation.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **coordoperation** – Object of type SingleOperation or derived classes (must not be NULL)
- **name** – Parameter name. Must not be NULL

Returns
index (>=0), or -1 in case of error.

int **proj_coordoperation_get_param**(PJ_CONTEXT *ctx, const PJ *coordoperation, int index, const char **out_name, const char **out_auth_name, const char **out_code, double *out_value, const char **out_value_string, double *out_unit_conv_factor, const char **out_unit_name, const char **out_unit_auth_name, const char **out_unit_code, const char **out_unit_category)

Return a parameter of a SingleOperation.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **coordoperation** – Object of type SingleOperation or derived classes (must not be NULL)
- **index** – Parameter index.
- **out_name** – Pointer to a string value to store the parameter name. or NULL
- **out_auth_name** – Pointer to a string value to store the parameter authority name. or NULL
- **out_code** – Pointer to a string value to store the parameter code. or NULL
- **out_value** – Pointer to a double value to store the parameter value (if numeric). or NULL
- **out_value_string** – Pointer to a string value to store the parameter value (if of type string). or NULL
- **out_unit_conv_factor** – Pointer to a double value to store the parameter unit conversion factor. or NULL
- **out_unit_name** – Pointer to a string value to store the parameter unit name. or NULL
- **out_unit_auth_name** – Pointer to a string value to store the unit authority name. or NULL
- **out_unit_code** – Pointer to a string value to store the unit code. or NULL

- `out_unit_category` – Pointer to a string value to store the parameter name. or NULL. This value might be "unknown", "none", "linear", "linear_per_time", "angular", "angular_per_time", "scale", "scale_per_time", "time", "parametric" or "parametric_per_time"

Returns
TRUE in case of success.

int **proj_coordoperation_get_grid_used_count**(PJ_CONTEXT *ctx, const PJ *coordoperation)

Return the number of grids used by a CoordinateOperation.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `coordoperation` – Object of type CoordinateOperation or derived classes (must not be NULL)

int **proj_coordoperation_get_grid_used**(PJ_CONTEXT *ctx, const PJ *coordoperation, int index, const char **out_short_name, const char **out_full_name, const char **out_package_name, const char **out_url, int *out_direct_download, int *out_open_license, int *out_available)

Return a parameter of a SingleOperation.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `coordoperation` – Object of type SingleOperation or derived classes (must not be NULL)
- `index` – Parameter index.
- `out_short_name` – Pointer to a string value to store the grid short name. or NULL
- `out_full_name` – Pointer to a string value to store the grid full filename. or NULL
- `out_package_name` – Pointer to a string value to store the package name where the grid might be found. or NULL
- `out_url` – Pointer to a string value to store the grid URL or the package URL where the grid might be found. or NULL
- `out_direct_download` – Pointer to a int (boolean) value to store whether *out_url can be downloaded directly. or NULL
- `out_open_license` – Pointer to a int (boolean) value to store whether the grid is released with an open license. or NULL
- `out_available` – Pointer to a int (boolean) value to store whether the grid is available at runtime. or NULL

Returns
TRUE in case of success.

double **proj_coordoperation_get_accuracy**(PJ_CONTEXT *ctx, const PJ *obj)

Return the accuracy (in metre) of a coordinate operation.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `coordoperation` – Coordinate operation. Must not be NULL.

Returns
the accuracy, or a negative value if unknown or in case of error.

int **proj_coordoperation_get_towgs84_values**(PJ_CONTEXT *ctx, const PJ *coordoperation, double *out_values, int value_count, int emit_error_if_incompatible)

Return the parameters of a Helmert transformation as WKT1 TOWGS84 values.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **coordoperation** – Object of type Transformation, that can be represented as a WKT1 TOWGS84 node (must not be NULL)
- **out_values** – Pointer to an array of value_count double values.
- **value_count** – Size of out_values array. The suggested size is 7 to get translation, rotation and scale difference parameters. Rotation and scale difference terms might be zero if the transformation only includes translation parameters. In that case, value_count could be set to 3.
- **emit_error_if_incompatible** – Boolean to indicate if an error must be logged if coordoperation is not compatible with a WKT1 TOWGS84 representation.

Returns

TRUE in case of success, or FALSE if coordoperation is not compatible with a WKT1 TOWGS84 representation.

PJ ***proj_coordoperation_create_inverse**(PJ_CONTEXT *ctx, const PJ *obj)

Returns a PJ* coordinate operation object which represents the inverse operation of the specified coordinate operation.

Since

6.3

Parameters

- **ctx** – PROJ context, or NULL for default context
- **obj** – Object of type CoordinateOperation (must not be NULL)

Returns

a new PJ* object to free with proj_destroy() in case of success, or nullptr in case of error

int **proj_concatoperation_get_step_count**(PJ_CONTEXT *ctx, const PJ *concatoperation)

Returns the number of steps of a concatenated operation.

The input object must be a concatenated operation.

Parameters

- **ctx** – PROJ context, or NULL for default context
- **concatoperation** – Concatenated operation (must not be NULL)

Returns

the number of steps, or 0 in case of error.

PJ ***proj_concatoperation_get_step**(PJ_CONTEXT *ctx, const PJ *concatoperation, int i_step)

Returns a step of a concatenated operation.

The input object must be a concatenated operation.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- `ctx` – PROJ context, or NULL for default context
- `concatoperation` – Concatenated operation (must not be NULL)
- `i_step` – Index of the step to extract. Between 0 and *proj_concatoperation_get_step_count()*-1

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error.

10.5.4 C++ API

10.5.4.1 General documentation

page `general_doc`

General API design

The design of the class hierarchy is strongly derived from *ISO 19111:2019*.

Classes for which the constructors are not directly accessible have their instances constructed with create() methods. The returned object is a non-null shared pointer. Such objects are immutable, and thread-safe.

TODO

General properties

All classes deriving from IdentifiedObject have general properties that can be defined at creation time. Those properties are:

- *osgeo::proj::metadata::Identifier::DESCRIPTION_KEY* ("description"): the natural language description of the meaning of the code value, provided a a string.
- *osgeo::proj::metadata::Identifier::CODE_KEY* ("code"): a numeric or alphanumeric code, provided as a integer or a string. For example 4326, for the EPSG:4326 "WGS84" GeographicalCRS
- *osgeo::proj::metadata::Identifier::CODESPACE_KEY* ("codespace"): the organization responsible for definition and maintenance of the code., provided a a string. For example "EPSG".
- *osgeo::proj::metadata::Identifier::VERSION_KEY* ("version"): the version identifier for the namespace, provided a a string.
- *osgeo::proj::metadata::Identifier::AUTHORITY_KEY* ("authority"): a citation for the authority, provided as a string or a *osgeo::proj::metadata::Citation* object. Often unused
- *osgeo::proj::metadata::Identifier::URI_KEY* ("uri"): the URI of the identifier, provided as a string. Often unused

- *osgeo::proj::common::IdentifiedObject::NAME_KEY* ("name"): the name of a *osgeo::proj::common::IdentifiedObject*, provided as a string or *osgeo::proj::metadata::IdentifierNNPtr*.

- *osgeo::proj::common::IdentifiedObject::IDENTIFIERS_KEY* ("identifiers"): the identifier(s) of a *osgeo::proj::common::IdentifiedObject*, provided as a osgeo::proj::common::IdentifierNNPtr or a *osgeo::proj::util::ArrayOfBaseObjectNNPtr* of *osgeo::proj::metadata::IdentifierNNPtr*.
- *osgeo::proj::common::IdentifiedObject::ALIAS_KEY* ("alias"): the alias(es) of a *osgeo::proj::common::IdentifiedObject*, provided as string, a *osgeo::proj::util::GenericNameNNPtr* or a *osgeo::proj::util::ArrayOfBaseObjectNNPtr* of *osgeo::proj::util::GenericNameNNPtr*.
- *osgeo::proj::common::IdentifiedObject::REMARKS_KEY* ("remarks"): the remarks of a *osgeo::proj::common::IdentifiedObject*, provided as a string.
- *osgeo::proj::common::IdentifiedObject::DEPRECATED_KEY* ("deprecated"): the deprecation flag of a *osgeo::proj::common::IdentifiedObject*, provided as a boolean.

- *osgeo::proj::common::ObjectUsage::SCOPE_KEY* ("scope"): the scope of a *osgeo::proj::common::ObjectUsage*, provided as a string.
- *osgeo::proj::common::ObjectUsage::DOMAIN_OF_VALIDITY_KEY* ("domainOfValidity"): the domain of validity of a *osgeo::proj::common::ObjectUsage*, provided as a *osgeo::proj::metadata::ExtentNNPtr*.
- *osgeo::proj::common::ObjectUsage::OBJECT_DOMAIN_KEY* ("objectDomain"): the object domain(s) of a *osgeo::proj::common::ObjectUsage*, provided as a *osgeo::proj::common::ObjectDomainNNPtr* or a *osgeo::proj::util::ArrayOfBaseObjectNNPtr* of *osgeo::proj::common::ObjectDomainNNPtr*.

Applicable standards

ISO:19111 / OGC Topic 2 standard

Topic 2 - Spatial referencing by coordinates.

This is an Abstract Specification describes the data elements, relationships and associated metadata required for spatial referencing by coordinates. It describes Coordinate Reference Systems (CRS), coordinate systems (CS) and coordinate transformation or coordinate conversion between two different coordinate reference systems.

ISO 19111:2019

This is the revision mostly used for PROJ C++ modelling.

OGC 18-005r4, 2019-02-08, ISO 19111:2019

ISO 19111:2007

The precedent version of the specification was: OGC 08-015r2, 2010-04-27, ISO 19111:2007

WKT2 standard

Well-known text representation of coordinate reference systems.

Well-known Text (WKT) offers a compact machine- and human-readable representation of the critical elements of coordinate reference system (CRS) definitions, and coordinate operations. This is an implementation of *ISO:19111 / OGC Topic 2 standard*

PROJ implements the two following revisions of the standard:

WKT2:2019

OGC 18-010r7, 2019-06-24, WKT2-2019

WKT2:2015

OGC 12-063r5, 2015-05-01, ISO 19162:2015(E), WKT2-2015

WKT1 specification

Older specifications of well-known text representation of coordinate reference systems are also supported by PROJ, mostly for compatibility with legacy systems, or older versions of GDAL.

GDAL v2.4 and earlier mostly implements:

OGC 01-009, 2001-01-12, OpenGIS Coordinate Transformation Service Implementation Specification

The GDAL documentation, OGC WKT Coordinate System Issues discusses issues, and GDAL implementation choices.

An older specification of WKT1 is/was used by some software packages:

OGC 99-049, 1999-05-05, OpenGIS Simple Features Specification For SQL v1.1

ISO 19115 (Metadata)

Defines the schema required for describing geographic information and services. It provides information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference, and distribution of digital geographic data.

PROJ implements a simplified subset of ISO 19115.

GeoAPI

A set of Java and Python language programming interfaces for geospatial applications.

GeoAPI main page

GeoAPI Javadoc

OGC GeoAPI Implementation Specification

10.5.4.2 common namespace

namespace **common**

Common classes.

osgeo.proj.common namespace

Typedefs

typedef std::shared_ptr<*UnitOfMeasure*> **UnitOfMeasurePtr**

Shared pointer of *UnitOfMeasure*.

typedef *util*::nn<*UnitOfMeasurePtr*> **UnitOfMeasureNNPtr**

Non-null shared pointer of *UnitOfMeasure*.

typedef std::shared_ptr<*IdentifiedObject*> **IdentifiedObjectPtr**

Shared pointer of *IdentifiedObject*.

typedef *util*::nn<*IdentifiedObjectPtr*> **IdentifiedObjectNNPtr**

Non-null shared pointer of *IdentifiedObject*.

using **ObjectDomainPtr** = std::shared_ptr<*ObjectDomain*>

Shared pointer of *ObjectDomain*.

using **ObjectDomainNNPtr** = *util*::nn<*ObjectDomainPtr*>

Non-null shared pointer of *ObjectDomain*.

using **ObjectUsagePtr** = std::shared_ptr<*ObjectUsage*>

Shared pointer of *ObjectUsage*.

using **ObjectUsageNNPtr** = *util*::nn<*ObjectUsagePtr*>

Non-null shared pointer of *ObjectUsage*.

class **UnitOfMeasure** : public osgeo::proj::*util*::*BaseObject*

#include <common.hpp> Unit of measure.

This is a mutable object.

Public Types

enum class **Type**

Type of unit of measure.

Values:

enumerator **UNKNOWN**

Unknown unit of measure

enumerator **NONE**

No unit of measure

enumerator **ANGULAR**

Angular unit of measure

enumerator **LINEAR**

Linear unit of measure

enumerator **SCALE**

Scale unit of measure

enumerator **TIME**

Time unit of measure

enumerator **PARAMETRIC**

Parametric unit of measure

Public Functions

UnitOfMeasure(const std::string &nameIn = std::string(), double toSIIn = 1.0, *Type* typeIn = *Type*::*UNKNOWN*, const std::string &codeSpaceIn = std::string(), const std::string &codeIn = std::string())

Creates a *UnitOfMeasure*.

const std::string &**name**()

Return the name of the unit of measure.

double **conversionToSI**()

Return the conversion factor to the unit of the International System of Units of the same Type.

For example, for foot, this would be 0.3048 (metre)

Returns

the conversion factor, or 0 if no conversion exists.

Type **type**()

Return the type of the unit of measure.

const std::string &**codeSpace**()

Return the code space of the unit of measure.

For example "EPSG"

Returns

the code space, or empty string.

const std::string &**code**()

Return the code of the unit of measure.

Returns
the code, or empty string.

bool **operator==**(const *UnitOfMeasure* &other)

Returns whether two units of measures are equal.

The comparison is based on the name.

bool **operator!=**(const *UnitOfMeasure* &other)

Returns whether two units of measures are different.

The comparison is based on the name.

Public Static Attributes

static const *UnitOfMeasure* **NONE**

"Empty"/"None", unit of measure of type NONE.

static const *UnitOfMeasure* **SCALE_UNITY**

Scale unity, unit of measure of type SCALE.

static const *UnitOfMeasure* **PARTS_PER_MILLION**

Parts-per-million, unit of measure of type SCALE.

static const *UnitOfMeasure* **PPM_PER_YEAR**

Parts-per-million per year, unit of measure of type SCALE.

static const *UnitOfMeasure* **METRE**

Metre, unit of measure of type LINEAR (SI unit).

static const *UnitOfMeasure* **METRE_PER_YEAR**

Metre per year, unit of measure of type LINEAR.

static const *UnitOfMeasure* **RADIAN**

Radian, unit of measure of type ANGULAR (SI unit).

static const *UnitOfMeasure* **MICRORADIAN**

Microradian, unit of measure of type ANGULAR.

static const *UnitOfMeasure* **DEGREE**

Degree, unit of measure of type ANGULAR.

static const *UnitOfMeasure* **ARC_SECOND**

Arc-second, unit of measure of type ANGULAR.

static const *UnitOfMeasure* **GRAD**

Grad, unit of measure of type ANGULAR.

static const *UnitOfMeasure* **ARC_SECOND_PER_YEAR**

Arc-second per year, unit of measure of type ANGULAR.

static const *UnitOfMeasure* **SECOND**

Second, unit of measure of type TIME (SI unit).

static const *UnitOfMeasure* **YEAR**

Year, unit of measure of type TIME.

class **Measure** : public osgeo::proj::*util*::*BaseObject*

#include <common.hpp> Numeric value associated with a *UnitOfMeasure*.

Subclassed by *osgeo::proj::common::Angle*, *osgeo::proj::common::Length*, *osgeo::proj::common::Scale*

Public Functions

Measure(double valueIn = 0.0, const *UnitOfMeasure* &unitIn = *UnitOfMeasure*())

Instantiate a *Measure*.

const *UnitOfMeasure* &**unit**()

Return the unit of the *Measure*.

double **getSIValue**()

Return the value of the *Measure*, after conversion to the corresponding unit of the International System.

double **value**()

Return the value of the measure, expressed in the *unit()*

double **convertToUnit**(const *UnitOfMeasure* &otherUnit)

Return the value of this measure expressed into the provided unit.

bool **operator==**(const *Measure* &other)

Return whether two measures are equal.

The comparison is done both on the value and the unit.

bool **_isEquivalentTo**(const *Measure* &other, *util*::*IComparable*::*Criterion* criterion = *util*::*IComparable*::*Criterion*::*STRICT*, double maxRelativeError = *DEFAULT_MAX_REL_ERROR*) const

Returns whether an object is equivalent to another one.

Parameters

- **other** – other object to compare to
- **criterion** – comparison criterion.
- **maxRelativeError** – Maximum relative error allowed.

Returns

true if objects are equivalent.

Public Static Attributes

static constexpr double **DEFAULT_MAX_REL_ERROR** = 1e-10

Default maximum resulative error.

class **Scale** : public osgeo::proj::*common*::*Measure*

#include <common.hpp> Numeric value, without a physical unit of measure.

Public Functions

explicit **Scale**(double valueIn = 0.0)

Instantiate a *Scale*.

Parameters

valueIn – value

explicit **Scale**(double valueIn, const *UnitOfMeasure* &unitIn)

Instantiate a *Scale*.

Parameters

- **valueIn** – value
- **unitIn** – unit. Constraint: unit.type() == *UnitOfMeasure::Type::SCALE*

class **Angle** : public osgeo::proj::*common*::*Measure*

#include <common.hpp> Numeric value, with a angular unit of measure.

Public Functions

explicit **Angle**(double valueIn = 0.0)

Instantiate a *Angle*.

Parameters

valueIn – value

Angle(double valueIn, const *UnitOfMeasure* &unitIn)

Instantiate a *Angle*.

Parameters

- **valueIn** – value
- **unitIn** – unit. Constraint: unit.type() == *UnitOfMeasure::Type::ANGULAR*

class **Length** : public osgeo::proj::*common*::*Measure*

#include <common.hpp> Numeric value, with a linear unit of measure.

Public Functions

explicit **Length**(double valueIn = 0.0)

Instantiate a *Length*.

Parameters

valueIn – value

Length(double valueIn, const *UnitOfMeasure* &unitIn)

Instantiate a *Length*.

Parameters

- **valueIn** – value
- **unitIn** – unit. Constraint: unit.type() == *UnitOfMeasure::Type::LINEAR*

class **DateTime**

#include <common.hpp> Date-time value, as a ISO:8601 encoded string, or other string encoding.

Public Functions

bool **isISO_8601**() const

Return whether the *DateTime* is ISO:8601 compliant.

Remark

The current implementation is really simplistic, and aimed at detecting date-times that are not ISO:8601 compliant.

std::string **toString**() const

Return the *DateTime* as a string.

Public Static Functions

static *DateTime* **create**(const std::string &str)

Instantiate a *DateTime*.

class **DataEpoch**

#include <common.hpp> Data epoch.

Public Functions

const *Measure* &**coordinateEpoch**() const

Return the coordinate epoch, as a measure in decimal year.

class **IdentifiedObject** : public osgeo::proj::*util*::*BaseObject*, public osgeo::proj::*util*::*IComparable*, public osgeo::proj::*io*::*IWKTExportable*

#include <common.hpp> Abstract class representating a CRS-related object that has an identification.

Remark

Implements *IdentifiedObject* from *ISO 19111:2019*

Subclassed by *osgeo::proj::common::ObjectUsage*, *osgeo::proj::cs::CoordinateSystem*, *osgeo::proj::cs::CoordinateSystemAxis*, *osgeo::proj::cs::Meridian*, *osgeo::proj::datum::Ellipsoid*, *osgeo::proj::datum::PrimeMeridian*, *osgeo::proj::operation::GeneralOperationParameter*, *osgeo::proj::operation::OperationMethod*

Public Functions

const *metadata*::*IdentifierNNPtr* &**name**()

Return the name of the object.

Generally, the only interesting field of the name will be *name()*->description().

const std::string &**nameStr**()

Return the name of the object.

Return *(*name()*->description())

const std::vector<*metadata*::*IdentifierNNPtr*> &**identifiers**()

Return the identifier(s) of the object.

Generally, those will have Identifier::code() and Identifier::codeSpace() filled.

const std::vector<*util*::*GenericNameNNPtr*> &**aliases**()

Return the alias(es) of the object.

const std::string &**remarks**()

Return the remarks.

bool **isDeprecated**()

Return whether the object is deprecated.

Remark

Extension of *ISO 19111:2019*

std::string **alias**()

Return the (first) alias of the object as a string.

Shortcut for *aliases()*[0]->toFullyQualifiedName()->toString()

int **getEPSGCode**()

Return the EPSG code.

Returns

code, or 0 if not found

Public Static Attributes

static const std::string **NAME_KEY**

Key to set the name of a *common::IdentifiedObject*.

The value is to be provided as a string or *metadata::IdentifierNNPtr*.

static const std::string **IDENTIFIERS_KEY**

Key to set the identifier(s) of a *common::IdentifiedObject*.

The value is to be provided as a common::IdentifierNNPtr or a *util::ArrayOfBaseObjectNNPtr* of common::IdentifierNNPtr.

static const std::string **ALIAS_KEY**

Key to set the alias(es) of a *common::IdentifiedObject*.

The value is to be provided as string, a *util::GenericNameNNPtr* or a *util::ArrayOfBaseObjectNNPtr* of *util::GenericNameNNPtr*.

static const std::string **REMARKS_KEY**

Key to set the remarks of a *common::IdentifiedObject*.

The value is to be provided as a string.

static const std::string **DEPRECATED_KEY**

Key to set the deprecation flag of a *common::IdentifiedObject*.

The value is to be provided as a boolean.

class **ObjectDomain** : public osgeo::proj::*util*::*BaseObject*, public osgeo::proj::*util*::*IComparable*

#include <common.hpp> The scope and validity of a CRS-related object.

Remark

Implements *ObjectDomain* from *ISO 19111:2019*

Public Functions

const *util*::*optional*<std::string> &**scope**()

Return the scope.

Returns

the scope, or empty.

const *metadata*::*ExtentPtr* &**domainOfValidity**()

Return the domain of validity.

Returns

the domain of validity, or nullptr.

Public Static Functions

static *ObjectDomainNNPtr* **create**(const *util*::*optional*<std::string> &scopeIn, const *metadata*::*ExtentPtr* &extent)

Instantiate a *ObjectDomain*.

class **ObjectUsage** : public osgeo::proj::*common*::*IdentifiedObject*

#include <common.hpp> Abstract class of a CRS-related object that has usages.

Remark

Implements *ObjectUsage* from *ISO 19111:2019*

Subclassed by *osgeo::proj::crs::CRS*, *osgeo::proj::datum::Datum*, *osgeo::proj::datum::DatumEnsemble*, *osgeo::proj::operation::CoordinateOperation*

Public Functions

const std::vector<*ObjectDomainNNPtr*> &**domains**()

Return the domains of the object.

Public Static Attributes

static const std::string **SCOPE_KEY**

Key to set the scope of a *common::ObjectUsage*.

The value is to be provided as a string.

static const std::string **DOMAIN_OF_VALIDITY_KEY**

Key to set the domain of validity of a *common::ObjectUsage*.

The value is to be provided as a common::ExtentNNPtr.

static const std::string **OBJECT_DOMAIN_KEY**

Key to set the object domain(s) of a *common::ObjectUsage*.

The value is to be provided as a *common::ObjectDomainNNPtr* or a *util::ArrayOfBaseObjectNNPtr* of *common::ObjectDomainNNPtr*.

10.5.4.3 util namespace

namespace **util**

A set of base types from ISO 19103, *GeoAPI* and other PROJ specific classes.

osgeo.proj.util namespace.

Typedefs

using **BaseObjectPtr** = std::shared_ptr<*BaseObject*>

Shared pointer of *BaseObject*.

using **BoxedValuePtr** = std::shared_ptr<*BoxedValue*>

Shared pointer of *BoxedValue*.

using **BoxedValueNNPtr** = *util*::nn<*BoxedValuePtr*>

Non-null shared pointer of *BoxedValue*.

using **ArrayOfBaseObjectPtr** = std::shared_ptr<*ArrayOfBaseObject*>

Shared pointer of *ArrayOfBaseObject*.

using **ArrayOfBaseObjectNNPtr** = *util*::nn<*ArrayOfBaseObjectPtr*>

Non-null shared pointer of *ArrayOfBaseObject*.

using **LocalNamePtr** = std::shared_ptr<*LocalName*>

Shared pointer of *LocalName*.

using **LocalNameNNPtr** = *util*::nn<*LocalNamePtr*>

Non-null shared pointer of *LocalName*.

using **NameSpacePtr** = std::shared_ptr<*NameSpace*>

Shared pointer of *NameSpace*.

using **NameSpaceNNPtr** = *util*::nn<*NameSpacePtr*>

Non-null shared pointer of *NameSpace*.

using **GenericNamePtr** = std::shared_ptr<*GenericName*>

Shared pointer of *GenericName*.

using **GenericNameNNPtr** = *util*::nn<*GenericNamePtr*>

Non-null shared pointer of *GenericName*.

template<class **T**>

class **optional**

#include <util.hpp> Loose transposition of std::optional available from C++17.

Public Functions

inline const *T* ***operator->**() const

Returns a pointer to the contained value.

inline const *T* &**operator***() const

Returns a reference to the contained value.

inline explicit **operator bool**() const noexcept

Return whether the optional has a value

inline bool **has_value**() const noexcept

Return whether the optional has a value

struct **BaseObjectNNPtr** : public *util*::nn<*BaseObjectPtr*>

#include <util.hpp> Non-null shared pointer of *BaseObject*.

class **BaseObject**

#include <util.hpp> Class that can be derived from, to emulate Java's Object behavior.

Subclassed by *osgeo::proj::common::IdentifiedObject*, *osgeo::proj::common::Measure*, *osgeo::proj::common::ObjectDomain*, *osgeo::proj::common::UnitOfMeasure*, *osgeo::proj::metadata::Citation*, *osgeo::proj::metadata::Extent*, *osgeo::proj::metadata::GeographicExtent*, *osgeo::proj::metadata::Identifier*, *osgeo::proj::metadata::PositionalAccuracy*, *osgeo::proj::metadata::TemporalExtent*, *osgeo::proj::metadata::VerticalExtent*, *osgeo::proj::operation::GeneralParameterValue*, *osgeo::proj::operation::ParameterValue*, *osgeo::proj::util::ArrayOfBaseObject*, *osgeo::proj::util::BoxedValue*, *osgeo::proj::util::GenericName*

class **IComparable**

#include <util.hpp> Interface for an object that can be compared to another.

Subclassed by *osgeo::proj::common::IdentifiedObject*, *osgeo::proj::common::ObjectDomain*, *osgeo::proj::metadata::Extent*, *osgeo::proj::metadata::GeographicExtent*, *osgeo::proj::metadata::TemporalExtent*, *osgeo::proj::metadata::VerticalExtent*, *osgeo::proj::operation::GeneralParameterValue*, *osgeo::proj::operation::ParameterValue*

Public Types

enum class **Criterion**

Comparison criterion.

Values:

enumerator **STRICT**

All properties are identical.

enumerator **EQUIVALENT**

The objects are equivalent for the purpose of coordinate operations. They can differ by the name of their objects, identifiers, other metadata. Parameters may be expressed in different units, provided that the value is (with some tolerance) the same once expressed in a common unit.

enumerator **EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS**

Same as EQUIVALENT, relaxed with an exception that the axis order of the base CRS of a DerivedCRS/ProjectedCRS or the axis order of a GeographicCRS is ignored. Only to be used with DerivedCRS/ProjectedCRS/GeographicCRS

Public Functions

bool **isEquivalentTo**(const *IComparable* *other, *Criterion* criterion = *Criterion*::*STRICT*, const *io*::*DatabaseContextPtr* &dbContext = nullptr) const

Returns whether an object is equivalent to another one.

Parameters

- **other** – other object to compare to
- **criterion** – comparison criterion.
- **dbContext** – Database context, or nullptr.

Returns

true if objects are equivalent.

class **BoxedValue** : public osgeo::proj::*util*::*BaseObject*

#include <util.hpp> Encapsulate standard datatypes in an object.

Public Functions

BoxedValue(const char *stringValueIn)

Constructs a *BoxedValue* from a string.

BoxedValue(const std::string &stringValueIn)

Constructs a *BoxedValue* from a string.

BoxedValue(int integerValueIn)

Constructs a *BoxedValue* from an integer.

BoxedValue(bool booleanValueIn)

Constructs a *BoxedValue* from a boolean.

class **ArrayOfBaseObject** : public osgeo::proj::*util*::*BaseObject*

#include <util.hpp> Array of *BaseObject*.

Public Functions

void **add**(const *BaseObjectNNPtr* &obj)

Adds an object to the array.

Parameters

obj – the object to add.

Public Static Functions

static *ArrayOfBaseObjectNNPtr* **create**()

Instantiate a *ArrayOfBaseObject*.

Returns

a new *ArrayOfBaseObject*.

class **PropertyMap**

#include <util.hpp> Wrapper of a std::map<std::string, BaseObjectNNPtr>

Public Functions

PropertyMap &**set**(const std::string &key, const *BaseObjectNNPtr* &val)

Set a *BaseObjectNNPtr* as the value of a key.

PropertyMap &**set**(const std::string &key, const char *val)

Set a string as the value of a key.

PropertyMap &**set**(const std::string &key, const std::string &val)

Set a string as the value of a key.

PropertyMap &**set**(const std::string &key, int val)

Set a integer as the value of a key.

PropertyMap &**set**(const std::string &key, bool val)

Set a boolean as the value of a key.

PropertyMap &**set**(const std::string &key, const std::vector<std::string> &array)

Set a vector of strings as the value of a key.

class **GenericName** : public osgeo::proj::*util*::*BaseObject*

#include <util.hpp> A sequence of identifiers rooted within the context of a namespace.

Remark

Simplified version of GenericName from *GeoAPI*

Subclassed by *osgeo::proj::util::LocalName*

Public Functions

virtual const *NameSpacePtr* **scope**() const = 0

Return the scope of the object, possibly a global one.

virtual std::string **toString**() const = 0

Return the *LocalName* as a string.

virtual *GenericNameNNPtr* **toFullyQualifiedName**() const = 0

Return a fully qualified name corresponding to the local name.

The namespace of the resulting name is a global one.

class **NameSpace**

#include <util.hpp> A domain in which names given by strings are defined.

Remark

Simplified version of NameSpace from *GeoAPI*

Public Functions

bool **isGlobal()** const

Returns whether this is a global namespace.

const *GenericNamePtr* &**name()** const

Returns the name of this namespace.

class **LocalName** : public osgeo::proj::*util*::*GenericName*

#include <util.hpp> Identifier within a *NameSpace* for a local object.

Local names are names which are directly accessible to and maintained by a *NameSpace* within which they are local, indicated by the scope.

Remark

Simplified version of LocalName from *GeoAPI*

Public Functions

virtual const *NameSpacePtr* **scope()** const override

Return the scope of the object, possibly a global one.

virtual std::string **toString()** const override

Return the *LocalName* as a string.

virtual *GenericNameNNPtr* **toFullyQualifiedName()** const override

Return a fully qualified name corresponding to the local name.

The namespace of the resulting name is a global one.

class **NameFactory**

#include <util.hpp> Factory for generic names.

Remark

Simplified version of NameFactory from *GeoAPI*

Public Static Functions

static *NameSpaceNNPtr* **createNameSpace**(const *GenericNameNNPtr* &name, const *PropertyMap* &properties)

Instantiate a *NameSpace*.

Parameters
- **name** – name of the namespace.
- **properties** – Properties. Allowed keys are "separator" and "separator.head".

Returns
a new *NameFactory*.

static *LocalNameNNPtr* **createLocalName**(const *NameSpacePtr* &scope, const std::string &name)

Instantiate a *LocalName*.

Parameters
- **scope** – scope.
- **name** – string of the local name.

Returns
a new *LocalName*.

static *GenericNameNNPtr* **createGenericName**(const *NameSpacePtr* &scope, const std::vector<std::string> &parsedNames)

Instantiate a *GenericName*.

Parameters
- **scope** – scope.
- **parsedNames** – the components of the name.

Returns
a new *GenericName*.

class **CodeList**

#include <util.hpp> Abstract class to define an enumeration of values.

Subclassed by *osgeo::proj::cs::AxisDirection*, *osgeo::proj::datum::RealizationMethod*

Public Functions

inline const std::string &**toString**()

Return the *CodeList* item as a string.

inline **operator std::string**()

Return the *CodeList* item as a string.

class **Exception** : public std::exception

#include <util.hpp> Root exception class.

Subclassed by *osgeo::proj::crs::InvalidCompoundCRSException*, *osgeo::proj::io::FactoryException*, *osgeo::proj::io::FormattingException*, *osgeo::proj::io::ParsingException*, *osgeo::proj::operation::InvalidOperation*, *osgeo::proj::util::InvalidValueTypeException*, *osgeo::proj::util::UnsupportedOperationException*

Public Functions

virtual const char ***what**() const noexcept override

Return the exception text.

class **InvalidValueTypeException** : public osgeo::proj::*util*::*Exception*

#include <util.hpp> *Exception* thrown when an invalid value type is set as the value of a key of a *PropertyMap*.

class **UnsupportedOperationException** : public osgeo::proj::*util*::*Exception*

#include <util.hpp> *Exception* Thrown to indicate that the requested operation is not supported.

10.5.4.4 metadata namespace

namespace **metadata**

Common classes from *ISO 19115 (Metadata)* standard.

osgeo.proj.metadata namespace

Typedefs

typedef std::shared_ptr<*Extent*> **ExtentPtr**

Shared pointer of *Extent*.

typedef *util*::nn<*ExtentPtr*> **ExtentNNPtr**

Non-null shared pointer of *Extent*.

using **GeographicExtentPtr** = std::shared_ptr<*GeographicExtent*>

Shared pointer of *GeographicExtent*.

using **GeographicExtentNNPtr** = *util*::nn<*GeographicExtentPtr*>

Non-null shared pointer of *GeographicExtent*.

using **GeographicBoundingBoxPtr** = std::shared_ptr<*GeographicBoundingBox*>

Shared pointer of *GeographicBoundingBox*.

using **GeographicBoundingBoxNNPtr** = *util*::nn<*GeographicBoundingBoxPtr*>

Non-null shared pointer of *GeographicBoundingBox*.

using **TemporalExtentPtr** = std::shared_ptr<*TemporalExtent*>

Shared pointer of *TemporalExtent*.

using **TemporalExtentNNPtr** = *util*::nn<*TemporalExtentPtr*>

Non-null shared pointer of *TemporalExtent*.

using **VerticalExtentPtr** = std::shared_ptr<*VerticalExtent*>

Shared pointer of *VerticalExtent*.

using **VerticalExtentNNPtr** = *util*::nn<*VerticalExtentPtr*>

Non-null shared pointer of *VerticalExtent*.

using **IdentifierPtr** = std::shared_ptr<*Identifier*>

Shared pointer of *Identifier*.

using **IdentifierNNPtr** = *util*::nn<*IdentifierPtr*>

Non-null shared pointer of *Identifier*.

using **PositionalAccuracyPtr** = std::shared_ptr<*PositionalAccuracy*>

Shared pointer of *PositionalAccuracy*.

using **PositionalAccuracyNNPtr** = *util*::nn<*PositionalAccuracyPtr*>

Non-null shared pointer of *PositionalAccuracy*.

class **Citation** : public osgeo::proj::*util*::*BaseObject*

#include <metadata.hpp> Standardized resource reference.

A citation contains a title.

Remark

Simplified version of Citation from *GeoAPI*

Public Functions

explicit **Citation**(const std::string &titleIn)

Constructs a citation by its title.

const *util*::*optional*<std::string> &**title**()

Returns the name by which the cited resource is known.

class **GeographicExtent** : public osgeo::proj::*util*::*BaseObject*, public osgeo::proj::*util*::*IComparable*

#include <metadata.hpp> Base interface for geographic area of the dataset.

Remark

Simplified version of GeographicExtent from *GeoAPI*

Subclassed by *osgeo::proj::metadata::GeographicBoundingBox*

Public Functions

virtual bool **contains**(const *GeographicExtentNNPtr* &other) const = 0

Returns whether this extent contains the other one.

virtual bool **intersects**(const *GeographicExtentNNPtr* &other) const = 0

Returns whether this extent intersects the other one.

virtual *GeographicExtentPtr* **intersection**(const *GeographicExtentNNPtr* &other) const = 0

Returns the intersection of this extent with another one.

class **GeographicBoundingBox** : public osgeo::proj::*metadata*::*GeographicExtent*

#include <metadata.hpp> Geographic position of the dataset.

This is only an approximate so specifying the co-ordinate reference system is unnecessary.

Remark

Implements GeographicBoundingBox from *GeoAPI*

Public Functions

double **westBoundLongitude**()

Returns the western-most coordinate of the limit of the dataset extent.

The unit is degrees.

If eastBoundLongitude < *westBoundLongitude()*, then the bounding box crosses the anti-meridian.

double **southBoundLatitude**()

Returns the southern-most coordinate of the limit of the dataset extent.

The unit is degrees.

double **eastBoundLongitude**()

Returns the eastern-most coordinate of the limit of the dataset extent.

The unit is degrees.

If eastBoundLongitude < *westBoundLongitude()*, then the bounding box crosses the anti-meridian.

double **northBoundLatitude**()

Returns the northern-most coordinate of the limit of the dataset extent.

The unit is degrees.

virtual bool **contains**(const *GeographicExtentNNPtr* &other) const override

Returns whether this extent contains the other one.

virtual bool **intersects**(const *GeographicExtentNNPtr* &other) const override

Returns whether this extent intersects the other one.

virtual *GeographicExtentPtr* **intersection**(const *GeographicExtentNNPtr* &other) const override

Returns the intersection of this extent with another one.

Public Static Functions

static *GeographicBoundingBoxNNPtr* **create**(double west, double south, double east, double north)

Instantiate a *GeographicBoundingBox*.

If east < west, then the bounding box crosses the anti-meridian.

Parameters
- **west** – Western-most coordinate of the limit of the dataset extent (in degrees).
- **south** – Southern-most coordinate of the limit of the dataset extent (in degrees).
- **east** – Eastern-most coordinate of the limit of the dataset extent (in degrees).
- **north** – Northern-most coordinate of the limit of the dataset extent (in degrees).

Returns
a new *GeographicBoundingBox*.

class **TemporalExtent** : public osgeo::proj::*util*::*BaseObject*, public osgeo::proj::*util*::*IComparable*

#include <metadata.hpp> Time period covered by the content of the dataset.

Remark

Simplified version of TemporalExtent from *GeoAPI*

Public Functions

const std::string &**start**()

Returns the start of the temporal extent.

const std::string &**stop**()

Returns the end of the temporal extent.

bool **contains**(const *TemporalExtentNNPtr* &other) const

Returns whether this extent contains the other one.

bool **intersects**(const *TemporalExtentNNPtr* &other) const

Returns whether this extent intersects the other one.

Public Static Functions

static *TemporalExtentNNPtr* **create**(const std::string &start, const std::string &stop)

Instantiate a *TemporalExtent*.

Parameters
- **start** – start.
- **stop** – stop.

Returns
a new *TemporalExtent*.

class **VerticalExtent** : public osgeo::proj::*util*::*BaseObject*, public osgeo::proj::*util*::*IComparable*

#include <metadata.hpp> Vertical domain of dataset.

Remark

Simplified version of VerticalExtent from *GeoAPI*

Public Functions

double **minimumValue**()

Returns the minimum of the vertical extent.

double **maximumValue**()

Returns the maximum of the vertical extent.

common::*UnitOfMeasureNNPtr* &**unit**()

Returns the unit of the vertical extent.

bool **contains**(const *VerticalExtentNNPtr* &other) const

Returns whether this extent contains the other one.

bool **intersects**(const *VerticalExtentNNPtr* &other) const

Returns whether this extent intersects the other one.

Public Static Functions

static *VerticalExtentNNPtr* **create**(double minimumValue, double maximumValue, const *common*::*UnitOfMeasureNNPtr* &unitIn)

Instantiate a *VerticalExtent*.

Parameters

- **minimumIn** – minimum.
- **maximumIn** – maximum.
- **unitIn** – unit.

Returns

a new *VerticalExtent*.

class **Extent** : public osgeo::proj::*util*::*BaseObject*, public osgeo::proj::*util*::*IComparable*

#include <metadata.hpp> Information about spatial, vertical, and temporal extent.

Remark

Simplified version of Extent from *GeoAPI*

Public Functions

const *util*::*optional*<std::string> &**description**()

Return a textual description of the extent.

Returns
the description, or empty.

const std::vector<*GeographicExtentNNPtr*> &**geographicElements**()

Return the geographic element(s) of the extent

Returns
the geographic element(s), or empty.

const std::vector<*TemporalExtentNNPtr*> &**temporalElements**()

Return the temporal element(s) of the extent

Returns
the temporal element(s), or empty.

const std::vector<*VerticalExtentNNPtr*> &**verticalElements**()

Return the vertical element(s) of the extent

Returns
the vertical element(s), or empty.

bool **contains**(const *ExtentNNPtr* &other) const

Returns whether this extent contains the other one.

Behavior only well specified if each sub-extent category as at most one element.

bool **intersects**(const *ExtentNNPtr* &other) const

Returns whether this extent intersects the other one.

Behavior only well specified if each sub-extent category as at most one element.

ExtentPtr **intersection**(const *ExtentNNPtr* &other) const

Returns the intersection of this extent with another one.

Behavior only well specified if there is one single *GeographicExtent* in each object. Returns nullptr otherwise.

Public Static Functions

static *ExtentNNPtr* **create**(const *util*::*optional*<std::string> &descriptionIn, const std::vector<*GeographicExtentNNPtr*> &geographicElementsIn, const std::vector<*VerticalExtentNNPtr*> &verticalElementsIn, const std::vector<*TemporalExtentNNPtr*> &temporalElementsIn)

Instantiate a *Extent*.

Parameters
- **descriptionIn** – Textual description, or empty.
- **geographicElementsIn** – Geographic element(s), or empty.
- **verticalElementsIn** – Vertical element(s), or empty.
- **temporalElementsIn** – Temporal element(s), or empty.

Returns
a new *Extent*.

static *ExtentNNPtr* **createFromBBOX**(double west, double south, double east, double north, const *util*::*optional*<std::string> &descriptionIn = *util*::*optional*<std::string>())

Instantiate a *Extent* from a bounding box.

Parameters

- **west** – Western-most coordinate of the limit of the dataset extent (in degrees).
- **south** – Southern-most coordinate of the limit of the dataset extent (in degrees).
- **east** – Eastern-most coordinate of the limit of the dataset extent (in degrees).
- **north** – Northern-most coordinate of the limit of the dataset extent (in degrees).
- **descriptionIn** – Textual description, or empty.

Returns

a new *Extent*.

Public Static Attributes

static const *ExtentNNPtr* **WORLD**

World extent.

class **Identifier** : public osgeo::proj::*util*::*BaseObject*, public osgeo::proj::*io*::*IWKTExportable*, public osgeo::proj::*io*::*IJSONExportable*

#include <metadata.hpp> Value uniquely identifying an object within a namespace.

Remark

Implements *Identifier* as described in *ISO 19111:2019* but which originates from *ISO 19115 (Metadata)*

Public Functions

const *util*::*optional*<*Citation*> &**authority**()

Return a citation for the organization responsible for definition and maintenance of the code.

Returns

the citation for the authority, or empty.

const std::string &**code**()

Return the alphanumeric value identifying an instance in the codespace.

e.g. “4326” (for EPSG:4326 WGS 84 GeographicCRS)

Returns

the code.

const *util*::*optional*<std::string> &**codeSpace**()

Return the organization responsible for definition and maintenance of the code.

e.g “EPSG”

Returns

the authority codespace, or empty.

const *util*::*optional*<std::string> &**version**()

Return the version identifier for the namespace.

When appropriate, the edition is identified by the effective date, coded using ISO 8601 date format.

Returns

the version or empty.

const *util*::*optional*<std::string> &**description**()

Return the natural language description of the meaning of the code value.

Returns
the description or empty.

const *util*::*optional*<std::string> &**uri**()

Return the URI of the identifier.

Returns
the URI or empty.

Public Static Functions

static *IdentifierNNPtr* **create**(const std::string &codeIn = std::string(), const *util*::*PropertyMap* &properties = *util*::*PropertyMap*())

Instantiate a *Identifier*.

Parameters
- **codeIn** – Alphanumeric value identifying an instance in the codespace
- **properties** – See *General properties*. Generally, the *Identifier::CODESPACE_KEY* should be set.

Returns
a new *Identifier*.

static bool **isEquivalentName**(const char *a, const char *b) noexcept

Returns whether two names are considered equivalent.

Two names are equivalent by removing any space, underscore, dash, slash, { or } character from them, and comparing in a case insensitive way.

Public Static Attributes

static const std::string **AUTHORITY_KEY**

Key to set the authority citation of a *metadata::Identifier*.

The value is to be provided as a string or a *metadata::Citation*.

static const std::string **CODE_KEY**

Key to set the code of a *metadata::Identifier*.

The value is to be provided as a integer or a string.

static const std::string **CODESPACE_KEY**

Key to set the organization responsible for definition and maintenance of the code of a *metadata::Identifier*.

The value is to be provided as a string.

static const std::string **VERSION_KEY**

Key to set the version identifier for the namespace of a *metadata::Identifier*.

The value is to be provided as a string.

static const std::string **DESCRIPTION_KEY**

Key to set the natural language description of the meaning of the code value of a *metadata::Identifier*.

The value is to be provided as a string.

static const std::string **URI_KEY**

Key to set the URI of a *metadata::Identifier*.

The value is to be provided as a string.

static const std::string **EPSG**

EPSG codespace.

static const std::string **OGC**

OGC codespace.

class **PositionalAccuracy** : public osgeo::proj::*util*::*BaseObject*

#include <metadata.hpp> Accuracy of the position of features.

Remark

Simplified version of PositionalAccuracy from *GeoAPI*, which originates from *ISO 19115 (Metadata)*

Public Functions

const std::string &**value**()

Return the value of the positional accuracy.

Public Static Functions

static *PositionalAccuracyNNPtr* **create**(const std::string &valueIn)

Instantiate a *PositionalAccuracy*.

Parameters

valueIn – positional accuracy value.

Returns

a new *PositionalAccuracy*.

10.5.4.5 cs namespace

namespace **cs**

Coordinate systems and their axis.

osgeo.proj.cs namespace

Typedefs

using **MeridianPtr** = std::shared_ptr<*Meridian*>

Shared pointer of *Meridian*.

using **MeridianNNPtr** = *util*::nn<*MeridianPtr*>

Non-null shared pointer of *Meridian*.

using **CoordinateSystemAxisPtr** = std::shared_ptr<*CoordinateSystemAxis*>

Shared pointer of *CoordinateSystemAxis*.

using **CoordinateSystemAxisNNPtr** = *util*::nn<*CoordinateSystemAxisPtr*>

Non-null shared pointer of *CoordinateSystemAxis*.

typedef std::shared_ptr<*CoordinateSystem*> **CoordinateSystemPtr**

Shared pointer of *CoordinateSystem*.

typedef *util*::nn<*CoordinateSystemPtr*> **CoordinateSystemNNPtr**

Non-null shared pointer of *CoordinateSystem*.

using **SphericalCSPtr** = std::shared_ptr<*SphericalCS*>

Shared pointer of *SphericalCS*.

using **SphericalCSNNPtr** = *util*::nn<*SphericalCSPtr*>

Non-null shared pointer of *SphericalCS*.

using **EllipsoidalCSPtr** = std::shared_ptr<*EllipsoidalCS*>

Shared pointer of *EllipsoidalCS*.

using **EllipsoidalCSNNPtr** = *util*::nn<*EllipsoidalCSPtr*>

Non-null shared pointer of *EllipsoidalCS*.

using **VerticalCSPtr** = std::shared_ptr<*VerticalCS*>

Shared pointer of *VerticalCS*.

using **VerticalCSNNPtr** = *util*::nn<*VerticalCSPtr*>

Non-null shared pointer of *VerticalCS*.

using **CartesianCSPtr** = std::shared_ptr<*CartesianCS*>

Shared pointer of *CartesianCS*.

using **CartesianCSNNPtr** = *util*::nn<*CartesianCSPtr*>

Non-null shared pointer of *CartesianCS*.

using **OrdinalCSPtr** = std::shared_ptr<*OrdinalCS*>

Shared pointer of *OrdinalCS*.

using **OrdinalCSNNPtr** = *util*::nn<*OrdinalCSPtr*>

Non-null shared pointer of *OrdinalCS*.

using **ParametricCSPtr** = std::shared_ptr<*ParametricCS*>

Shared pointer of *ParametricCS*.

using **ParametricCSNNPtr** = *util*::nn<*ParametricCSPtr*>

Non-null shared pointer of *ParametricCS*.

using **TemporalCSPtr** = std::shared_ptr<*TemporalCS*>

Shared pointer of *TemporalCS*.

using **TemporalCSNNPtr** = *util*::nn<*TemporalCSPtr*>

Non-null shared pointer of *TemporalCS*.

using **DateTimeTemporalCSPtr** = std::shared_ptr<*DateTimeTemporalCS*>

Shared pointer of *DateTimeTemporalCS*.

using **DateTimeTemporalCSNNPtr** = *util*::nn<*DateTimeTemporalCSPtr*>

Non-null shared pointer of *DateTimeTemporalCS*.

using **TemporalCountCSPtr** = std::shared_ptr<*TemporalCountCS*>

Shared pointer of *TemporalCountCS*.

using **TemporalCountCSNNPtr** = *util*::nn<*TemporalCountCSPtr*>

Non-null shared pointer of *TemporalCountCS*.

using **TemporalMeasureCSPtr** = std::shared_ptr<*TemporalMeasureCS*>

Shared pointer of *TemporalMeasureCS*.

using **TemporalMeasureCSNNPtr** = *util*::nn<*TemporalMeasureCSPtr*>

Non-null shared pointer of *TemporalMeasureCS*.

class **AxisDirection** : public osgeo::proj::*util*::*CodeList*

#include <coordinatesystem.hpp> The direction of positive increase in the coordinate value for a coordinate system axis.

Remark

Implements *AxisDirection* from *ISO 19111:2019*

Public Static Attributes

static const *AxisDirection* **NORTH**

Axis positive direction is north. In a geodetic or projected CRS, north is defined through the geodetic reference frame. In an engineering CRS, north may be defined with respect to an engineering object rather than a geographical direction.

static const *AxisDirection* **NORTH_NORTH_EAST**

Axis positive direction is approximately north-north-east.

static const *AxisDirection* **NORTH_EAST**

Axis positive direction is approximately north-east.

static const *AxisDirection* **EAST_NORTH_EAST**

Axis positive direction is approximately east-north-east.

static const *AxisDirection* **EAST**

Axis positive direction is 90deg clockwise from north.

static const *AxisDirection* **EAST_SOUTH_EAST**

Axis positive direction is approximately east-south-east.

static const *AxisDirection* **SOUTH_EAST**

Axis positive direction is approximately south-east.

static const *AxisDirection* **SOUTH_SOUTH_EAST**

Axis positive direction is approximately south-south-east.

static const *AxisDirection* **SOUTH**

Axis positive direction is 180deg clockwise from north.

static const *AxisDirection* **SOUTH_SOUTH_WEST**

Axis positive direction is approximately south-south-west.

static const *AxisDirection* **SOUTH_WEST**

Axis positive direction is approximately south-west.

static const *AxisDirection* **WEST_SOUTH_WEST**

Axis positive direction is approximately west-south-west.

static const *AxisDirection* **WEST**

Axis positive direction is 270deg clockwise from north.

static const *AxisDirection* **WEST_NORTH_WEST**

Axis positive direction is approximately west-north-west.

static const *AxisDirection* **NORTH_WEST**

Axis positive direction is approximately north-west.

static const *AxisDirection* **NORTH_NORTH_WEST**

Axis positive direction is approximately north-north-west.

static const *AxisDirection* **UP**

Axis positive direction is up relative to gravity.

static const *AxisDirection* **DOWN**

Axis positive direction is down relative to gravity.

static const *AxisDirection* **GEOCENTRIC_X**

Axis positive direction is in the equatorial plane from the centre of the modelled Earth towards the intersection of the equator with the prime meridian.

static const *AxisDirection* **GEOCENTRIC_Y**

Axis positive direction is in the equatorial plane from the centre of the modelled Earth towards the intersection of the equator and the meridian 90deg eastwards from the prime meridian.

static const *AxisDirection* **GEOCENTRIC_Z**

Axis positive direction is from the centre of the modelled Earth parallel to its rotation axis and towards its north pole.

static const *AxisDirection* **COLUMN_POSITIVE**

Axis positive direction is towards higher pixel column.

static const *AxisDirection* **COLUMN_NEGATIVE**

Axis positive direction is towards lower pixel column.

static const *AxisDirection* **ROW_POSITIVE**

Axis positive direction is towards higher pixel row.

static const *AxisDirection* **ROW_NEGATIVE**

Axis positive direction is towards lower pixel row.

static const *AxisDirection* **DISPLAY_RIGHT**

Axis positive direction is right in display.

static const *AxisDirection* **DISPLAY_LEFT**

Axis positive direction is left in display.

static const *AxisDirection* **DISPLAY_UP**

Axis positive direction is towards top of approximately vertical display surface.

static const *AxisDirection* **DISPLAY_DOWN**

Axis positive direction is towards bottom of approximately vertical display surface.

static const *AxisDirection* **FORWARD**

Axis positive direction is forward; for an observer at the centre of the object this is will be towards its front, bow or nose.

static const *AxisDirection* **AFT**

Axis positive direction is aft; for an observer at the centre of the object this will be towards its back, stern or tail.

static const *AxisDirection* **PORT**

Axis positive direction is port; for an observer at the centre of the object this will be towards its left.

static const *AxisDirection* **STARBOARD**

Axis positive direction is starboard; for an observer at the centre of the object this will be towards its right.

static const *AxisDirection* **CLOCKWISE**

Axis positive direction is clockwise from a specified direction.

static const *AxisDirection* **COUNTER_CLOCKWISE**

Axis positive direction is counter clockwise from a specified direction.

static const *AxisDirection* **TOWARDS**

Axis positive direction is towards the object.

static const *AxisDirection* **AWAY_FROM**

Axis positive direction is away from the object.

static const *AxisDirection* **FUTURE**

Temporal axis positive direction is towards the future.

static const *AxisDirection* **PAST**

Temporal axis positive direction is towards the past.

static const *AxisDirection* **UNSPECIFIED**

Axis positive direction is unspecified.

class **Meridian** : public osgeo::proj::*common*::*IdentifiedObject*

#include <coordinatesystem.hpp> The meridian that the axis follows from the pole, for a coordinate reference system centered on a pole.

Remark

Implements MERIDIAN from *WKT2 standard*

Note: There is no modelling for this concept in *ISO 19111:2019*

Public Functions

const *common*::*Angle* &**longitude**()

Return the longitude of the meridian that the axis follows from the pole.

Returns
the longitude.

Public Static Functions

static *MeridianNNPtr* **create**(const *common*::*Angle* &longitudeIn)

Instantiate a *Meridian*.

Parameters
longitudeIn – longitude of the meridian that the axis follows from the pole.

Returns
new *Meridian*.

class **CoordinateSystemAxis** : public osgeo::proj::*common*::*IdentifiedObject*, public osgeo::proj::*io*::*IJSONExportable*

#include <coordinatesystem.hpp> The definition of a coordinate system axis.

Remark

Implements *CoordinateSystemAxis* from *ISO 19111:2019*

Public Functions

const std::string &**abbreviation**()

Return the axis abbreviation.

The abbreviation used for this coordinate system axis; this abbreviation is also used to identify the coordinates in the coordinate tuple. Examples are X and Y.

Returns
the abbreviation.

const *AxisDirection* &**direction**()

Return the axis direction.

The direction of this coordinate system axis (or in the case of Cartesian projected coordinates, the direction of this coordinate system axis locally) Examples: north or south, east or west, up or down. Within any set of coordinate system axes, only one of each pair of terms can be used. For Earth-fixed CRSs, this direction is often approximate and intended to provide a human interpretable meaning to the axis. When a geodetic reference frame is used, the precise directions of the axes may therefore vary slightly from this approximate direction. Note that an EngineeringCRS often requires specific descriptions of the directions of its coordinate system axes.

Returns
the direction.

const *common*::*UnitOfMeasure* &**unit**()

Return the axis unit.

This is the spatial unit or temporal quantity used for this coordinate system axis. The value of a coordinate in a coordinate tuple shall be recorded using this unit.

Returns
the axis unit.

const *util*::*optional*<double> &**minimumValue**()

Return the minimum value normally allowed for this axis, in the unit for the axis.

Returns
the minimum value, or empty.

const *util*::*optional*<double> &**maximumValue**()

Return the maximum value normally allowed for this axis, in the unit for the axis.

Returns
the maximum value, or empty.

const *MeridianPtr* &**meridian**()

Return the meridian that the axis follows from the pole, for a coordinate reference system centered on a pole.

Returns
the meridian, or null.

Public Static Functions

static *CoordinateSystemAxisNNPtr* **create**(const *util*::*PropertyMap* &properties, const std::string &abbreviationIn, const *AxisDirection* &directionIn, const *common*::*UnitOfMeasure* &unitIn, const *MeridianPtr* &meridianIn = nullptr)

Instantiate a *CoordinateSystemAxis*.

Parameters
- `properties` – See *General properties*. The name should generally be defined.
- `abbreviationIn` – Axis abbreviation (might be empty)
- `directionIn` – Axis direction
- `unitIn` – Axis unit
- `meridianIn` – The meridian that the axis follows from the pole, for a coordinate reference system centered on a pole, or nullptr

Returns
a new *CoordinateSystemAxis*.

class **CoordinateSystem** : public osgeo::proj::*common*::*IdentifiedObject*, public osgeo::proj::*io*::*IJSONExportable*

#include <coordinatesystem.hpp> Abstract class modelling a coordinate system (CS)

A CS is the non-repeating sequence of coordinate system axes that spans a given coordinate space. A CS is derived from a set of mathematical rules for specifying how coordinates in a given space are to be assigned to points. The coordinate values in a coordinate tuple shall be recorded in the order in which the coordinate system axes associations are recorded.

Remark

Implements *CoordinateSystem* from *ISO 19111:2019*

Subclassed by *osgeo::proj::cs::CartesianCS*, *osgeo::proj::cs::EllipsoidalCS*, *osgeo::proj::cs::OrdinalCS*, *osgeo::proj::cs::ParametricCS*, *osgeo::proj::cs::SphericalCS*, *osgeo::proj::cs::TemporalCS*, *osgeo::proj::cs::VerticalCS*

Public Functions

const std::vector<*CoordinateSystemAxisNNPtr*> &**axisList**()

Return the list of axes of this coordinate system.

Returns

the axes.

class **SphericalCS** : public osgeo::proj::*cs*::*CoordinateSystem*

#include <coordinatesystem.hpp> A three-dimensional coordinate system in Euclidean space with one distance measured from the origin and two angular coordinates.

Not to be confused with an ellipsoidal coordinate system based on an ellipsoid "degenerated" into a sphere. A *SphericalCS* shall have three axis associations.

Remark

Implements *SphericalCS* from *ISO 19111:2019*

Public Static Functions

static *SphericalCSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *CoordinateSystemAxisNNPtr* &axis1, const *CoordinateSystemAxisNNPtr* &axis2, const *CoordinateSystemAxisNNPtr* &axis3)

Instantiate a *SphericalCS*.

Parameters

- **properties** – See *General properties*.
- **axis1** – The first axis.
- **axis2** – The second axis.
- **axis3** – The third axis.

Returns

a new *SphericalCS*.

class **EllipsoidalCS** : public osgeo::proj::*cs*::*CoordinateSystem*

#include <coordinatesystem.hpp> A two- or three-dimensional coordinate system in which position is specified by geodetic latitude, geodetic longitude, and (in the three-dimensional case) ellipsoidal height.

An *EllipsoidalCS* shall have two or three associations.

Remark

Implements *EllipsoidalCS* from *ISO 19111:2019*

Public Static Functions

static *EllipsoidalCSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *CoordinateSystemAxisNNPtr* &axis1, const *CoordinateSystemAxisNNPtr* &axis2)

Instantiate a *EllipsoidalCS*.

Parameters

- **properties** – See *General properties*.
- **axis1** – The first axis.
- **axis2** – The second axis.

Returns

a new *EllipsoidalCS*.

static *EllipsoidalCSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *CoordinateSystemAxisNNPtr* &axis1, const *CoordinateSystemAxisNNPtr* &axis2, const *CoordinateSystemAxisNNPtr* &axis3)

Instantiate a *EllipsoidalCS*.

Parameters

- **properties** – See *General properties*.
- **axis1** – The first axis.
- **axis2** – The second axis.
- **axis3** – The third axis.

Returns

a new *EllipsoidalCS*.

static *EllipsoidalCSNNPtr* **createLatitudeLongitude**(const *common*::*UnitOfMeasure* &unit)

Instantiate a *EllipsoidalCS* with a Latitude (first) and Longitude (second) axis.

Parameters

unit – Angular unit of the axes.

Returns

a new *EllipsoidalCS*.

static *EllipsoidalCSNNPtr* **createLatitudeLongitudeEllipsoidalHeight**(const *common*::*UnitOfMeasure* &angularUnit, const *common*::*UnitOfMeasure* &linearUnit)

Instantiate a *EllipsoidalCS* with a Latitude (first), Longitude (second) axis and ellipsoidal height (third) axis.

Parameters

- **angularUnit** – Angular unit of the latitude and longitude axes.
- **linearUnit** – Linear unit of the ellipsoidal height axis.

Returns

a new *EllipsoidalCS*.

static *EllipsoidalCSNNPtr* **createLongitudeLatitude**(const *common*::*UnitOfMeasure* &unit)

Instantiate a *EllipsoidalCS* with a Longitude (first) and Latitude (second) axis.

Parameters

unit – Angular unit of the axes.

Returns

a new *EllipsoidalCS*.

static *EllipsoidalCSNNPtr* **createLongitudeLatitudeEllipsoidalHeight**(const *common*::*UnitOfMeasure* &angularUnit, const *common*::*UnitOfMeasure* &linearUnit)

Instantiate a *EllipsoidalCS* with a Longitude (first), Latitude (second) axis and ellipsoidal height (third) axis.

Since

7.0

Parameters

- **angularUnit** – Angular unit of the latitude and longitude axes.
- **linearUnit** – Linear unit of the ellipsoidal height axis.

Returns

a new *EllipsoidalCS*.

class **VerticalCS** : public osgeo::proj::*cs*::*CoordinateSystem*

#include <coordinatesystem.hpp> A one-dimensional coordinate system used to record the heights or depths of points.

Such a coordinate system is usually dependent on the Earth's gravity field. A *VerticalCS* shall have one axis association.

Remark

Implements *VerticalCS* from *ISO 19111:2019*

Public Static Functions

static *VerticalCSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *CoordinateSystemAxisNNPtr* &axis)

Instantiate a *VerticalCS*.

Parameters

- **properties** – See *General properties*.
- **axis** – The axis.

Returns

a new *VerticalCS*.

static *VerticalCSNNPtr* **createGravityRelatedHeight**(const *common*::*UnitOfMeasure* &unit)

Instantiate a *VerticalCS* with a Gravity-related height axis.

Parameters

unit – linear unit.

Returns
a new *VerticalCS*.

class **CartesianCS** : public osgeo::proj::*cs*::*CoordinateSystem*

#include <coordinatesystem.hpp> A two- or three-dimensional coordinate system in Euclidean space with orthogonal straight axes.

All axes shall have the same length unit. A *CartesianCS* shall have two or three axis associations; the number of associations shall equal the dimension of the CS.

Remark

Implements *CartesianCS* from *ISO 19111:2019*

Public Static Functions

static *CartesianCSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *CoordinateSystemAxisNNPtr* &axis1, const *CoordinateSystemAxisNNPtr* &axis2)

Instantiate a *CartesianCS*.

Parameters
- **properties** – See *General properties*.
- **axis1** – The first axis.
- **axis2** – The second axis.

Returns
a new *CartesianCS*.

static *CartesianCSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *CoordinateSystemAxisNNPtr* &axis1, const *CoordinateSystemAxisNNPtr* &axis2, const *CoordinateSystemAxisNNPtr* &axis3)

Instantiate a *CartesianCS*.

Parameters
- **properties** – See *General properties*.
- **axis1** – The first axis.
- **axis2** – The second axis.
- **axis3** – The third axis.

Returns
a new *CartesianCS*.

static *CartesianCSNNPtr* **createEastingNorthing**(const *common*::*UnitOfMeasure* &unit)

Instantiate a *CartesianCS* with a Easting (first) and Northing (second) axis.

Parameters
unit – Linear unit of the axes.

Returns
a new *CartesianCS*.

static *CartesianCSNNPtr* **createNorthingEasting**(const *common*::*UnitOfMeasure* &unit)

Instantiate a *CartesianCS* with a Northing (first) and Easting (second) axis.

Parameters
unit – Linear unit of the axes.

Returns
a new *CartesianCS*.

static *CartesianCSNNPtr* **`createNorthPoleEastingSouthNorthingSouth`**(const *common*::*UnitOfMeasure* &unit)

Instantiate a *CartesianCS*, north-pole centered, with a Easting (first) South-Oriented and Northing (second) South-Oriented axis.

Parameters
`unit` – Linear unit of the axes.

Returns
a new *CartesianCS*.

static *CartesianCSNNPtr* **`createSouthPoleEastingNorthNorthingNorth`**(const *common*::*UnitOfMeasure* &unit)

Instantiate a *CartesianCS*, south-pole centered, with a Easting (first) North-Oriented and Northing (second) North-Oriented axis.

Parameters
`unit` – Linear unit of the axes.

Returns
a new *CartesianCS*.

static *CartesianCSNNPtr* **`createWestingSouthing`**(const *common*::*UnitOfMeasure* &unit)

Instantiate a *CartesianCS* with a Westing (first) and Southing (second) axis.

Parameters
`unit` – Linear unit of the axes.

Returns
a new *CartesianCS*.

static *CartesianCSNNPtr* **`createGeocentric`**(const *common*::*UnitOfMeasure* &unit)

Instantiate a *CartesianCS* with the three geocentric axes.

Parameters
`unit` – Linear unit of the axes.

Returns
a new *CartesianCS*.

class **`OrdinalCS`** : public osgeo::proj::*cs*::*CoordinateSystem*

#include <coordinatesystem.hpp> n-dimensional coordinate system in which every axis uses integers.

The number of associations shall equal the dimension of the CS.

Remark

Implements *OrdinalCS* from *ISO 19111:2019*

Public Static Functions

static *OrdinalCSNNPtr* **create**(const *util*::*PropertyMap* &properties, const std::vector<*CoordinateSystemAxisNNPtr*> &axisIn)

Instantiate a *OrdinalCS*.

Parameters

- **properties** – See *General properties*.
- **axisIn** – List of axis.

Returns

a new *OrdinalCS*.

class **ParametricCS** : public osgeo::proj::*cs*::*CoordinateSystem*

#include <coordinatesystem.hpp> one-dimensional coordinate reference system which uses parameter values or functions that may vary monotonically with height.

Remark

Implements *ParametricCS* from *ISO 19111:2019*

Public Static Functions

static *ParametricCSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *CoordinateSystemAxisNNPtr* &axisIn)

Instantiate a *ParametricCS*.

Parameters

- **properties** – See *General properties*.
- **axisIn** – Axis.

Returns

a new *ParametricCS*.

class **TemporalCS** : public osgeo::proj::*cs*::*CoordinateSystem*

#include <coordinatesystem.hpp> (Abstract class) A one-dimensional coordinate system used to record time.

A *TemporalCS* shall have one axis association.

Remark

Implements *TemporalCS* from *ISO 19111:2019*

Subclassed by *osgeo::proj::cs::DateTimeTemporalCS*, *osgeo::proj::cs::TemporalCountCS*, *osgeo::proj::cs::TemporalMeasureCS*

class **DateTimeTemporalCS** : public osgeo::proj::*cs*::*TemporalCS*

#include <coordinatesystem.hpp> A one-dimensional coordinate system used to record time in dateTime representation as defined in ISO 8601.

A *DateTimeTemporalCS* shall have one axis association. It does not use axisUnitID; the temporal quantities are defined through the ISO 8601 representation.

Remark

Implements *DateTimeTemporalCS* from *ISO 19111:2019*

Public Static Functions

static *DateTimeTemporalCSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *CoordinateSystemAxisNNPtr* &axis)

Instantiate a *DateTimeTemporalCS*.

Parameters

- **properties** – See *General properties*.
- **axisIn** – The axis.

Returns

a new *DateTimeTemporalCS*.

class **TemporalCountCS** : public osgeo::proj::*cs*::*TemporalCS*

#include <coordinatesystem.hpp> A one-dimensional coordinate system used to record time as an integer count.

A *TemporalCountCS* shall have one axis association.

Remark

Implements *TemporalCountCS* from *ISO 19111:2019*

Public Static Functions

static *TemporalCountCSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *CoordinateSystemAxisNNPtr* &axis)

Instantiate a *TemporalCountCS*.

Parameters

- **properties** – See *General properties*.
- **axisIn** – The axis.

Returns

a new *TemporalCountCS*.

class **TemporalMeasureCS** : public osgeo::proj::*cs*::*TemporalCS*

#include <coordinatesystem.hpp> A one-dimensional coordinate system used to record a time as a real number.

A *TemporalMeasureCS* shall have one axis association.

Remark

Implements *TemporalMeasureCS* from *ISO 19111:2019*

Public Static Functions

static *TemporalMeasureCSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *CoordinateSystemAxisNNPtr* &axis)

Instantiate a *TemporalMeasureCS*.

Parameters

- **properties** – See *General properties*.
- **axisIn** – The axis.

Returns

a new *TemporalMeasureCS*.

10.5.4.6 datum namespace

namespace **datum**

Datum (the relationship of a coordinate system to the body).

osgeo.proj.datum namespace

Typedefs

typedef std::shared_ptr<*Datum*> **DatumPtr**

Shared pointer of *Datum*

typedef *util*::nn<*DatumPtr*> **DatumNNPtr**

Non-null shared pointer of *Datum*

typedef std::shared_ptr<*DatumEnsemble*> **DatumEnsemblePtr**

Shared pointer of *DatumEnsemble*

typedef *util*::nn<*DatumEnsemblePtr*> **DatumEnsembleNNPtr**

Non-null shared pointer of *DatumEnsemble*

typedef std::shared_ptr<*PrimeMeridian*> **PrimeMeridianPtr**

Shared pointer of *PrimeMeridian*

typedef *util*::nn<*PrimeMeridianPtr*> **PrimeMeridianNNPtr**

Non-null shared pointer of *PrimeMeridian*

typedef std::shared_ptr<*Ellipsoid*> **EllipsoidPtr**

Shared pointer of *Ellipsoid*

typedef *util*::nn<*EllipsoidPtr*> **EllipsoidNNPtr**

Non-null shared pointer of *Ellipsoid*

typedef std::shared_ptr<*GeodeticReferenceFrame*> **GeodeticReferenceFramePtr**

Shared pointer of *GeodeticReferenceFrame*

typedef *util*::nn<*GeodeticReferenceFramePtr*> **GeodeticReferenceFrameNNPtr**

Non-null shared pointer of *GeodeticReferenceFrame*

using **DynamicGeodeticReferenceFramePtr** = std::shared_ptr<*DynamicGeodeticReferenceFrame*>

Shared pointer of *DynamicGeodeticReferenceFrame*

using **DynamicGeodeticReferenceFrameNNPtr** = *util*::nn<*DynamicGeodeticReferenceFramePtr*>

Non-null shared pointer of *DynamicGeodeticReferenceFrame*

typedef std::shared_ptr<*VerticalReferenceFrame*> **VerticalReferenceFramePtr**

Shared pointer of *VerticalReferenceFrame*

typedef *util*::nn<*VerticalReferenceFramePtr*> **VerticalReferenceFrameNNPtr**

Non-null shared pointer of *VerticalReferenceFrame*

using **DynamicVerticalReferenceFramePtr** = std::shared_ptr<*DynamicVerticalReferenceFrame*>

Shared pointer of *DynamicVerticalReferenceFrame*

using **DynamicVerticalReferenceFrameNNPtr** = *util*::nn<*DynamicVerticalReferenceFramePtr*>

Non-null shared pointer of *DynamicVerticalReferenceFrame*

using **TemporalDatumPtr** = std::shared_ptr<*TemporalDatum*>

Shared pointer of *TemporalDatum*

using **TemporalDatumNNPtr** = *util*::nn<*TemporalDatumPtr*>

Non-null shared pointer of *TemporalDatum*

using **EngineeringDatumPtr** = std::shared_ptr<*EngineeringDatum*>

Shared pointer of *EngineeringDatum*

using **EngineeringDatumNNPtr** = *util*::nn<*EngineeringDatumPtr*>

Non-null shared pointer of *EngineeringDatum*

using **ParametricDatumPtr** = std::shared_ptr<*ParametricDatum*>

Shared pointer of *ParametricDatum*

using **ParametricDatumNNPtr** = *util*::nn<*ParametricDatumPtr*>

Non-null shared pointer of *ParametricDatum* class **Datum** : public osgeo::proj::*common*::*ObjectUsage*, public osgeo::proj::*io*::*IJSONExportable*

#include <datum.hpp> Abstract class of the relationship of a coordinate system to an object, thus creating a coordinate reference system.

For geodetic and vertical coordinate reference systems, it relates a coordinate system to the Earth (or the celestial body considered). With other types of coordinate reference systems, the datum may relate the coordinate system to another physical or virtual object. A datum uses a parameter or set of parameters that determine the location of the origin of the coordinate reference system. Each datum subtype can be associated with only specific types of coordinate reference systems.

Remark

Implements *Datum* from *ISO 19111:2019*

Subclassed by *osgeo::proj::datum::EngineeringDatum*, *osgeo::proj::datum::GeodeticReferenceFrame*, *osgeo::proj::datum::ParametricDatum*, *osgeo::proj::datum::TemporalDatum*, *osgeo::proj::datum::VerticalReferenceFrame*

Public Functions

const *util*::*optional*<std::string> &**anchorDefinition**() const

Return the anchor definition.

A description - possibly including coordinates of an identified point or points - of the relationship used to anchor a coordinate system to the Earth or alternate object.

- For modern geodetic reference frames the anchor may be a set of station coordinates; if the reference frame is dynamic it will also include coordinate velocities. For a traditional geodetic datum, this anchor may be a point known as the fundamental point, which is traditionally the point where the relationship between geoid and ellipsoid is defined, together with a direction from that point.
- For a vertical reference frame the anchor may be the zero level at one or more defined locations or a conventionally defined surface.
- For an engineering datum, the anchor may be an identified physical point with the orientation defined relative to the object.

Returns

the anchor definition, or empty.

const *util*::*optional*<*common*::*DateTime*> &**publicationDate**() const

Return the date on which the datum definition was published.

Note: Departure from *ISO 19111:2019* : we return a DateTime instead of a Citation::Date.

Returns

the publication date, or empty.

const *common*::*IdentifiedObjectPtr* &**conventionalRS**() const

Return the conventional reference system.

This is the name, identifier, alias and remarks for the terrestrial reference system or vertical reference system realized by this reference frame, for example “ITRS” for ITRF88 through ITRF2008 and ITRF2014, or “EVRS” for EVRF2000 and EVRF2007.

Returns
the conventional reference system, or nullptr.

class **DatumEnsemble** : public osgeo::proj::*common*::*ObjectUsage*, public osgeo::proj::*io*::*IJSONExportable*

#include <datum.hpp> A collection of two or more geodetic or vertical reference frames (or if not geodetic or vertical reference frame, a collection of two or more datums) which for all but the highest accuracy requirements may be considered to be insignificantly different from each other.

Every frame within the datum ensemble must be a realizations of the same Terrestrial Reference System or Vertical Reference System.

Remark

Implements *DatumEnsemble* from *ISO 19111:2019*

Public Functions

const std::vector<*DatumNNPtr*> &**datums**() const

Return the set of datums which may be considered to be insignificantly different from each other.

Returns
the set of datums of the *DatumEnsemble*.

const *metadata*::*PositionalAccuracyNNPtr* &**positionalAccuracy**() const

Return the inaccuracy introduced through use of this collection of datums.

It is an indication of the differences in coordinate values at all points between the various realizations that have been grouped into this datum ensemble.

Returns
the accuracy.

Public Static Functions

static *DatumEnsembleNNPtr* **create**(const *util*::*PropertyMap* &properties, const std::vector<*DatumNNPtr*> &datumsIn, const *metadata*::*PositionalAccuracyNNPtr* &accuracy)

Instantiate a *DatumEnsemble*.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **datumsIn** – Array of at least 2 datums.
- **accuracy** – Accuracy of the datum ensemble

Throws
util::*Exception* –

Returns
new *DatumEnsemble*.

class **PrimeMeridian** : public osgeo::proj::*common*::*IdentifiedObject*, public osgeo::proj::*io*::*IPROJStringExportable*, public osgeo::proj::*io*::*IJSONExportable*

#include <datum.hpp> The origin meridian from which longitude values are determined.

Remark

Implements *PrimeMeridian* from *ISO 19111:2019*

Note: The default value for prime meridian name is "Greenwich". When the default applies, the value for the longitude shall be 0 (degrees).

Public Functions

const *common*::*Angle* &**longitude**()

Return the longitude of the prime meridian.

It is measured from the internationally-recognised reference meridian ('Greenwich meridian'), positive eastward. The default value is 0 degrees.

Returns

the longitude of the prime meridian.

Public Static Functions

static *PrimeMeridianNNPtr* **create**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &longitudeIn)

Instantiate a *PrimeMeridian*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **longitudeIn** – the longitude of the prime meridian.

Returns

new *PrimeMeridian*.

Public Static Attributes

static const *PrimeMeridianNNPtr* **GREENWICH**

The Greenwich *PrimeMeridian*.

static const *PrimeMeridianNNPtr* **REFERENCE_MERIDIAN**

The "Reference Meridian" *PrimeMeridian*.

This is a meridian of longitude 0 to be used with non-Earth bodies.

static const *PrimeMeridianNNPtr* **PARIS**

The Paris *PrimeMeridian*.

class **Ellipsoid** : public osgeo::proj::*common*::*IdentifiedObject*, public osgeo::proj::*io*::*IPROJStringExportable*, public osgeo::proj::*io*::*IJSONExportable*

#include <datum.hpp> A geometric figure that can be used to describe the approximate shape of an object.

For the Earth an oblate biaxial ellipsoid is used: in mathematical terms, it is a surface formed by the rotation of an ellipse about its minor axis.

Remark

Implements *Ellipsoid* from *ISO 19111:2019*

Public Functions

const *common*::*Length* &**semiMajorAxis**()

Return the length of the semi-major axis of the ellipsoid.

Returns
the semi-major axis.

const *util*::*optional*<*common*::*Scale*> &**inverseFlattening**()

Return the inverse flattening value of the ellipsoid, if the ellipsoid has been defined with this value.

See also:

computeInverseFlattening() that will always return a valid value of the inverse flattening, whether the ellipsoid has been defined through inverse flattening or semi-minor axis.

Returns
the inverse flattening value of the ellipsoid, or empty.

const *util*::*optional*<*common*::*Length*> &**semiMinorAxis**()

Return the length of the semi-minor axis of the ellipsoid, if the ellipsoid has been defined with this value.

See also:

computeSemiMinorAxis() that will always return a valid value of the semi-minor axis, whether the ellipsoid has been defined through inverse flattening or semi-minor axis.

Returns
the semi-minor axis of the ellipsoid, or empty.

bool **isSphere**()

Return whether the ellipsoid is spherical.

That is to say is *semiMajorAxis()* == *computeSemiMinorAxis()*.

A sphere is completely defined by the semi-major axis, which is the radius of the sphere.

Returns
true if the ellipsoid is spherical.

const *util*::*optional*<*common*::*Length*> &**semiMedianAxis**()

Return the length of the semi-median axis of a triaxial ellipsoid.

This parameter is not required for a biaxial ellipsoid.

Returns
the semi-median axis of the ellipsoid, or empty.

double **computedInverseFlattening**()

Return or compute the inverse flattening value of the ellipsoid.

If computed, the inverse flattening is the result of a / (a - b), where a is the semi-major axis and b the semi-minor axis.

Returns

the inverse flattening value of the ellipsoid, or 0 for a sphere.

double **squaredEccentricity**()

Return the squared eccentricity of the ellipsoid.

Returns

the squared eccentricity, or a negative value if invalid.

common::*Length* **computeSemiMinorAxis**() const

Return or compute the length of the semi-minor axis of the ellipsoid.

If computed, the semi-minor axis is the result of a * (1 - 1 / rf) where a is the semi-major axis and rf the reverse/inverse flattening.

Returns

the semi-minor axis of the ellipsoid.

const std::string &**celestialBody**()

Return the name of the celestial body on which the ellipsoid refers to.

EllipsoidNNPtr **identify**() const

Return a *Ellipsoid* object where some parameters are better identified.

Returns

a new *Ellipsoid*.

Public Static Functions

static *EllipsoidNNPtr* **createSphere**(const *util*::*PropertyMap* &properties, const *common*::*Length* &radius, const std::string &celestialBody = *EARTH*)

Instantiate a *Ellipsoid* as a sphere.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **radius** – the sphere radius (semi-major axis).
- **celestialBody** – Name of the celestial body on which the ellipsoid refers to.

Returns

new *Ellipsoid*.

static *EllipsoidNNPtr* **createFlattenedSphere**(const *util*::*PropertyMap* &properties, const *common*::*Length* &semiMajorAxisIn, const *common*::*Scale* &invFlattening, const std::string &celestialBody = *EARTH*)

Instantiate a *Ellipsoid* from its inverse/reverse flattening.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **semiMajorAxisIn** – the semi-major axis.
- **invFlattening** – the inverse/reverse flattening. If set to 0, this will be considered as a sphere.
- **celestialBody** – Name of the celestial body on which the ellipsoid refers to.

Returns

new *Ellipsoid*.

static *EllipsoidNNPtr* **createTwoAxis**(const *util*::*PropertyMap* &properties, const *common*::*Length* &semiMajorAxisIn, const *common*::*Length* &semiMinorAxisIn, const std::string &celestialBody = *EARTH*)

Instantiate a *Ellipsoid* from the value of its two semi axis.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **semiMajorAxisIn** – the semi-major axis.
- **semiMinorAxisIn** – the semi-minor axis.
- **celestialBody** – Name of the celestial body on which the ellipsoid refers to.

Returns

new *Ellipsoid*.

Public Static Attributes

static const std::string **EARTH**

Earth celestial body.

static const *EllipsoidNNPtr* **CLARKE_1866**

The EPSG:7008 / "Clarke 1866" *Ellipsoid*.

static const *EllipsoidNNPtr* **WGS84**

The EPSG:7030 / "WGS 84" *Ellipsoid*.

static const *EllipsoidNNPtr* **GRS1980**

The EPSG:7019 / "GRS 1980" *Ellipsoid*.

class **GeodeticReferenceFrame** : public osgeo::proj::*datum*::*Datum*

#include <datum.hpp> The definition of the position, scale and orientation of a geocentric Cartesian 3D coordinate system relative to the Earth.

It may also identify a defined ellipsoid (or sphere) that approximates the shape of the Earth and which is centred on and aligned to this geocentric coordinate system. Older geodetic datums define the location and orientation of a defined ellipsoid (or sphere) that approximates the shape of the earth.

Remark

Implements *GeodeticReferenceFrame* from *ISO 19111:2019*

Note: The terminology "Datum" is often used to mean a *GeodeticReferenceFrame*.

Note: In *ISO 19111:2007*, this class was called GeodeticDatum.

Subclassed by *osgeo::proj::datum::DynamicGeodeticReferenceFrame*

Public Functions

const *PrimeMeridianNNPtr* &**primeMeridian**()

Return the *PrimeMeridian* associated with a *GeodeticReferenceFrame*.

Returns
the *PrimeMeridian*.

const *EllipsoidNNPtr* &**ellipsoid**()

Return the *Ellipsoid* associated with a *GeodeticReferenceFrame*.

Note: The *ISO 19111:2019* modelling allows (but discourages) a *GeodeticReferenceFrame* to not be associated with a *Ellipsoid* in the case where it is used by a geocentric *crs::GeodeticCRS*. We have made the choice of making the ellipsoid specification compulsory.

Returns
the *Ellipsoid*.

Public Static Functions

static *GeodeticReferenceFrameNNPtr* **create**(const *util*::*PropertyMap* &properties, const *EllipsoidNNPtr* &ellipsoid, const *util*::*optional*<std::string> &anchor, const *PrimeMeridianNNPtr* &primeMeridian)

Instantiate a *GeodeticReferenceFrame*.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **ellipsoid** – the *Ellipsoid*.
- **anchor** – the anchor definition, or empty.
- **primeMeridian** – the *PrimeMeridian*.

Returns
new *GeodeticReferenceFrame*.

Public Static Attributes

static const *GeodeticReferenceFrameNNPtr* **EPSG_6267**

The EPSG:6267 / “North_American_Datum_1927” *GeodeticReferenceFrame*.

static const *GeodeticReferenceFrameNNPtr* **EPSG_6269**

The EPSG:6269 / “North_American_Datum_1983” *GeodeticReferenceFrame*.

static const *GeodeticReferenceFrameNNPtr* **EPSG_6326**

The EPSG:6326 / “WGS_1984” *GeodeticReferenceFrame*.

class **DynamicGeodeticReferenceFrame** : public osgeo::proj::*datum*::*GeodeticReferenceFrame*

#include <datum.hpp> A geodetic reference frame in which some of the parameters describe time evolution of defining station coordinates.

For example defining station coordinates having linear velocities to account for crustal motion.

Remark

Implements *DynamicGeodeticReferenceFrame* from *ISO 19111:2019*

Public Functions

const *common*::*Measure* &**frameReferenceEpoch**() const

Return the epoch to which the coordinates of stations defining the dynamic geodetic reference frame are referenced.

Usually given as a decimal year e.g. 2016.47.

Returns
the frame reference epoch.

const *util*::*optional*<std::string> &**deformationModelName**() const

Return the name of the deformation model.

Note: This is an extension to the *ISO 19111:2019* modeling, to hold the content of the DYNAMIC.MODEL WKT2 node.

Returns
the name of the deformation model.

Public Static Functions

static *DynamicGeodeticReferenceFrameNNPtr* **create**(const *util*::*PropertyMap* &properties, const *EllipsoidNNPtr* &ellipsoid, const *util*::*optional*<std::string> &anchor, const *PrimeMeridianNNPtr* &primeMeridian, const *common*::*Measure* &frameReferenceEpochIn, const *util*::*optional*<std::string> &deformationModelNameIn)

Instantiate a *DynamicGeodeticReferenceFrame*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **ellipsoid** – the *Ellipsoid*.
- **anchor** – the anchor definition, or empty.
- **primeMeridian** – the *PrimeMeridian*.
- **frameReferenceEpochIn** – the frame reference epoch.
- **deformationModelNameIn** – deformation model name, or empty

Returns
new *DynamicGeodeticReferenceFrame*.

class **RealizationMethod** : public osgeo::proj::*util*::*CodeList*

#include <datum.hpp> The specification of the method by which the vertical reference frame is realized.

Remark

Implements *RealizationMethod* from *ISO 19111:2019*

Public Static Attributes

static const *RealizationMethod* **LEVELLING**

The realization is by adjustment of a levelling network fixed to one or more tide gauges.

static const *RealizationMethod* **GEOID**

The realization is through a geoid height model or a height correction model. This is applied to a specified geodetic CRS.

static const *RealizationMethod* **TIDAL**

The realization is through a tidal model or by tidal predictions.

class **VerticalReferenceFrame** : public osgeo::proj::*datum*::*Datum*

#include <datum.hpp> A textual description and/or a set of parameters identifying a particular reference level surface used as a zero-height or zero-depth surface, including its position with respect to the Earth.

Remark

Implements *VerticalReferenceFrame* from *ISO 19111:2019*

Note: In *ISO 19111:2007*, this class was called VerticalDatum.

Subclassed by *osgeo::proj::datum::DynamicVerticalReferenceFrame*

Public Functions

const *util*::*optional*<*RealizationMethod*> &**realizationMethod**() const

Return the method through which this vertical reference frame is realized.

Returns

the realization method.

Public Static Functions

static *VerticalReferenceFrameNNPtr* **create**(const *util*::*PropertyMap* &properties, const *util*::*optional*<std::string> &anchor = *util*::*optional*<std::string>(), const *util*::*optional*<*RealizationMethod*> &realizationMethodIn = *util*::*optional*<*RealizationMethod*>())

Instantiate a *VerticalReferenceFrame*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **anchor** – the anchor definition, or empty.

- **realizationMethodIn** – the realization method, or empty.

Returns

new *VerticalReferenceFrame*.

class **DynamicVerticalReferenceFrame** : public osgeo::proj::*datum*::*VerticalReferenceFrame*

#include <datum.hpp> A vertical reference frame in which some of the defining parameters have time dependency.

For example defining station heights have velocity to account for post-glacial isostatic rebound motion.

Remark

Implements *DynamicVerticalReferenceFrame* from *ISO 19111:2019*

Public Functions

const *common*::*Measure* &**frameReferenceEpoch**() const

Return the epoch to which the coordinates of stations defining the dynamic geodetic reference frame are referenced.

Usually given as a decimal year e.g. 2016.47.

Returns

the frame reference epoch.

const *util*::*optional*<std::string> &**deformationModelName**() const

Return the name of the deformation model.

Note: This is an extension to the *ISO 19111:2019* modeling, to hold the content of the DYNAMIC.MODEL WKT2 node.

Returns

the name of the deformation model.

Public Static Functions

static *DynamicVerticalReferenceFrameNNPtr* **create**(const *util*::*PropertyMap* &properties, const *util*::*optional*<std::string> &anchor, const *util*::*optional*<*RealizationMethod*> &realizationMethodIn, const *common*::*Measure* &frameReferenceEpochIn, const *util*::*optional*<std::string> &deformationModelNameIn)

Instantiate a *DynamicVerticalReferenceFrame*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **anchor** – the anchor definition, or empty.
- **realizationMethodIn** – the realization method, or empty.
- **frameReferenceEpochIn** – the frame reference epoch.
- **deformationModelNameIn** – deformation model name, or empty

Returns
new *DynamicVerticalReferenceFrame*.

class **TemporalDatum** : public osgeo::proj::*datum*::*Datum*

#include <datum.hpp> The definition of the relationship of a temporal coordinate system to an object. The object is normally time on the Earth.

Remark

Implements *TemporalDatum* from *ISO 19111:2019*

Public Functions

const *common*::*DateTime* &**temporalOrigin**() const

Return the date and time to which temporal coordinates are referenced, expressed in conformance with ISO 8601.

Returns
the temporal origin.

const std::string &**calendar**() const

Return the calendar to which the temporal origin is referenced.

Default value: *TemporalDatum::CALENDAR_PROLEPTIC_GREGORIAN*.

Returns
the calendar.

Public Static Functions

static *TemporalDatumNNPtr* **create**(const *util*::*PropertyMap* &properties, const *common*::*DateTime* &temporalOriginIn, const std::string &calendarIn)

Instantiate a *TemporalDatum*.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **temporalOriginIn** – the temporal origin into which temporal coordinates are referenced.
- **calendarIn** – the calendar (generally *TemporalDatum::CALENDAR_PROLEPTIC_GREGORIAN*)

Returns
new *TemporalDatum*.

Public Static Attributes

static const std::string **CALENDAR_PROLEPTIC_GREGORIAN**

The proleptic Gregorian calendar.

class **EngineeringDatum** : public osgeo::proj::*datum*::*Datum*

#include <datum.hpp> The definition of the origin and orientation of an engineering coordinate reference system.

Remark

Implements *EngineeringDatum* from *ISO 19111:2019*

Note: The origin can be fixed with respect to the Earth (such as a defined point at a construction site), or be a defined point on a moving vehicle (such as on a ship or satellite), or a defined point of an image.

Public Static Functions

static *EngineeringDatumNNPtr* **create**(const *util*::*PropertyMap* &properties, const *util*::*optional*<std::string> &anchor = *util*::*optional*<std::string>())

Instantiate a *EngineeringDatum*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **anchor** – the anchor definition, or empty.

Returns

new *EngineeringDatum*.

class **ParametricDatum** : public osgeo::proj::*datum*::*Datum*

#include <datum.hpp> Textual description and/or a set of parameters identifying a particular reference surface used as the origin of a parametric coordinate system, including its position with respect to the Earth.

Remark

Implements *ParametricDatum* from *ISO 19111:2019*

Public Static Functions

static *ParametricDatumNNPtr* **create**(const *util*::*PropertyMap* &properties, const *util*::*optional*<std::string> &anchor = *util*::*optional*<std::string>())

Instantiate a *ParametricDatum*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **anchor** – the anchor definition, or empty.

Returns

new *ParametricDatum*.

10.5.4.7 crs namespace

namespace **crs**

CRS (coordinate reference system = coordinate system with a datum).

osgeo.proj.crs namespace

Typedefs

typedef std::shared_ptr<*CRS*> **CRSPtr**

Shared pointer of *CRS*

typedef *util*::nn<*CRSPtr*> **CRSNNPtr**

Non-null shared pointer of *CRS*

typedef std::shared_ptr<*GeographicCRS*> **GeographicCRSPtr**

Shared pointer of *GeographicCRS*

typedef *util*::nn<*GeographicCRSPtr*> **GeographicCRSNNPtr**

Non-null shared pointer of *GeographicCRS*

typedef std::shared_ptr<*VerticalCRS*> **VerticalCRSPtr**

Shared pointer of *VerticalCRS*

typedef *util*::nn<*VerticalCRSPtr*> **VerticalCRSNNPtr**

Non-null shared pointer of *VerticalCRS*

using **BoundCRSPtr** = std::shared_ptr<*BoundCRS*>

Shared pointer of *BoundCRS*

using **BoundCRSNNPtr** = *util*::nn<*BoundCRSPtr*>

Non-null shared pointer of *BoundCRS*

typedef std::shared_ptr<*CompoundCRS*> **CompoundCRSPtr**

Shared pointer of *CompoundCRS*

typedef *util*::nn<*CompoundCRSPtr*> **CompoundCRSNNPtr**

Non-null shared pointer of *CompoundCRS*

using **SingleCRSPtr** = std::shared_ptr<*SingleCRS*>

Shared pointer of *SingleCRS*

using **SingleCRSNNPtr** = *util*::nn<*SingleCRSPtr*>

Non-null shared pointer of *SingleCRS*

typedef std::shared_ptr<*GeodeticCRS*> **GeodeticCRSPtr**

Shared pointer of *GeodeticCRS*

typedef *util*::nn<*GeodeticCRSPtr*> **GeodeticCRSNNPtr**

Non-null shared pointer of *GeodeticCRS*

using **DerivedCRSPtr** = std::shared_ptr<*DerivedCRS*>

Shared pointer of *DerivedCRS*

using **DerivedCRSNNPtr** = *util*::nn<*DerivedCRSPtr*>

Non-null shared pointer of *DerivedCRS*

typedef std::shared_ptr<*ProjectedCRS*> **ProjectedCRSPtr**

Shared pointer of *ProjectedCRS*

typedef *util*::nn<*ProjectedCRSPtr*> **ProjectedCRSNNPtr**

Non-null shared pointer of *ProjectedCRS*

using **TemporalCRSPtr** = std::shared_ptr<*TemporalCRS*>

Shared pointer of *TemporalCRS*

using **TemporalCRSNNPtr** = *util*::nn<*TemporalCRSPtr*>

Non-null shared pointer of *TemporalCRS*

using **EngineeringCRSPtr** = std::shared_ptr<*EngineeringCRS*>

Shared pointer of *EngineeringCRS*

using **EngineeringCRSNNPtr** = *util*::nn<*EngineeringCRSPtr*>

Non-null shared pointer of *EngineeringCRS*

using **ParametricCRSPtr** = std::shared_ptr<*ParametricCRS*>

Shared pointer of *ParametricCRS*

using **ParametricCRSNNPtr** = *util*::nn<*ParametricCRSPtr*>

Non-null shared pointer of *ParametricCRS*

using **DerivedGeodeticCRSPtr** = std::shared_ptr<*DerivedGeodeticCRS*>

Shared pointer of *DerivedGeodeticCRS*

using **DerivedGeodeticCRSNNPtr** = *util*::nn<*DerivedGeodeticCRSPtr*>

Non-null shared pointer of *DerivedGeodeticCRS*

using **DerivedGeographicCRSPtr** = std::shared_ptr<*DerivedGeographicCRS*>

Shared pointer of *DerivedGeographicCRS*

using **DerivedGeographicCRSNNPtr** = *util*::nn<*DerivedGeographicCRSPtr*>

Non-null shared pointer of *DerivedGeographicCRS*

using **DerivedProjectedCRSPtr** = std::shared_ptr<*DerivedProjectedCRS*>

Shared pointer of *DerivedProjectedCRS*

using **DerivedProjectedCRSNNPtr** = *util*::nn<*DerivedProjectedCRSPtr*>

Non-null shared pointer of *DerivedProjectedCRS*

using **DerivedVerticalCRSPtr** = std::shared_ptr<*DerivedVerticalCRS*>

Shared pointer of *DerivedVerticalCRS*

using **DerivedVerticalCRSNNPtr** = *util*::nn<*DerivedVerticalCRSPtr*>

Non-null shared pointer of *DerivedVerticalCRS*

using **DerivedEngineeringCRSPtr** = std::shared_ptr<*DerivedEngineeringCRS*>

Shared pointer of *DerivedEngineeringCRS*

using **DerivedEngineeringCRSNNPtr** = *util*::nn<*DerivedEngineeringCRSPtr*>

Non-null shared pointer of *DerivedEngineeringCRS*

using **DerivedParametricCRSPtr** = std::shared_ptr<*DerivedParametricCRS*>

Shared pointer of *DerivedParametricCRS*

using **DerivedParametricCRSNNPtr** = *util*::nn<*DerivedParametricCRSPtr*>

Non-null shared pointer of *DerivedParametricCRS*

using **DerivedTemporalCRSPtr** = std::shared_ptr<*DerivedTemporalCRS*>

Shared pointer of *DerivedTemporalCRS*

using **DerivedTemporalCRSNNPtr** = *util*::nn<*DerivedTemporalCRSPtr*>

Non-null shared pointer of *DerivedTemporalCRS* class **CRS** : public osgeo::proj::*common*::*ObjectUsage*, public osgeo::proj::*io*::*IJSONExportable*

#include <crs.hpp> Abstract class modelling a coordinate reference system which is usually single but may be compound.

Remark

Implements *CRS* from *ISO 19111:2019*

Subclassed by *osgeo::proj::crs::BoundCRS*, *osgeo::proj::crs::CompoundCRS*, *osgeo::proj::crs::SingleCRS*

Public Functions

GeodeticCRSPtr **extractGeodeticCRS**() const

Return the *GeodeticCRS* of the *CRS*.

Returns the *GeodeticCRS* contained in a *CRS*. This works currently with input parameters of type *GeodeticCRS* or derived, *ProjectedCRS*, *CompoundCRS* or *BoundCRS*.

Returns

a GeodeticCRSPtr, that might be null.

GeographicCRSPtr **extractGeographicCRS**() const

Return the *GeographicCRS* of the *CRS*.

Returns the *GeographicCRS* contained in a *CRS*. This works currently with input parameters of type *GeographicCRS* or derived, *ProjectedCRS*, *CompoundCRS* or *BoundCRS*.

Returns

a GeographicCRSPtr, that might be null.

VerticalCRSPtr **extractVerticalCRS**() const

Return the *VerticalCRS* of the *CRS*.

Returns the *VerticalCRS* contained in a *CRS*. This works currently with input parameters of type *VerticalCRS* or derived, *CompoundCRS* or *BoundCRS*.

Returns

a VerticalCRSPtr, that might be null.

CRSNNPtr **createBoundCRSToWGS84IfPossible**(const *io*::*DatabaseContextPtr* &dbContext, *operation*::*CoordinateOperationContext*::*IntermediateCRSUse* allowIntermediateCRSUse) const

Returns potentially a *BoundCRS*, with a transformation to EPSG:4326, wrapping this *CRS*.

If no such *BoundCRS* is possible, the object will be returned.

The purpose of this method is to be able to format a PROJ.4 string with a +towgs84 parameter or a WKT1:GDAL string with a TOWGS node.

This method will fetch the *GeographicCRS* of this *CRS* and find a transformation to EPSG:4326 using the domain of the validity of the main *CRS*, and there's only one Helmert transformation.

Returns

a *CRS*.

CRSNNPtr **stripVerticalComponent**() const

Returns a *CRS* whose coordinate system does not contain a vertical component.

Returns
a *CRS*.

const *BoundCRSPtr* &**canonicalBoundCRS**()

Return the *BoundCRS* potentially attached to this *CRS*.

In the case this method is called on a object returned by *BoundCRS::baseCRSWithCanonicalBoundCRS()*, this method will return this *BoundCRS*

Returns
a BoundCRSPtr, that might be null.

std::list<std::pair<*CRSNNPtr*, int>> **identify**(const *io*::*AuthorityFactoryPtr* &authorityFactory) const

Identify the *CRS* with reference CRSs.

The candidate CRSs are either hard-coded, or looked in the database when authorityFactory is not null.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference *CRS*, and the percentage (0-100) of confidence in the match. The list is sorted by decreasing confidence.

- 100% means that the name of the reference entry perfectly matches the *CRS* name, and both are equivalent. In which case a single result is returned. Note: in the case of a *GeographicCRS* whose axis order is implicit in the input definition (for example ESRI WKT), then axis order is ignored for the purpose of identification. That is the *CRS* built from GEOGCS[“GCS_WGS_1984”,DATUM[“D_WGS_1984”,SPHEROID[“WGS_1984”,6378137.0,298.257223563]], PRIMEM[“Greenwich”,0.0],UNIT[“Degree”,0.0174532925199433]] will be identified to EPSG:4326, but will not pass a isEquivalentTo(EPSG_4326, util::IComparable::Criterion::EQUIVALENT) test, but rather isEquivalentTo(EPSG_4326, *util::IComparable::Criterion::EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS*)
- 90% means that *CRS* are equivalent, but the names are not exactly the same.
- 70% means that *CRS* are equivalent), but the names do not match at all.
- 25% means that the *CRS* are not equivalent, but there is some similarity in the names.

Other confidence values may be returned by some specialized implementations.

This is implemented for *GeodeticCRS*, *ProjectedCRS*, *VerticalCRS* and *CompoundCRS*.

Parameters
authorityFactory – Authority factory (or null, but degraded functionality)

Returns
a list of matching reference *CRS*, and the percentage (0-100) of confidence in the match.

std::list<*CRSNNPtr*> **getNonDeprecated**(const *io*::*DatabaseContextNNPtr* &dbContext) const

Return CRSs that are non-deprecated substitutes for the current *CRS*.

CRSNNPtr **promoteTo3D**(const std::string &newName, const *io*::*DatabaseContextPtr* &dbContext) const

Return a variant of this *CRS* “promoted” to a 3D one, if not already the case.

The new axis will be ellipsoidal height, oriented upwards, and with metre units.

Since
6.3

Parameters
- **newName** – Name of the new *CRS*. If empty, *nameStr()* will be used.

- **dbContext** – Database context to look for potentially already registered 3D *CRS*. May be nullptr.

Returns
a new *CRS* promoted to 3D, or the current one if already 3D or not applicable.

CRSNNPtr **demoteTo2D**(const std::string &newName, const *io*::*DatabaseContextPtr* &dbContext) const

Return a variant of this *CRS* "demoted" to a 2D one, if not already the case.

Since
6.3

Parameters
- **newName** – Name of the new *CRS*. If empty, *nameStr()* will be used.
- **dbContext** – Database context to look for potentially already registered 2D *CRS*. May be nullptr.

Returns
a new *CRS* demoted to 2D, or the current one if already 2D or not applicable.

class **SingleCRS** : public osgeo::proj::*crs*::*CRS*

#include <crs.hpp> Abstract class modelling a coordinate reference system consisting of one Coordinate System and either one *datum::Datum* or one *datum::DatumEnsemble*.

Remark

Implements *SingleCRS* from *ISO 19111:2019*

Subclassed by *osgeo::proj::crs::DerivedCRS*, *osgeo::proj::crs::EngineeringCRS*, *osgeo::proj::crs::GeodeticCRS*, *osgeo::proj::crs::ParametricCRS*, *osgeo::proj::crs::TemporalCRS*, *osgeo::proj::crs::VerticalCRS*

Public Functions

const *datum*::DatumPtr &**datum**()

Return the *datum::Datum* associated with the *CRS*.

This might be null, in which case *datumEnsemble()* return will not be null.

Returns
a Datum that might be null.

const *datum*::DatumEnsemblePtr &**datumEnsemble**()

Return the *datum::DatumEnsemble* associated with the *CRS*.

This might be null, in which case *datum()* return will not be null.

Returns
a DatumEnsemble that might be null.

const *cs*::*CoordinateSystemNNPtr* &**coordinateSystem**()

Return the *cs::CoordinateSystem* associated with the *CRS*.

Returns
a CoordinateSystem.

class **GeodeticCRS** : public virtual osgeo::proj::*crs*::*SingleCRS*, public osgeo::proj::*io*::*IPROJStringExportable*

#include <crs.hpp> A coordinate reference system associated with a geodetic reference frame and a three-dimensional Cartesian or spherical coordinate system.

If the geodetic reference frame is dynamic or if the geodetic *CRS* has an association to a velocity model then the geodetic *CRS* is dynamic, else it is static.

Remark

Implements *GeodeticCRS* from *ISO 19111:2019*

Subclassed by *osgeo::proj::crs::DerivedGeodeticCRS*, *osgeo::proj::crs::GeographicCRS*

Public Functions

const *datum*::GeodeticReferenceFramePtr &**datum**()

Return the *datum::GeodeticReferenceFrame* associated with the *CRS*.

Returns

a GeodeticReferenceFrame or null (in which case *datumEnsemble()* should return a non-null pointer.)

const *datum*::PrimeMeridianNNPtr &**primeMeridian**()

Return the PrimeMeridian associated with the GeodeticReferenceFrame or with one of the GeodeticReferenceFrame of the *datumEnsemble()*.

Returns

the PrimeMeridian.

const *datum*::EllipsoidNNPtr &**ellipsoid**()

Return the ellipsoid associated with the GeodeticReferenceFrame or with one of the GeodeticReferenceFrame of the *datumEnsemble()*.

Returns

the PrimeMeridian.

const std::vector<*operation*::*PointMotionOperationNNPtr*> &**velocityModel**()

Return the velocity model associated with the *CRS*.

Returns

a velocity model. might be null.

bool **isGeocentric**()

Return whether the *CRS* is a geocentric one.

A geocentric *CRS* is a geodetic *CRS* that has a Cartesian coordinate system with three axis, whose direction is respectively *cs::AxisDirection::GEOCENTRIC_X*, *cs::AxisDirection::GEOCENTRIC_Y* and *cs::AxisDirection::GEOCENTRIC_Z*.

Returns

true if the *CRS* is a geocentric *CRS*.

std::list<std::pair<*GeodeticCRSNNPtr*, int>> **identify**(const *io*::*AuthorityFactoryPtr* &authorityFactory) const

Identify the *CRS* with reference CRSs.

The candidate CRSs are either hard-coded, or looked in the database when authorityFactory is not null.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference *CRS*, and the percentage (0-100) of confidence in the match:

- 100% means that the name of the reference entry perfectly matches the *CRS* name, and both are equivalent. In which case a single result is returned. Note: in the case of a *GeographicCRS* whose axis order is implicit in the input definition (for example ESRI WKT), then axis order is ignored for the purpose of identification. That is the *CRS* built from GEOGCS[“GCS_WGS_1984”,DATUM[“D_WGS_1984”,SPHEROID[“WGS_1984”,6378137.0,298.257223563]], PRIMEM[“Greenwich”,0.0],UNIT[“Degree”,0.0174532925199433]] will be identified to EPSG:4326, but will not pass a isEquivalentTo(EPSG_4326, util::IComparable::Criterion::EQUIVALENT) test, but rather isEquivalentTo(EPSG_4326, *util::IComparable::Criterion::EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS*)
- 90% means that *CRS* are equivalent, but the names are not exactly the same.
- 70% means that *CRS* are equivalent (equivalent datum and coordinate system), but the names are not equivalent.
- 60% means that ellipsoid, prime meridian and coordinate systems are equivalent, but the *CRS* and datum names do not match.
- 25% means that the *CRS* are not equivalent, but there is some similarity in the names.

Parameters
`authorityFactory` – Authority factory (or null, but degraded functionality)

Returns
a list of matching reference *CRS*, and the percentage (0-100) of confidence in the match.

Public Static Functions

static *GeodeticCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *datum*::GeodeticReferenceFrameNNPtr &datum, const *cs*::SphericalCSNNPtr &cs)

Instantiate a *GeodeticCRS* from a *datum::GeodeticReferenceFrame* and a *cs::SphericalCS*.

Parameters
- `properties` – See *General properties*. At minimum the name should be defined.
- `datum` – The datum of the *CRS*.
- `cs` – a SphericalCS.

Returns
new *GeodeticCRS*.

static *GeodeticCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *datum*::GeodeticReferenceFrameNNPtr &datum, const *cs*::CartesianCSNNPtr &cs)

Instantiate a *GeodeticCRS* from a *datum::GeodeticReferenceFrame* and a *cs::CartesianCS*.

Parameters
- `properties` – See *General properties*. At minimum the name should be defined.
- `datum` – The datum of the *CRS*.
- `cs` – a CartesianCS.

Returns
new *GeodeticCRS*.

static *GeodeticCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *datum*::GeodeticReferenceFramePtr &datum, const *datum*::DatumEnsemblePtr &datumEnsemble, const *cs*::SphericalCSNNPtr &cs)

Instantiate a *GeodeticCRS* from a *datum::GeodeticReferenceFrame* or *datum::DatumEnsemble* and a *cs::SphericalCS*.

One and only one of datum or datumEnsemble should be set to a non-null value.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **datum** – The datum of the *CRS*, or nullptr
- **datumEnsemble** – The datum ensemble of the *CRS*, or nullptr.
- **cs** – a SphericalCS.

Returns

new *GeodeticCRS*.

static *GeodeticCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *datum*::GeodeticReferenceFramePtr &datum, const *datum*::DatumEnsemblePtr &datumEnsemble, const *cs*::CartesianCSNNPtr &cs)

Instantiate a *GeodeticCRS* from a *datum::GeodeticReferenceFrame* or *datum::DatumEnsemble* and a *cs::CartesianCS*.

One and only one of datum or datumEnsemble should be set to a non-null value.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **datum** – The datum of the *CRS*, or nullptr
- **datumEnsemble** – The datum ensemble of the *CRS*, or nullptr.
- **cs** – a CartesianCS

Returns

new *GeodeticCRS*.

Public Static Attributes

static const *GeodeticCRSNNPtr* **EPSG_4978**

EPSG:4978 / "WGS 84" Geocentric.

class **GeographicCRS** : public osgeo::proj::*crs*::*GeodeticCRS*

#include <crs.hpp> A coordinate reference system associated with a geodetic reference frame and a two- or three-dimensional ellipsoidal coordinate system.

If the geodetic reference frame is dynamic or if the geographic *CRS* has an association to a velocity model then the geodetic *CRS* is dynamic, else it is static.

Remark

Implements *GeographicCRS* from *ISO 19111:2019*

Subclassed by *osgeo::proj::crs::DerivedGeographicCRS*

Public Functions

const *cs*::*EllipsoidalCSNNPtr* &**coordinateSystem**()

Return the *cs::EllipsoidalCS* associated with the *CRS*.

Returns
a EllipsoidalCS.

GeographicCRSNNPtr **demoteTo2D**(const std::string &newName, const *io*::*DatabaseContextPtr* &dbContext) const

Return a variant of this *CRS* "demoted" to a 2D one, if not already the case.

Since
6.3

Parameters
- **newName** – Name of the new *CRS*. If empty, *nameStr()* will be used.
- **dbContext** – Database context to look for potentially already registered 2D *CRS*. May be nullptr.

Returns
a new *CRS* demoted to 2D, or the current one if already 2D or not applicable.

Public Static Functions

static *GeographicCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *datum*::GeodeticReferenceFrameNNPtr &datum, const *cs*::EllipsoidalCSNNPtr &cs)

Instantiate a *GeographicCRS* from a *datum::GeodeticReferenceFrameNNPtr* and a *cs::EllipsoidalCS*.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **datum** – The datum of the *CRS*.
- **cs** – a EllipsoidalCS.

Returns
new *GeographicCRS*.

static *GeographicCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *datum*::GeodeticReferenceFramePtr &datum, const *datum*::DatumEnsemblePtr &datumEnsemble, const *cs*::EllipsoidalCSNNPtr &cs)

Instantiate a *GeographicCRS* from a *datum::GeodeticReferenceFramePtr* or *datum::DatumEnsemble* and a *cs::EllipsoidalCS*.

One and only one of datum or datumEnsemble should be set to a non-null value.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **datum** – The datum of the *CRS*, or nullptr
- **datumEnsemble** – The datum ensemble of the *CRS*, or nullptr.
- **cs** – a EllipsoidalCS.

Returns
new *GeographicCRS*.

Public Static Attributes

static const *GeographicCRSNNPtr* **EPSG_4267**

EPSG:4267 / "NAD27" 2D *GeographicCRS*.

static const *GeographicCRSNNPtr* **EPSG_4269**

EPSG:4269 / "NAD83" 2D *GeographicCRS*.

static const *GeographicCRSNNPtr* **EPSG_4326**

EPSG:4326 / "WGS 84" 2D *GeographicCRS*.

static const *GeographicCRSNNPtr* **OGC_CRS84**

OGC:CRS84 / "CRS 84" 2D *GeographicCRS* (long, lat)

static const *GeographicCRSNNPtr* **EPSG_4807**

EPSG:4807 / "NTF (Paris)" 2D *GeographicCRS*.

static const *GeographicCRSNNPtr* **EPSG_4979**

EPSG:4979 / "WGS 84" 3D *GeographicCRS*.

class **VerticalCRS** : public virtual osgeo::proj::*crs*::*SingleCRS*, public osgeo::proj::*io*::*IPROJStringExportable*

#include <crs.hpp> A coordinate reference system having a vertical reference frame and a one-dimensional vertical coordinate system used for recording gravity-related heights or depths.

Vertical CRSs make use of the direction of gravity to define the concept of height or depth, but the relationship with gravity may not be straightforward. If the vertical reference frame is dynamic or if the vertical *CRS* has an association to a velocity model then the *CRS* is dynamic, else it is static.

Remark

Implements *VerticalCRS* from *ISO 19111:2019*

Note: Ellipsoidal heights cannot be captured in a vertical coordinate reference system. They exist only as an inseparable part of a 3D coordinate tuple defined in a geographic 3D coordinate reference system.

Subclassed by *osgeo::proj::crs::DerivedVerticalCRS*

Public Functions

const *datum*::VerticalReferenceFramePtr **datum**() const

Return the *datum::VerticalReferenceFrame* associated with the *CRS*.

Returns

a VerticalReferenceFrame.

const *cs*::*VerticalCSNNPtr* **coordinateSystem**() const

Return the *cs::VerticalCS* associated with the *CRS*.

Returns

a VerticalCS.

const std::vector<*operation*::*TransformationNNPtr*> &**geoidModel**()

Return the geoid model associated with the *CRS*.

Geoid height model or height correction model linked to a geoid-based vertical *CRS*.

Returns

a geoid model. might be null

const std::vector<*operation*::*PointMotionOperationNNPtr*> &**velocityModel**()

Return the velocity model associated with the *CRS*.

Returns

a velocity model. might be null.

std::list<std::pair<*VerticalCRSNNPtr*, int>> **identify**(const *io*::*AuthorityFactoryPtr* &authorityFactory) const

Identify the *CRS* with reference CRSs.

The candidate CRSs are looked in the database when authorityFactory is not null.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference *CRS*, and the percentage (0-100) of confidence in the match. 100% means that the name of the reference entry perfectly matches the *CRS* name, and both are equivalent. In which case a single result is returned. 90% means that *CRS* are equivalent, but the names are not exactly the same. 70% means that *CRS* are equivalent (equivalent datum and coordinate system), but the names are not equivalent. 25% means that the *CRS* are not equivalent, but there is some similarity in the names.

Parameters

authorityFactory – Authority factory (if null, will return an empty list)

Returns

a list of matching reference *CRS*, and the percentage (0-100) of confidence in the match.

Public Static Functions

static *VerticalCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *datum*::VerticalReferenceFrameNNPtr &datumIn, const *cs*::*VerticalCSNNPtr* &csIn)

Instantiate a *VerticalCRS* from a *datum::VerticalReferenceFrame* and a *cs::VerticalCS*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined. The GEOID_MODEL property can be set to a TransformationNNPtr object.
- **datumIn** – The datum of the *CRS*.
- **csIn** – a VerticalCS.

Returns
new *VerticalCRS*.

static *VerticalCRSNNPtr* `create`(const *util*::*PropertyMap* &properties, const *datum*::VerticalReferenceFramePtr &datumIn, const *datum*::DatumEnsemblePtr &datumEnsembleIn, const *cs*::*VerticalCSNNPtr* &csIn)

Instantiate a *VerticalCRS* from a *datum::VerticalReferenceFrame* or *datum::DatumEnsemble* and a *cs::VerticalCS*.

One and only one of datum or datumEnsemble should be set to a non-null value.

Parameters
- `properties` – See *General properties*. At minimum the name should be defined. The GEOID_MODEL property can be set to a TransformationNNPtr object.
- `datumIn` – The datum of the *CRS*, or nullptr
- `datumEnsembleIn` – The datum ensemble of the *CRS*, or nullptr.
- `csIn` – a VerticalCS.

Returns
new *VerticalCRS*.

class `DerivedCRS` : public virtual osgeo::proj::*crs*::*SingleCRS*

#include <crs.hpp> Abstract class modelling a single coordinate reference system that is defined through the application of a specified coordinate conversion to the definition of a previously established single coordinate reference system referred to as the base *CRS*.

A derived coordinate reference system inherits its datum (or datum ensemble) from its base *CRS*. The coordinate conversion between the base and derived coordinate reference system is implemented using the parameters and formula(s) specified in the definition of the coordinate conversion.

Remark

Implements *DerivedCRS* from *ISO 19111:2019*

Subclassed by *osgeo::proj::crs::DerivedCRSTemplate< DerivedTemporalCRSTraits >*, *osgeo::proj::crs::DerivedCRSTemplate< DerivedParametricCRSTraits >*, *osgeo::proj::crs::DerivedCRSTemplate< DerivedEngineeringCRSTraits >*, *osgeo::proj::crs::DerivedCRSTemplate< DerivedCRSTraits >*, *osgeo::proj::crs::DerivedGeodeticCRS*, *osgeo::proj::crs::DerivedGeographicCRS*, *osgeo::proj::crs::DerivedProjectedCRS*, *osgeo::proj::crs::DerivedVerticalCRS*, *osgeo::proj::crs::ProjectedCRS*

Public Functions

const *SingleCRSNNPtr* &`baseCRS`()

Return the base *CRS* of a *DerivedCRS*.

Returns
the base *CRS*.

const *operation*::*ConversionNNPtr* `derivingConversion`() const

Return the deriving conversion from the base *CRS* to this *CRS*.

Returns
the deriving conversion.

class **ProjectedCRS** : public osgeo::proj::*crs*::*DerivedCRS*, public osgeo::proj::*io*::*IPROJStringExportable*

#include <crs.hpp> A derived coordinate reference system which has a geodetic (usually geographic) coordinate reference system as its base *CRS*, thereby inheriting a geodetic reference frame, and is converted using a map projection.

It has a Cartesian coordinate system, usually two-dimensional but may be three-dimensional; in the 3D case the base geographic CRSs ellipsoidal height is passed through unchanged and forms the vertical axis of the projected *CRS*'s Cartesian coordinate system.

Remark

Implements *ProjectedCRS* from *ISO 19111:2019*

Public Functions

const *GeodeticCRSNNPtr* &**baseCRS**()

Return the base *CRS* (a *GeodeticCRS*, which is generally a *GeographicCRS*) of the *ProjectedCRS*.

Returns

the base *CRS*.

const *cs*::*CartesianCSNNPtr* &**coordinateSystem**()

Return the *cs::CartesianCS* associated with the *CRS*.

Returns

a CartesianCS

std::list<std::pair<*ProjectedCRSNNPtr*, int>> **identify**(const *io*::*AuthorityFactoryPtr* &authorityFactory) const

Identify the *CRS* with reference CRSs.

The candidate CRSs are either hard-coded, or looked in the database when authorityFactory is not null.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference *CRS*, and the percentage (0-100) of confidence in the match. The list is sorted by decreasing confidence.

100% means that the name of the reference entry perfectly matches the *CRS* name, and both are equivalent. In which case a single result is returned. 90% means that *CRS* are equivalent, but the names are not exactly the same. 70% means that *CRS* are equivalent (equivalent base *CRS*, conversion and coordinate system), but the names are not equivalent. 60% means that *CRS* have strong similarity (equivalent base datum, conversion and coordinate system), but the names are not equivalent. 50% means that *CRS* have similarity (equivalent base ellipsoid and conversion), but the coordinate system do not match (e.g. different axis ordering or axis unit). 25% means that the *CRS* are not equivalent, but there is some similarity in the names.

For the purpose of this function, equivalence is tested with the *util::IComparable::Criterion::EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS*, that is to say that the axis order of the base *GeographicCRS* is ignored.

Parameters

authorityFactory – Authority factory (or null, but degraded functionality)

Returns

a list of matching reference *CRS*, and the percentage (0-100) of confidence in the match.

ProjectedCRSNNPtr **demoteTo2D**(const std::string &newName, const *io*::*DatabaseContextPtr* &dbContext) const

Return a variant of this *CRS* "demoted" to a 2D one, if not already the case.

Since
6.3

Parameters
- **newName** – Name of the new *CRS*. If empty, *nameStr()* will be used.
- **dbContext** – Database context to look for potentially already registered 2D *CRS*. May be nullptr.

Returns
a new *CRS* demoted to 2D, or the current one if already 2D or not applicable.

Public Static Functions

static *ProjectedCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *GeodeticCRSNNPtr* &baseCRSIn, const *operation*::*ConversionNNPtr* &derivingConversionIn, const *cs*::*CartesianCSNNPtr* &csIn)

Instantiate a *ProjectedCRS* from a base *CRS*, a deriving *operation::Conversion* and a coordinate system.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **baseCRSIn** – The base *CRS*, a *GeodeticCRS* that is generally a *GeographicCRS*.
- **derivingConversionIn** – The deriving *operation::Conversion* (typically using a map projection method)
- **csIn** – The coordniate system.

Returns
new *ProjectedCRS*.

class **TemporalCRS** : public virtual osgeo::proj::*crs*::*SingleCRS*

#include <crs.hpp> A coordinate reference system associated with a temporal datum and a one-dimensional temporal coordinate system.

Remark

Implements *TemporalCRS* from *ISO 19111:2019*

Public Functions

const *datum*::TemporalDatumNNPtr **datum**() const

Return the *datum::TemporalDatum* associated with the *CRS*.

Returns
a TemporalDatum

const *cs*::*TemporalCSNNPtr* **coordinateSystem**() const

Return the *cs::TemporalCS* associated with the *CRS*.

Returns
a TemporalCS

Public Static Functions

static *TemporalCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *datum*::TemporalDatumNNPtr &datumIn, const *cs*::*TemporalCSNNPtr* &csIn)

Instantiate a *TemporalCRS* from a datum and a coordinate system.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **datumIn** – the datum.
- **csIn** – the coordinate system.

Returns

new *TemporalCRS*.

class **EngineeringCRS** : public virtual osgeo::proj::*crs*::*SingleCRS*

#include <crs.hpp> Contextually local coordinate reference system associated with an engineering datum.

It is applied either to activities on or near the surface of the Earth without geodetic corrections, or on moving platforms such as road vehicles, vessels, aircraft or spacecraft, or as the internal *CRS* of an image.

In *WKT2 standard*, it maps to a ENGINEERINGCRS / ENGCRS keyword. In *WKT1 specification*, it maps to a LOCAL_CS keyword.

Remark

Implements *EngineeringCRS* from *ISO 19111:2019*

Public Functions

const *datum*::EngineeringDatumNNPtr **datum**() const

Return the *datum::EngineeringDatum* associated with the *CRS*.

Returns

a EngineeringDatum

Public Static Functions

static *EngineeringCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *datum*::EngineeringDatumNNPtr &datumIn, const *cs*::*CoordinateSystemNNPtr* &csIn)

Instantiate a *EngineeringCRS* from a datum and a coordinate system.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **datumIn** – the datum.
- **csIn** – the coordinate system.

Returns

new *EngineeringCRS*.

class **ParametricCRS** : public virtual osgeo::proj::*crs*::*SingleCRS*

#include <crs.hpp> Contextually local coordinate reference system associated with an engineering datum.

This is applied either to activities on or near the surface of the Earth without geodetic corrections, or on moving platforms such as road vehicles vessels, aircraft or spacecraft, or as the internal *CRS* of an image.

Remark

Implements *ParametricCRS* from *ISO 19111:2019*

Public Functions

const *datum*::ParametricDatumNNPtr **datum**() const

Return the *datum::ParametricDatum* associated with the *CRS*.

Returns
a ParametricDatum

const *cs*::*ParametricCSNNPtr* **coordinateSystem**() const

Return the *cs::TemporalCS* associated with the *CRS*.

Returns
a TemporalCS

Public Static Functions

static *ParametricCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *datum*::ParametricDatumNNPtr &datumIn, const *cs*::*ParametricCSNNPtr* &csIn)

Instantiate a *ParametricCRS* from a datum and a coordinate system.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **datumIn** – the datum.
- **csIn** – the coordinate system.

Returns
new *ParametricCRS*.

class **InvalidCompoundCRSException** : public osgeo::proj::*util*::*Exception*

#include <crs.hpp> Exception thrown when attempting to create an invalid compound *CRS*.

class **CompoundCRS** : public osgeo::proj::*crs*::*CRS*, public osgeo::proj::*io*::*IPROJStringExportable*

#include <crs.hpp> A coordinate reference system describing the position of points through two or more independent single coordinate reference systems.

Remark

Implements *CompoundCRS* from *ISO 19111:2019*

Note: Two coordinate reference systems are independent of each other if coordinate values in one cannot be converted or transformed into coordinate values in the other.

Note: As a departure to *ISO 19111:2019*, we allow to build a *CompoundCRS* from *CRS* objects, whereas ISO19111:2019 restricts the components to *SingleCRS*.

Public Functions

const std::vector<*CRSNNPtr*> &**componentReferenceSystems**()

Return the components of a *CompoundCRS*.

Returns
the components.

std::list<std::pair<*CompoundCRSNNPtr*, int>> **identify**(const *io*::*AuthorityFactoryPtr* &authorityFactory) const

Identify the *CRS* with reference CRSs.

The candidate CRSs are looked in the database when authorityFactory is not null.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference *CRS*, and the percentage (0-100) of confidence in the match. The list is sorted by decreasing confidence.

100% means that the name of the reference entry perfectly matches the *CRS* name, and both are equivalent. In which case a single result is returned. 90% means that *CRS* are equivalent, but the names are not exactly the same. 70% means that *CRS* are equivalent (equivalent horizontal and vertical *CRS*), but the names are not equivalent. 25% means that the *CRS* are not equivalent, but there is some similarity in the names.

Parameters
authorityFactory – Authority factory (if null, will return an empty list)

Returns
a list of matching reference *CRS*, and the percentage (0-100) of confidence in the match.

Public Static Functions

static *CompoundCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const std::vector<*CRSNNPtr*> &components)

Instantiate a *CompoundCRS* from a vector of *CRS*.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **components** – the component *CRS* of the *CompoundCRS*.

Throws
InvalidCompoundCRSException –

Returns
new *CompoundCRS*.

class **BoundCRS** : public osgeo::proj::*crs*::*CRS*, public osgeo::proj::*io*::*IPROJStringExportable*

#include <crs.hpp> A coordinate reference system with an associated transformation to a target/hub *CRS*.

The definition of a *CRS* is not dependent upon any relationship to an independent *CRS*. However in an implementation that merges datasets referenced to differing CRSs, it is sometimes useful to associate the definition of the transformation that has been used with the *CRS* definition. This facilitates the interrelationship of *CRS* by concatenating transformations via a common or hub *CRS*. This is sometimes referred to as "early-binding". *WKT2 standard* permits the association of an abridged coordinate transformation description with a coordinate reference system description in a single text string. In a *BoundCRS*, the abridged coordinate transformation is applied to the source *CRS* with the target *CRS* being the common or hub system.

Coordinates referring to a *BoundCRS* are expressed into its source/base *CRS*.

This abstraction can for example model the concept of TOWGS84 datum shift present in *WKT1 specification*.

Remark

Implements *BoundCRS* from *WKT2 standard*

Note: Contrary to other *CRS* classes of this package, there is no *ISO 19111:2019* modelling of a *BoundCRS*.

Public Functions

const *CRSNNPtr* &**`baseCRS`**()

Return the base *CRS*.

This is the *CRS* into which coordinates of the *BoundCRS* are expressed.

Returns

the base *CRS*.

CRSNNPtr **`baseCRSWithCanonicalBoundCRS`**() const

Return a shallow clone of the base *CRS* that points to a shallow clone of this *BoundCRS*.

The base *CRS* is the *CRS* into which coordinates of the *BoundCRS* are expressed.

The returned *CRS* will actually be a shallow clone of the actual base *CRS*, with the extra property that *CRS::canonicalBoundCRS()* will point to a shallow clone of this *BoundCRS*. Use this only if you want to work with the base *CRS* object rather than the *BoundCRS*, but wanting to be able to retrieve the *BoundCRS* later.

Returns

the base *CRS*.

const *CRSNNPtr* &**`hubCRS`**()

Return the target / hub *CRS*.

Returns

the hub *CRS*.

const *operation*::*TransformationNNPtr* &**`transformation`**()

Return the transformation to the hub RS.

Returns

transformation.

Public Static Functions

static *BoundCRSNNPtr* **create**(const *CRSNNPtr* &baseCRSIn, const *CRSNNPtr* &hubCRSIn, const *operation*::*TransformationNNPtr* &transformationIn)

Instantiate a *BoundCRS* from a base *CRS*, a hub *CRS* and a transformation.

Parameters
- **baseCRSIn** – base *CRS*.
- **hubCRSIn** – hub *CRS*.
- **transformationIn** – transformation from base *CRS* to hub *CRS*.

Returns
new *BoundCRS*.

static *BoundCRSNNPtr* **createFromTOWGS84**(const *CRSNNPtr* &baseCRSIn, const std::vector<double> &TOWGS84Parameters)

Instantiate a *BoundCRS* from a base *CRS* and TOWGS84 parameters.

Parameters
- **baseCRSIn** – base *CRS*.
- **TOWGS84Parameters** – a vector of 3 or 7 double values representing WKT1 TOWGS84 parameter.

Returns
new *BoundCRS*.

static *BoundCRSNNPtr* **createFromNadgrids**(const *CRSNNPtr* &baseCRSIn, const std::string &filename)

Instantiate a *BoundCRS* from a base *CRS* and nadgrids parameters.

Parameters
- **baseCRSIn** – base *CRS*.
- **filename** – Horizontal grid filename

Returns
new *BoundCRS*.

class **DerivedGeodeticCRS** : public osgeo::proj::*crs*::*GeodeticCRS*, public osgeo::proj::*crs*::*DerivedCRS*

#include <crs.hpp> A derived coordinate reference system which has either a geodetic or a geographic coordinate reference system as its base *CRS*, thereby inheriting a geodetic reference frame, and associated with a 3D Cartesian or spherical coordinate system.

Remark

Implements *DerivedGeodeticCRS* from *ISO 19111:2019*

Public Functions

const *GeodeticCRSNNPtr* **baseCRS**() const

Return the base *CRS* (a *GeodeticCRS*) of a *DerivedGeodeticCRS*.

Returns
the base *CRS*.

Public Static Functions

static *DerivedGeodeticCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *GeodeticCRSNNPtr* &baseCRSIn, const *operation*::*ConversionNNPtr* &derivingConversionIn, const *cs*::*CartesianCSNNPtr* &csIn)

Instantiate a *DerivedGeodeticCRS* from a base *CRS*, a deriving conversion and a *cs::CartesianCS*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **baseCRSIn** – base *CRS*.
- **derivingConversionIn** – the deriving conversion from the base *CRS* to this *CRS*.
- **csIn** – the coordinate system.

Returns

new *DerivedGeodeticCRS*.

static *DerivedGeodeticCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *GeodeticCRSNNPtr* &baseCRSIn, const *operation*::*ConversionNNPtr* &derivingConversionIn, const *cs*::*SphericalCSNNPtr* &csIn)

Instantiate a *DerivedGeodeticCRS* from a base *CRS*, a deriving conversion and a *cs::SphericalCS*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **baseCRSIn** – base *CRS*.
- **derivingConversionIn** – the deriving conversion from the base *CRS* to this *CRS*.
- **csIn** – the coordinate system.

Returns

new *DerivedGeodeticCRS*.

class **DerivedGeographicCRS** : public osgeo::proj::*crs*::*GeographicCRS*, public osgeo::proj::*crs*::*DerivedCRS*

#include <crs.hpp> A derived coordinate reference system which has either a geodetic or a geographic coordinate reference system as its base *CRS*, thereby inheriting a geodetic reference frame, and an ellipsoidal coordinate system.

A derived geographic *CRS* can be based on a geodetic *CRS* only if that geodetic *CRS* definition includes an ellipsoid.

Remark

Implements *DerivedGeographicCRS* from *ISO 19111:2019*

Public Functions

const *GeodeticCRSNNPtr* **baseCRS**() const

Return the base *CRS* (a *GeodeticCRS*) of a *DerivedGeographicCRS*.

Returns

the base *CRS*.

Public Static Functions

static *DerivedGeographicCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *GeodeticCRSNNPtr* &baseCRSIn, const *operation*::*ConversionNNPtr* &derivingConversionIn, const *cs*::*EllipsoidalCSNNPtr* &csIn)

Instantiate a *DerivedGeographicCRS* from a base *CRS*, a deriving conversion and a *cs::EllipsoidalCS*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **baseCRSIn** – base *CRS*.
- **derivingConversionIn** – the deriving conversion from the base *CRS* to this *CRS*.
- **csIn** – the coordinate system.

Returns

new *DerivedGeographicCRS*.

class **DerivedProjectedCRS** : public osgeo::proj::*crs*::*DerivedCRS*

#include <crs.hpp> A derived coordinate reference system which has a projected coordinate reference system as its base *CRS*, thereby inheriting a geodetic reference frame, but also inheriting the distortion characteristics of the base projected *CRS*.

A *DerivedProjectedCRS* is not a *ProjectedCRS*.

Remark

Implements *DerivedProjectedCRS* from *ISO 19111:2019*

Public Functions

const *ProjectedCRSNNPtr* **baseCRS**() const

Return the base *CRS* (a *ProjectedCRS*) of a *DerivedProjectedCRS*.

Returns

the base *CRS*.

Public Static Functions

static *DerivedProjectedCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *ProjectedCRSNNPtr* &baseCRSIn, const *operation*::*ConversionNNPtr* &derivingConversionIn, const *cs*::*CoordinateSystemNNPtr* &csIn)

Instantiate a *DerivedProjectedCRS* from a base *CRS*, a deriving conversion and a cs::CS.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **baseCRSIn** – base *CRS*.
- **derivingConversionIn** – the deriving conversion from the base *CRS* to this *CRS*.
- **csIn** – the coordinate system.

Returns

new *DerivedProjectedCRS*.

class **DerivedVerticalCRS** : public osgeo::proj::*crs*::*VerticalCRS*, public osgeo::proj::*crs*::*DerivedCRS*

#include <crs.hpp> A derived coordinate reference system which has a vertical coordinate reference system as its base *CRS*, thereby inheriting a vertical reference frame, and a vertical coordinate system.

Remark

Implements *DerivedVerticalCRS* from *ISO 19111:2019*

Public Functions

const *VerticalCRSNNPtr* **baseCRS**() const

Return the base *CRS* (a *VerticalCRS*) of a *DerivedVerticalCRS*.

Returns

the base *CRS*.

Public Static Functions

static *DerivedVerticalCRSNNPtr* **create**(const *util*::*PropertyMap* &properties, const *VerticalCRSNNPtr* &baseCRSIn, const *operation*::*ConversionNNPtr* &derivingConversionIn, const *cs*::*VerticalCSNNPtr* &csIn)

Instantiate a *DerivedVerticalCRS* from a base *CRS*, a deriving conversion and a *cs::VerticalCS*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **baseCRSIn** – base *CRS*.
- **derivingConversionIn** – the deriving conversion from the base *CRS* to this *CRS*.
- **csIn** – the coordinate system.

Returns

new *DerivedVerticalCRS*.

template<class **DerivedCRSTraits**>

class **DerivedCRSTemplate** : public *DerivedCRSTraits*::BaseType, public osgeo::proj::*crs*::*DerivedCRS*

#include <crs.hpp> Template representing a derived coordinate reference system.

Public Types

typedef *util*::nn<std::shared_ptr<*DerivedCRSTemplate*>> **NNPtr**

Non-null shared pointer of *DerivedCRSTemplate*

typedef *util*::nn<std::shared_ptr<BaseType>> **BaseNNPtr**

Non-null shared pointer of BaseType

typedef *util*::nn<std::shared_ptr<CSType>> **CSNNPtr**

Non-null shared pointer of CSType

Public Functions

const *BaseNNPtr* **baseCRS**() const

Return the base *CRS* of a *DerivedCRSTemplate*.

Returns
the base *CRS*.

Public Static Functions

static *NNPtr* **create**(const *util*::*PropertyMap* &properties, const *BaseNNPtr* &baseCRSIn, const *operation*::*ConversionNNPtr* &derivingConversionIn, const *CSNNPtr* &csIn)

Instantiate a *DerivedCRSTemplate* from a base *CRS*, a deriving conversion and a *cs::CoordinateSystem*.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **baseCRSIn** – base *CRS*.
- **derivingConversionIn** – the deriving conversion from the base *CRS* to this *CRS*.
- **csIn** – the coordinate system.

Returns
new *DerivedCRSTemplate*.

class **DerivedEngineeringCRS** : public osgeo::proj::*crs*::*DerivedCRSTemplate*<DerivedEngineeringCRSTraits>

#include <crs.hpp> A derived coordinate reference system which has an engineering coordinate reference system as its base *CRS*, thereby inheriting an engineering datum, and is associated with one of the coordinate system types for an *EngineeringCRS*.

Remark

Implements *DerivedEngineeringCRS* from *ISO 19111:2019*

---

class **DerivedParametricCRS** : public osgeo::proj::*crs*::*DerivedCRSTemplate*<DerivedParametricCRSTraits>

#include <crs.hpp> A derived coordinate reference system which has a parametric coordinate reference system as its base *CRS*, thereby inheriting a parametric datum, and a parametric coordinate system.

Remark

Implements *DerivedParametricCRS* from *ISO 19111:2019*

---

class **DerivedTemporalCRS** : public osgeo::proj::*crs*::*DerivedCRSTemplate*<DerivedTemporalCRSTraits>

#include <crs.hpp> A derived coordinate reference system which has a temporal coordinate reference system as its base *CRS*, thereby inheriting a temporal datum, and a temporal coordinate system.

Remark

Implements *DerivedTemporalCRS* from *ISO 19111:2019*

10.5.4.8 operation namespace

namespace **operation**

Coordinate operations (relationship between any two coordinate reference systems).

osgeo.proj.operation namespace

This covers *Conversion*, *Transformation*, *PointMotionOperation* or *ConcatenatedOperation*.

Typedefs

typedef std::shared_ptr<*CoordinateOperation*> **CoordinateOperationPtr**

Shared pointer of *CoordinateOperation*

typedef *util*::nn<*CoordinateOperationPtr*> **CoordinateOperationNNPtr**

Non-null shared pointer of *CoordinateOperation*

using **GeneralOperationParameterPtr** = std::shared_ptr<*GeneralOperationParameter*>

Shared pointer of *GeneralOperationParameter*

using **GeneralOperationParameterNNPtr** = *util*::nn<*GeneralOperationParameterPtr*>

Non-null shared pointer of *GeneralOperationParameter*

using **OperationParameterPtr** = std::shared_ptr<*OperationParameter*>

Shared pointer of *OperationParameter*

using **OperationParameterNNPtr** = *util*::nn<*OperationParameterPtr*>

Non-null shared pointer of *OperationParameter*

using **GeneralParameterValuePtr** = std::shared_ptr<*GeneralParameterValue*>

Shared pointer of *GeneralParameterValue*

using **GeneralParameterValueNNPtr** = *util*::nn<*GeneralParameterValuePtr*>

Non-null shared pointer of *GeneralParameterValue*

using **ParameterValuePtr** = std::shared_ptr<*ParameterValue*>

Shared pointer of *ParameterValue*

using **ParameterValueNNPtr** = *util*::nn<*ParameterValuePtr*>

Non-null shared pointer of *ParameterValue*

using **OperationParameterValuePtr** = std::shared_ptr<*OperationParameterValue*>

Shared pointer of *OperationParameterValue* using **OperationParameterValueNNPtr** = *util*::nn<*OperationParameterValuePtr*>

Non-null shared pointer of *OperationParameterValue*

using **OperationMethodPtr** = std::shared_ptr<*OperationMethod*>

Shared pointer of *OperationMethod*

using **OperationMethodNNPtr** = *util*::nn<*OperationMethodPtr*>

Non-null shared pointer of *OperationMethod*

using **SingleOperationPtr** = std::shared_ptr<*SingleOperation*>

Shared pointer of *SingleOperation*

using **SingleOperationNNPtr** = *util*::nn<*SingleOperationPtr*>

Non-null shared pointer of *SingleOperation*

typedef std::shared_ptr<*Conversion*> **ConversionPtr**

Shared pointer of *Conversion*

typedef *util*::nn<*ConversionPtr*> **ConversionNNPtr**

Non-null shared pointer of *Conversion*

using **TransformationPtr** = std::shared_ptr<*Transformation*>

Shared pointer of *Transformation*

using **TransformationNNPtr** = *util*::nn<*TransformationPtr*>

Non-null shared pointer of *Transformation*

using **PointMotionOperationPtr** = std::shared_ptr<*PointMotionOperation*>

Shared pointer of *PointMotionOperation*

using **PointMotionOperationNNPtr** = *util*::nn<*PointMotionOperationPtr*>

Non-null shared pointer of *PointMotionOperation*

using **ConcatenatedOperationPtr** = std::shared_ptr<*ConcatenatedOperation*>

Shared pointer of *ConcatenatedOperation*

using **ConcatenatedOperationNNPtr** = *util*::nn<*ConcatenatedOperationPtr*>

Non-null shared pointer of *ConcatenatedOperation*

using **CoordinateOperationContextPtr** = std::unique_ptr<*CoordinateOperationContext*>

Unique pointer of *CoordinateOperationContext*

using **CoordinateOperationContextNNPtr** = *util*::nn<*CoordinateOperationContextPtr*>

Non-null unique pointer of *CoordinateOperationContext* using **CoordinateOperationFactoryPtr** = std::unique_ptr<*CoordinateOperationFactory*>

Unique pointer of *CoordinateOperationFactory*

using **CoordinateOperationFactoryNNPtr** = *util*::nn<*CoordinateOperationFactoryPtr*>

Non-null unique pointer of *CoordinateOperationFactory*

Functions

static double **negate**(double val)

static *CoordinateOperationPtr* **createApproximateInverseIfPossible**(const *Transformation* *op)

struct **GridDescription**

#include <coordinateoperation.hpp> Grid description.

Public Members

std::string **shortName**

Grid short filename

std::string **fullName**

Grid full path name (if found)

std::string **packageName**

Package name (or empty)

std::string **url**

Grid URL (if packageName is empty), or package URL (or empty)

bool **directDownload**

Whether url can be fetched directly.

bool **openLicense**

Whether the grid is released with an open license.

bool **available**

Whether GRID is available.

class **CoordinateOperation** : public osgeo::proj::*common*::*ObjectUsage*, public osgeo::proj::*io*::*IPROJStringExportable*, public osgeo::proj::*io*::*IJSONExportable*

#include <coordinateoperation.hpp> Abstract class for a mathematical operation on coordinates.

A mathematical operation:

- on coordinates that transforms or converts them from one coordinate reference system to another coordinate reference system

- or that describes the change of coordinate values within one coordinate reference system due to the motion of the point between one coordinate epoch and another coordinate epoch.

Many but not all coordinate operations (from CRS A to CRS B) also uniquely define the inverse coordinate operation (from CRS B to CRS A). In some cases, the coordinate operation method algorithm for the inverse coordinate operation is the same as for the forward algorithm, but the signs of some coordinate operation parameter values have to be reversed. In other cases, different algorithms are required for the forward and inverse coordinate operations, but the same coordinate operation parameter values are used. If (some) entirely different parameter values are needed, a different coordinate operation shall be defined.

Remark

Implements *CoordinateOperation* from *ISO 19111:2019*

Subclassed by *osgeo::proj::operation::ConcatenatedOperation*, *osgeo::proj::operation::SingleOperation*

Public Functions

const *util*::*optional*<std::string> &**operationVersion**() const

Return the version of the coordinate transformation (i.e. instantiation due to the stochastic nature of the parameters).

Mandatory when describing a coordinate transformation or point motion operation, and should not be supplied for a coordinate conversion.

Returns

version or empty.

const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &**coordinateOperationAccuracies**() const

Return estimate(s) of the impact of this coordinate operation on point accuracy.

Gives position error estimates for target coordinates of this coordinate operation, assuming no errors in source coordinates.

Returns

estimate(s) or empty vector.

const *crs*::*CRSPtr* **sourceCRS**() const

Return the source CRS of this coordinate operation.

This should not be null, expect for of a derivingConversion of a DerivedCRS when the owning DerivedCRS has been destroyed.

Returns

source CRS, or null.

const *crs*::*CRSPtr* **targetCRS**() const

Return the target CRS of this coordinate operation.

This should not be null, expect for of a derivingConversion of a DerivedCRS when the owning DerivedCRS has been destroyed.

Returns

target CRS, or null.

const *crs*::*CRSPtr* &**interpolationCRS**() const

Return the interpolation CRS of this coordinate operation.

Returns

interpolation CRS, or null.

const *util*::*optional*<*common*::*DataEpoch*> &**sourceCoordinateEpoch**() const

Return the source epoch of coordinates.

Returns

source epoch of coordinates, or empty.

const *util*::*optional*<*common*::*DataEpoch*> &**targetCoordinateEpoch**() const

Return the target epoch of coordinates.

Returns

target epoch of coordinates, or empty.

virtual *CoordinateOperationNNPtr* **inverse**() const = 0

Return the inverse of the coordinate operation.

Throws

`util::UnsupportedOperationException` –

virtual std::set<*GridDescription*> **gridsNeeded**(const *io*::*DatabaseContextPtr* &databaseContext, bool considerKnownGridsAsAvailable) const = 0

Return grids needed by an operation.

bool **isPROJInstantiable**(const *io*::*DatabaseContextPtr* &databaseContext, bool considerKnownGridsAsAvailable) const

Return whether a coordinate operation can be instantiated as a PROJ pipeline, checking in particular that referenced grids are available.

bool **hasBallparkTransformation**() const

Return whether a coordinate operation has a "ballpark" transformation, that is a very approximate one, due to lack of more accurate transformations.

Typically a null geographic offset between two horizontal datum, or a null vertical offset (or limited to unit changes) between two vertical datum. Errors of several tens to one hundred meters might be expected, compared to more accurate transformations.

CoordinateOperationNNPtr **normalizeForVisualization**() const

Return a variation of the current coordinate operation whose axis order is the one expected for visualization purposes.

Public Static Attributes

static const std::string **OPERATION_VERSION_KEY**

Key to set the operation version of a *operation::CoordinateOperation*.

The value is to be provided as a string.

class **GeneralOperationParameter** : public osgeo::proj::*common*::*IdentifiedObject*

#include <coordinateoperation.hpp> Abstract class modelling a parameter value (*OperationParameter*) or group of parameters.

Remark

Implements *GeneralOperationParameter* from *ISO 19111:2019*

Subclassed by *osgeo::proj::operation::OperationParameter* class `OperationParameter` : public osgeo::proj::*operation*::*GeneralOperationParameter*

#include <*coordinateoperation.hpp*> The definition of a parameter used by a coordinate operation method.

Most parameter values are numeric, but other types of parameter values are possible.

Remark

Implements *OperationParameter* from *ISO 19111:2019*

Public Functions

int `getEPSGCode()`

Return the EPSG code, either directly, or through the name.

Returns

code, or 0 if not found

Public Static Functions

static *OperationParameterNNPtr* `create`(const *util*::*PropertyMap* &properties)

Instantiate a *OperationParameter*.

Parameters

`properties` – See *General properties*. At minimum the name should be defined.

Returns

a new *OperationParameter*.

static const char *`getNameForEPSGCode`(int epsg_code) noexcept

Return the name of a parameter designed by its EPSG code.

Returns

name, or nullptr if not found

class `GeneralParameterValue` : public osgeo::proj::*util*::*BaseObject*, public osgeo::proj::*io*::*IWKTExportable*, public osgeo::proj::*io*::*IJSONExportable*, public osgeo::proj::*util*::*IComparable*

#include <*coordinateoperation.hpp*> Abstract class modelling a parameter value (*OperationParameterValue*) or group of parameter values.

Remark

Implements *GeneralParameterValue* from *ISO 19111:2019*

Subclassed by *osgeo::proj::operation::OperationParameterValue*

class `ParameterValue` : public osgeo::proj::*util*::*BaseObject*, public osgeo::proj::*io*::*IWKTExportable*, public osgeo::proj::*util*::*IComparable*

#include <*coordinateoperation.hpp*> The value of the coordinate operation parameter.

Most parameter values are numeric, but other types of parameter values are possible.

Remark

Implements *ParameterValue* from *ISO 19111:2019*

Public Types

enum class **Type**

Type of the value.

Values:

enumerator **MEASURE**

Measure (i.e. value with a unit)

enumerator **STRING**

String

enumerator **INTEGER**

Integer

enumerator **BOOLEAN**

Boolean

enumerator **FILENAME**

Filename

Public Functions

const *Type* &**type**()

Returns the type of a parameter value.

Returns

the type.

const *common*::*Measure* &**value**()

Returns the value as a Measure (assumes *type()* == *Type::MEASURE*)

Returns

the value as a Measure.

const std::string &**stringValue**()

Returns the value as a string (assumes *type()* == *Type::STRING*)

Returns

the value as a string.

const std::string &**valueFile**()

Returns the value as a filename (assumes *type()* == *Type::FILENAME*)

Returns

the value as a filename.

int **integerValue**()

Returns the value as a integer (assumes *type()* == *Type::INTEGER*)

Returns
the value as a integer.

bool **booleanValue**()

Returns the value as a boolean (assumes *type()* == *Type::BOOLEAN*)

Returns
the value as a boolean.

Public Static Functions

static *ParameterValueNNPtr* **create**(const *common*::*Measure* &measureIn)

Instantiate a *ParameterValue* from a Measure (i.e. a value associated with a unit)

Returns
a new *ParameterValue*.

static *ParameterValueNNPtr* **create**(const char *stringValueIn)

Instantiate a *ParameterValue* from a string value.

Returns
a new *ParameterValue*.

static *ParameterValueNNPtr* **create**(const std::string &stringValueIn)

Instantiate a *ParameterValue* from a string value.

Returns
a new *ParameterValue*.

static *ParameterValueNNPtr* **create**(int integerValueIn)

Instantiate a *ParameterValue* from a integer value.

Returns
a new *ParameterValue*.

static *ParameterValueNNPtr* **create**(bool booleanValueIn)

Instantiate a *ParameterValue* from a boolean value.

Returns
a new *ParameterValue*.

static *ParameterValueNNPtr* **createFilename**(const std::string &stringValueIn)

Instantiate a *ParameterValue* from a filename.

Returns
a new *ParameterValue*.

class **OperationParameterValue** : public osgeo::proj::*operation*::*GeneralParameterValue*

#include <coordinateoperation.hpp> A parameter value, ordered sequence of values, or reference to a file of parameter values.

This combines a *OperationParameter* with the corresponding *ParameterValue*.

Remark

Implements *OperationParameterValue* from *ISO 19111:2019*

Public Functions

const *OperationParameterNNPtr* &**parameter**()

Return the parameter (definition)

Returns

the parameter (definition).

const *ParameterValueNNPtr* &**parameterValue**()

Return the parameter value.

Returns

the parameter value.

Public Static Functions

static *OperationParameterValueNNPtr* **create**(const *OperationParameterNNPtr* &parameterIn, const *ParameterValueNNPtr* &valueIn)

Instantiate a *OperationParameterValue*.

Parameters

- **parameterIn** – Parameter (definition).
- **valueIn** – Parameter value.

Returns

a new *OperationParameterValue*.

class **OperationMethod** : public osgeo::proj::*common*::*IdentifiedObject*, public osgeo::proj::*io*::*IJSONExportable*

#include <coordinateoperation.hpp> The method (algorithm or procedure) used to perform the coordinate operation.

For a projection method, this contains the name of the projection method and the name of the projection parameters.

Remark

Implements *OperationMethod* from *ISO 19111:2019*

Public Functions

const *util*::*optional*<std::string> &**formula**()

Return the formula(s) or procedure used by this coordinate operation method.

This may be a reference to a publication (in which case use *formulaCitation()*).

Note that the operation method may not be analytic, in which case this attribute references or contains the procedure, not an analytic formula.

Returns

the formula, or empty.

const *util*::*optional*<*metadata*::*Citation*> &**formulaCitation**()

Return a reference to a publication giving the formula(s) or procedure used by the coordinate operation method.

Returns
the formula citation, or empty.

const std::vector<*GeneralOperationParameterNNPtr*> &**parameters**()

Return the parameters of this operation method.

Returns
the parameters.

int **getEPSGCode**()

Return the EPSG code, either directly, or through the name.

Returns
code, or 0 if not found

Public Static Functions

static *OperationMethodNNPtr* **create**(const *util*::*PropertyMap* &properties, const std::vector<*GeneralOperationParameterNNPtr*> &parameters)

Instantiate a operation method from a vector of *GeneralOperationParameter*.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **parameters** – Vector of GeneralOperationParameterNNPtr.

Returns
a new *OperationMethod*.

static *OperationMethodNNPtr* **create**(const *util*::*PropertyMap* &properties, const std::vector<*OperationParameterNNPtr*> &parameters)

Instantiate a operation method from a vector of *OperationParameter*.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **parameters** – Vector of OperationParameterNNPtr.

Returns
a new *OperationMethod*.

class **InvalidOperation** : public osgeo::proj::*util*::*Exception*

#include <coordinateoperation.hpp> Exception that can be thrown when an invalid operation is attempted to be constructed.

class **SingleOperation** : public virtual osgeo::proj::*operation*::*CoordinateOperation*

#include <coordinateoperation.hpp> A single (not concatenated) coordinate operation (*CoordinateOperation*)

Remark

Implements *SingleOperation* from *ISO 19111:2019*

Subclassed by *osgeo::proj::operation::Conversion*, *osgeo::proj::operation::PointMotionOperation*, *osgeo::proj::operation::Transformation*

Public Functions

const std::vector<*GeneralParameterValueNNPtr*> &**parameterValues**()

Return the parameter values.

Returns
the parameter values.

const *OperationMethodNNPtr* &**method**()

Return the operation method associated to the operation.

Returns
the operation method.

const *ParameterValuePtr* &**parameterValue**(const std::string &paramName, int epsg_code = 0) const noexcept

Return the parameter value corresponding to a parameter name or EPSG code.

Parameters
- **paramName** – the parameter name (or empty, in which case epsg_code should be non zero)
- **epsg_code** – the parameter EPSG code (possibly zero)

Returns
the value, or nullptr if not found.

const *ParameterValuePtr* &**parameterValue**(int epsg_code) const noexcept

Return the parameter value corresponding to a EPSG code.

Parameters
epsg_code – the parameter EPSG code

Returns
the value, or nullptr if not found.

const *common*::*Measure* &**parameterValueMeasure**(const std::string &paramName, int epsg_code = 0) const noexcept

Return the parameter value, as a measure, corresponding to a parameter name or EPSG code.

Parameters
- **paramName** – the parameter name (or empty, in which case epsg_code should be non zero)
- **epsg_code** – the parameter EPSG code (possibly zero)

Returns
the measure, or the empty Measure() object if not found.

const *common*::*Measure* &**parameterValueMeasure**(int epsg_code) const noexcept

Return the parameter value, as a measure, corresponding to a EPSG code.

Parameters
epsg_code – the parameter EPSG code

Returns
the measure, or the empty Measure() object if not found.

virtual std::set<*GridDescription*> **gridsNeeded**(const *io*::*DatabaseContextPtr* &databaseContext, bool considerKnownGridsAsAvailable) const override

Return grids needed by an operation.

std::list<std::string> **validateParameters**() const

Validate the parameters used by a coordinate operation.

Return whether the method is known or not, or a list of missing or extra parameters for the operations recognized by this implementation.

Public Static Functions

static *SingleOperationNNPtr* **createPROJBased**(const *util*::*PropertyMap* &properties, const std::string &PROJString, const *crs*::*CRSPtr* &sourceCRS, const *crs*::*CRSPtr* &targetCRS, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies = std::vector<*metadata*::*PositionalAccuracyNNPtr*>())

Instantiate a PROJ-based single operation.

Note: The operation might internally be a pipeline chaining several operations. The use of the *SingleOperation* modeling here is mostly to be able to get the PROJ string as a parameter.

Parameters
- **properties** – Properties
- **PROJString** – the PROJ string.
- **sourceCRS** – source CRS (might be null).
- **targetCRS** – target CRS (might be null).
- **accuracies** – Vector of positional accuracy (might be empty).

Returns
the new instance

class **Conversion** : public osgeo::proj::*operation*::*SingleOperation*

#include <coordinateoperation.hpp> A mathematical operation on coordinates in which the parameter values are defined rather than empirically derived.

Application of the coordinate conversion introduces no error into output coordinates. The best-known example of a coordinate conversion is a map projection. For coordinate conversions the output coordinates are referenced to the same datum as are the input coordinates.

Coordinate conversions forming a component of a derived CRS have a source *crs::CRS* and a target *crs::CRS* that are NOT specified through the source and target associations, but through associations from *crs::DerivedCRS* to *crs::SingleCRS*.

Remark

Implements *Conversion* from *ISO 19111:2019*

Projection parameters

Co-latitude of cone axis

The rotation applied to spherical coordinates for the oblique projection, measured on the conformal sphere in the plane of the meridian of origin.

EPSG:1036

Latitude of natural origin/Center Latitude

The latitude of the point from which the values of both the geographical coordinates on the ellipsoid and the grid coordinates on the projection are deemed to increment or decrement for computational purposes. Alternatively it may be considered as the latitude of the point which in the absence of application of false coordinates has grid coordinates of (0,0).

EPSG:8801

Longitude of natural origin/Central Meridian

The longitude of the point from which the values of both the geographical coordinates on the ellipsoid and the grid coordinates on the projection are deemed to increment or decrement for computational purposes. Alternatively it may be considered as the longitude of the point which in the absence of application of false coordinates has grid coordinates of (0,0). Sometimes known as "central meridian (CM)".

EPSG:8802

Scale Factor

The factor by which the map grid is reduced or enlarged during the projection process, defined by its value at the natural origin.

EPSG:8805

False Easting

Since the natural origin may be at or near the centre of the projection and under normal coordinate circumstances would thus give rise to negative coordinates over parts of the mapped area, this origin is usually given false coordinates which are large enough to avoid this inconvenience. The False Easting, FE, is the value assigned to the abscissa (east or west) axis of the projection grid at the natural origin.

EPSG:8806

False Northing

Since the natural origin may be at or near the centre of the projection and under normal coordinate circumstances would thus give rise to negative coordinates over parts of the mapped area, this origin is usually given false coordinates which are large enough to avoid this inconvenience. The False Northing, FN, is the value assigned to the ordinate (north or south) axis of the projection grid at the natural origin.

EPSG:8807

Latitute of projection centre

For an oblique projection, this is the latitude of the point at which the azimuth of the central line is defined.

EPSG:8811

Longitude of projection centre

For an oblique projection, this is the longitude of the point at which the azimuth of the central line is defined.

EPSG:8812

Azimuth of initial line

The azimuthal direction (north zero, east of north being positive) of the great circle which is the centre line of an oblique projection. The azimuth is given at the projection centre.

EPSG:8813

Angle from Rectified to Skew Grid

The angle at the natural origin of an oblique projection through which the natural coordinate reference system is rotated to make the projection north axis parallel with true north.

EPSG:8814

Scale factor on initial line

The factor by which the map grid is reduced or enlarged during the projection process, defined by its value at the projection center.

EPSG:8815

Easting at projection centre

The easting value assigned to the projection centre.

EPSG:8816

Northing at projection centre

The northing value assigned to the projection centre.

EPSG:8817

Latitude of pseudo standard

parallel

Latitude of the parallel on which the conic or cylindrical projection is based. This latitude is not geographic, but is defined on the conformal sphere AFTER its rotation to obtain the oblique aspect of the projection.

EPSG:8818

Scale factor on pseudo

standard parallel

The factor by which the map grid is reduced or enlarged during the projection process, defined by its value at the pseudo-standard parallel. EPSG:8819

Latitude of false origin

The latitude of the point which is not the natural origin and at which grid coordinate values false easting and false northing are defined.

EPSG:8821

Longitude of false origin

The longitude of the point which is not the natural origin and at which grid coordinate values false easting and false northing are defined.

EPSG:8822

Latitude of 1st standard parallel

For a conic projection with two standard parallels, this is the latitude of one of the parallels of intersection of the cone with the ellipsoid. It is normally but not necessarily that nearest to the pole. Scale is true along this parallel.

EPSG:8823

Latitude of 2nd standard parallel

For a conic projection with two standard parallels, this is the latitude of one of the parallels at which the cone intersects with the ellipsoid. It is normally but not necessarily that nearest to the equator. Scale is true along this parallel.

EPSG:8824

Easting of false origin

The easting value assigned to the false origin.

EPSG:8826

Northing of false origin

The northing value assigned to the false origin.

EPSG:8827

Latitude of standard parallel

For polar aspect azimuthal projections, the parallel on which the scale factor is defined to be unity.

EPSG:8832

Longitude of origin

For polar aspect azimuthal projections, the meridian along which the northing axis increments and also across which parallels of latitude increment towards the north pole.

EPSG:8833

Public Functions

virtual *CoordinateOperationNNPtr* **inverse**() const override

Return the inverse of the coordinate operation.

Throws

util::*UnsupportedOperationException* –

bool **isUTM**(int &zone, bool &north) const

Return whether a conversion is a Universal Transverse Mercator conversion.

Parameters

- **zone** – **[out]** UTM zone number between 1 and 60.
- **north** – **[out]** true for UTM northern hemisphere, false for UTM southern hemisphere.

Returns

true if it is a UTM conversion.

ConversionNNPtr **identify**() const

Return a *Conversion* object where some parameters are better identified.

Returns

a new *Conversion*.

ConversionPtr **convertToOtherMethod**(int targetEPSGCode) const

Return an equivalent projection.

Currently implemented:

- EPSG_CODE_METHOD_MERCATOR_VARIANT_A (1SP) to EPSG_CODE_METHOD_MERCATOR_VARIANT_B (2SP)
- EPSG_CODE_METHOD_MERCATOR_VARIANT_B (2SP) to EPSG_CODE_METHOD_MERCATOR_VARIANT_A (1SP)

- EPSG_CODE_METHOD_LAMBERT_CONIC_CONFORMAL_1SP to EPSG_CODE_METHOD_LAMBERT_CONIC_CONFORMAL_2SP
- EPSG_CODE_METHOD_LAMBERT_CONIC_CONFORMAL_2SP to EPSG_CODE_METHOD_LAMBERT_CONIC_CONFORMAL_1SP

Parameters
`targetEPSGCode` – EPSG code of the target method.

Returns
new conversion, or nullptr

Public Static Functions

static *ConversionNNPtr* **create**(const *util*::*PropertyMap* &properties, const *OperationMethodNNPtr* &methodIn, const std::vector<*GeneralParameterValueNNPtr*> &values)

Instantiate a *Conversion* from a vector of *GeneralParameterValue*.

Parameters
- **properties** – See *General properties*. At minimum the name should be defined.
- **methodIn** – the operation method.
- **values** – the values.

Throws
InvalidOperation –

Returns
a new *Conversion*.

static *ConversionNNPtr* **create**(const *util*::*PropertyMap* &propertiesConversion, const *util*::*PropertyMap* &propertiesOperationMethod, const std::vector<*OperationParameterNNPtr*> &parameters, const std::vector<*ParameterValueNNPtr*> &values)

Instantiate a *Conversion* and its *OperationMethod*.

Parameters
- **propertiesConversion** – See *General properties* of the conversion. At minimum the name should be defined.
- **propertiesOperationMethod** – See *General properties* of the operation method. At minimum the name should be defined.
- **parameters** – the operation parameters.
- **values** – the operation values. Constraint: values.size() == parameters.size()

Throws
InvalidOperation –

Returns
a new *Conversion*.

static *ConversionNNPtr* **createUTM**(const *util*::*PropertyMap* &properties, int zone, bool north)

Instantiate a Universal Transverse Mercator conversion.

UTM is a family of conversions, of EPSG codes from 16001 to 16060 for the northern hemisphere, and 17001 to 17060 for the southern hemisphere, based on the Transverse Mercator projection method.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **zone** – UTM zone number between 1 and 60.
- **north** – true for UTM northern hemisphere, false for UTM southern hemisphere.

Returns
a new *Conversion*.

static *ConversionNNPtr* **createTransverseMercator**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Scale* &scale, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Transverse Mercator projection method.

This method is defined as EPSG:9807.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **scale** – See *Scale Factor*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createGaussSchreiberTransverseMercator**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Scale* &scale, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Gauss Schreiber Transverse Mercator projection method.

This method is also known as Gauss-Laborde Reunion.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **scale** – See *Scale Factor*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createTransverseMercatorSouthOriented**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Scale* &scale, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Transverse Mercator South Orientated projection method.

This method is defined as EPSG:9808.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **scale** – See *Scale Factor*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createTwoPointEquidistant**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeFirstPoint, const *common*::*Angle* &longitudeFirstPoint, const *common*::*Angle* &latitudeSecondPoint, const *common*::*Angle* &longitudeSeconPoint, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Two Point Equidistant projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeFirstPoint** – Latitude of first point.
- **longitudeFirstPoint** – Longitude of first point.
- **latitudeSecondPoint** – Latitude of second point.
- **longitudeSeconPoint** – Longitude of second point.
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createTunisiaMappingGrid**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Tunisia Mapping Grid projection method.

This method is defined as EPSG:9816.

Note: There is currently no implementation of the method formulas in PROJ.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createAlbersEqualArea**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeFalseOrigin, const *common*::*Angle* &longitudeFalseOrigin, const *common*::*Angle* &latitudeFirstParallel, const *common*::*Angle* &latitudeSecondParallel, const *common*::*Length* &eastingFalseOrigin, const *common*::*Length* &northingFalseOrigin)

Instantiate a conversion based on the Albers Conic Equal Area projection method.

This method is defined as EPSG:9822.

Note: the order of arguments is conformant with the corresponding EPSG mode and different than OGRSpatialReference::setACEA() of GDAL <= 2.3

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeFalseOrigin** – See *Latitude of false origin*
- **longitudeFalseOrigin** – See *Longitude of false origin*
- **latitudeFirstParallel** – See *Latitude of 1st standard parallel*
- **latitudeSecondParallel** – See *Latitude of 2nd standard parallel*
- **eastingFalseOrigin** – See *Easting of false origin*
- **northingFalseOrigin** – See *Northing of false origin*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createLambertConicConformal_1SP**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Scale* &scale, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Lambert Conic Conformal 1SP projection method.

This method is defined as EPSG:9801.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **scale** – See *Scale Factor*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createLambertConicConformal_2SP**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeFalseOrigin, const *common*::*Angle* &longitudeFalseOrigin, const *common*::*Angle* &latitudeFirstParallel, const *common*::*Angle* &latitudeSecondParallel, const *common*::*Length* &eastingFalseOrigin, const *common*::*Length* &northingFalseOrigin)

Instantiate a conversion based on the Lambert Conic Conformal 2SP projection method.

This method is defined as EPSG:9802.

Note: the order of arguments is conformant with the corresponding EPSG mode and different than OGRSpatialReference::setLCC() of GDAL <= 2.3

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeFalseOrigin** – See *Latitude of false origin*
- **longitudeFalseOrigin** – See *Longitude of false origin*
- **latitudeFirstParallel** – See *Latitude of 1st standard parallel*
- **latitudeSecondParallel** – See *Latitude of 2nd standard parallel*
- **eastingFalseOrigin** – See *Easting of false origin*
- **northingFalseOrigin** – See *Northing of false origin*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createLambertConicConformal_2SP_Michigan**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeFalseOrigin, const *common*::*Angle* &longitudeFalseOrigin, const *common*::*Angle* &latitudeFirstParallel, const *common*::*Angle* &latitudeSecondParallel, const *common*::*Length* &eastingFalseOrigin, const *common*::*Length* &northingFalseOrigin, const *common*::*Scale* &ellipsoidScalingFactor)

Instantiate a conversion based on the Lambert Conic Conformal (2SP Michigan) projection method.

This method is defined as EPSG:1051.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeFalseOrigin** – See *Latitude of false origin*
- **longitudeFalseOrigin** – See *Longitude of false origin*

- **latitudeFirstParallel** – See *Latitude of 1st standard parallel*
- **latitudeSecondParallel** – See *Latitude of 2nd standard parallel*
- **eastingFalseOrigin** – See *Easting of false origin*
- **northingFalseOrigin** – See *Northing of false origin*
- **ellipsoidScalingFactor** – Ellipsoid scaling factor.

Returns
a new *Conversion*.

static *ConversionNNPtr* **createLambertConicConformal_2SP_Belgium**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeFalseOrigin, const *common*::*Angle* &longitudeFalseOrigin, const *common*::*Angle* &latitudeFirstParallel, const *common*::*Angle* &latitudeSecondParallel, const *common*::*Length* &eastingFalseOrigin, const *common*::*Length* &northingFalseOrigin)

Instantiate a conversion based on the Lambert Conic Conformal (2SP Belgium) projection method.

This method is defined as EPSG:9803.

Note: the order of arguments is conformant with the corresponding EPSG mode and different than OGRSpatialReference::setLCCB() of GDAL <= 2.3

Warning: The formulas used currently in PROJ are, incorrectly, the ones of the regular LCC_2SP method.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeFalseOrigin** – See *Latitude of false origin*
- **longitudeFalseOrigin** – See *Longitude of false origin*
- **latitudeFirstParallel** – See *Latitude of 1st standard parallel*
- **latitudeSecondParallel** – See *Latitude of 2nd standard parallel*
- **eastingFalseOrigin** – See *Easting of false origin*
- **northingFalseOrigin** – See *Northing of false origin*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createAzimuthalEquidistant**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeNatOrigin, const *common*::*Angle* &longitudeNatOrigin, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Modified Azimuthal Equidistant projection method.

This method is defined as EPSG:9832.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeNatOrigin** – See *Latitude of natural origin/Center Latitude*
- **longitudeNatOrigin** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createGuamProjection**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeNatOrigin, const *common*::*Angle* &longitudeNatOrigin, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Guam Projection method.

This method is defined as EPSG:9831.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeNatOrigin** – See *Latitude of natural origin/Center Latitude*
- **longitudeNatOrigin** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createBonne**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeNatOrigin, const *common*::*Angle* &longitudeNatOrigin, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Bonne projection method.

This method is defined as EPSG:9827.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeNatOrigin** – See *Latitude of natural origin/Center Latitude* . PROJ calls its the standard parallel 1.
- **longitudeNatOrigin** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createLambertCylindricalEqualAreaSpherical**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeFirstParallel, const *common*::*Angle* &longitudeNatOrigin, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Lambert Cylindrical Equal Area (Spherical) projection method.

This method is defined as EPSG:9834.

> **Warning:** The PROJ cea computation code would select the ellipsoidal form if a non-spherical ellipsoid is used for the base GeographicCRS.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeFirstParallel** – See *Latitude of 1st standard parallel*.
- **longitudeNatOrigin** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createLambertCylindricalEqualArea**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeFirstParallel, const *common*::*Angle* &longitudeNatOrigin, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Lambert Cylindrical Equal Area (ellipsoidal form) projection method.

This method is defined as EPSG:9835.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeFirstParallel** – See *Latitude of 1st standard parallel*.
- **longitudeNatOrigin** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createCassiniSoldner**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Cassini-Soldner projection method.

This method is defined as EPSG:9806.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createEquidistantConic**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Angle* &latitudeFirstParallel, const *common*::*Angle* &latitudeSecondParallel, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Equidistant Conic projection method.

There is no equivalent in EPSG.

Note: Although not found in EPSG, the order of arguments is conformant with the "spirit" of EPSG and different than OGRSpatialReference::setEC() of GDAL <= 2.3 *

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **latitudeFirstParallel** – See *Latitude of 1st standard parallel*
- **latitudeSecondParallel** – See *Latitude of 2nd standard parallel*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createEckertI**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Eckert I projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createEckertII**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Eckert II projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createEckertIII**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Eckert III projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createEckertIV**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Eckert IV projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createEckertV**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Eckert V projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createEckertVI**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Eckert VI projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*

- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createEquidistantCylindrical**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeFirstParallel, const *common*::*Angle* &longitudeNatOrigin, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Equidistant Cylindrical projection method.

This is also known as the Equirectangular method, and in the particular case where the latitude of first parallel is 0.

This method is defined as EPSG:1028.

Note: This is the equivalent OGRSpatialReference::SetEquirectangular2(0.0, latitudeFirstParallel, falseEasting, falseNorthing) of GDAL <= 2.3, where the lat_0 / center_latitude parameter is forced to 0.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeFirstParallel** – See *Latitude of 1st standard parallel*.
- **longitudeNatOrigin** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createEquidistantCylindricalSpherical**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeFirstParallel, const *common*::*Angle* &longitudeNatOrigin, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Equidistant Cylindrical (Spherical) projection method.

This is also known as the Equirectangular method, and in the particular case where the latitude of first parallel is 0.

This method is defined as EPSG:1029.

Note: This is the equivalent OGRSpatialReference::SetEquirectangular2(0.0, latitudeFirstParallel, falseEasting, falseNorthing) of GDAL <= 2.3, where the lat_0 / center_latitude parameter is forced to 0.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeFirstParallel** – See *Latitude of 1st standard parallel*.
- **longitudeNatOrigin** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createGall**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Gall (Stereographic) projection method.

There is no equivalent in EPSG.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createGoodeHomolosine**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Goode Homolosine projection method.

There is no equivalent in EPSG.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createInterruptedGoodeHomolosine**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Interrupted Goode Homolosine projection method.

There is no equivalent in EPSG.

Note: OGRSpatialReference::SetIGH() of GDAL <= 2.3 assumes the 3 projection parameters to be zero and this is the nominal case.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.

- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createGeostationarySatelliteSweepX**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &height, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Geostationary Satellite View projection method, with the sweep angle axis of the viewing instrument being x.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **height** – Height of the view point above the Earth.
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createGeostationarySatelliteSweepY**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &height, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Geostationary Satellite View projection method, with the sweep angle axis of the viewing instrument being y.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **height** – Height of the view point above the Earth.
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createGnomonic**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Gnomonic projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createHotineObliqueMercatorVariantA**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeProjectionCentre, const *common*::*Angle* &longitudeProjectionCentre, const *common*::*Angle* &azimuthInitialLine, const *common*::*Angle* &angleFromRectifiedToSkrewGrid, const *common*::*Scale* &scale, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Hotine Oblique Mercator (Variant A) projection method.

This is the variant with the no_uoff parameter, which corresponds to GDAL >=2.3 Hotine_Oblique_Mercator projection. In this variant, the false grid coordinates are defined at the intersection of the initial line and the aposphere (the equator on one of the intermediate surfaces inherent in the method), that is at the natural origin of the coordinate system).

This method is defined as EPSG:9812.

Note: In the case where azimuthInitialLine = angleFromRectifiedToSkrewGrid = 90deg, this maps to the Swiss Oblique Mercator formulas.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeProjectionCentre** – See *Latitute of projection centre*
- **longitudeProjectionCentre** – See *Longitude of projection centre*
- **azimuthInitialLine** – See *Azimuth of initial line*
- **angleFromRectifiedToSkrewGrid** – See *Angle from Rectified to Skew Grid*
- **scale** – See *Scale factor on initial line*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createHotineObliqueMercatorVariantB**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeProjectionCentre, const *common*::*Angle* &longitudeProjectionCentre, const *common*::*Angle* &azimuthInitialLine, const *common*::*Angle* &angleFromRectifiedToSkrewGrid, const *common*::*Scale* &scale, const *common*::*Length* &eastingProjectionCentre, const *common*::*Length* &northingProjectionCentre)

Instantiate a conversion based on the Hotine Oblique Mercator (Variant B) projection method.

This is the variant without the no_uoff parameter, which corresponds to GDAL >=2.3 Hotine_Oblique_Mercator_Azimuth_Center projection. In this variant, the false grid coordinates are defined at the projection centre.

This method is defined as EPSG:9815.

Note: In the case where azimuthInitialLine = angleFromRectifiedToSkrewGrid = 90deg, this maps to the Swiss Oblique Mercator formulas.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeProjectionCentre** – See *Latitute of projection centre*
- **longitudeProjectionCentre** – See *Longitude of projection centre*
- **azimuthInitialLine** – See *Azimuth of initial line*
- **angleFromRectifiedToSkrewGrid** – See *Angle from Rectified to Skew Grid*
- **scale** – See *Scale factor on initial line*
- **eastingProjectionCentre** – See *Easting at projection centre*
- **northingProjectionCentre** – See *Northing at projection centre*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createHotineObliqueMercatorTwoPointNaturalOrigin**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeProjectionCentre, const *common*::*Angle* &latitudePoint1, const *common*::*Angle* &longitudePoint1, const *common*::*Angle* &latitudePoint2, const *common*::*Angle* &longitudePoint2, const *common*::*Scale* &scale, const *common*::*Length* &eastingProjectionCentre, const *common*::*Length* &northingProjectionCentre)

Instantiate a conversion based on the Hotine Oblique Mercator Two Point Natural Origin projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeProjectionCentre** – See *Latitute of projection centre*
- **latitudePoint1** – Latitude of point 1.
- **longitudePoint1** – Latitude of point 1.
- **latitudePoint2** – Latitude of point 2.
- **longitudePoint2** – Longitude of point 2.
- **scale** – See *Scale factor on initial line*
- **eastingProjectionCentre** – See *Easting at projection centre*
- **northingProjectionCentre** – See *Northing at projection centre*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createLabordeObliqueMercator**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeProjectionCentre, const *common*::*Angle* &longitudeProjectionCentre, const *common*::*Angle* &azimuthInitialLine, const *common*::*Scale* &scale, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Laborde Oblique Mercator projection method.

This method is defined as EPSG:9813.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeProjectionCentre** – See *Latitute of projection centre*
- **longitudeProjectionCentre** – See *Longitude of projection centre*
- **azimuthInitialLine** – See *Azimuth of initial line*
- **scale** – See *Scale factor on initial line*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createInternationalMapWorldPolyconic**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Angle* &latitudeFirstParallel, const *common*::*Angle* &latitudeSecondParallel, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the International Map of the World Polyconic projection method.

There is no equivalent in EPSG.

Note: the order of arguments is conformant with the corresponding EPSG mode and different than OGRSpatialReference::SetIWMPolyconic() of GDAL <= 2.3

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **latitudeFirstParallel** – See *Latitude of 1st standard parallel*
- **latitudeSecondParallel** – See *Latitude of 2nd standard parallel*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createKrovakNorthOriented**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeProjectionCentre, const *common*::*Angle* &longitudeOfOrigin, const *common*::*Angle* &colatitudeConeAxis, const *common*::*Angle* &latitudePseudoStandardParallel, const *common*::*Scale* &scaleFactorPseudoStandardParallel, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Krovak (north oriented) projection method.

This method is defined as EPSG:1041.

The coordinates are returned in the "GIS friendly" order: easting, northing. This method is similar to *createKrovak()*, except that the later returns projected values as southing, westing, where southing(Krovak) = -northing(Krovak_North) and westing(Krovak) = -easting(Krovak_North).

Note: The current PROJ implementation of Krovak hard-codes colatitudeConeAxis = 30deg17'17.30311" and latitudePseudoStandardParallel = 78deg30'N, which are the values used for the ProjectedCRS S-JTSK (Ferro) / Krovak East North (EPSG:5221). It also hard-codes the parameters of the Bessel ellipsoid typically used for Krovak.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeProjectionCentre** – See *Latitute of projection centre*
- **longitudeOfOrigin** – See *Longitude of origin*
- **colatitudeConeAxis** – See *Co-latitude of cone axis*
- **latitudePseudoStandardParallel** – See *Latitude of pseudo standard*
- **scaleFactorPseudoStandardParallel** – See *Scale factor on pseudo*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createKrovak**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeProjectionCentre, const *common*::*Angle* &longitudeOfOrigin, const *common*::*Angle* &colatitudeConeAxis, const *common*::*Angle* &latitudePseudoStandardParallel, const *common*::*Scale* &scaleFactorPseudoStandardParallel, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Krovak projection method.

This method is defined as EPSG:9819.

The coordinates are returned in the historical order: southing, westing This method is similar to *createKrovakNorthOriented()*, except that the later returns projected values as easting, northing, where easting(Krovak_North) = -westing(Krovak) and northing(Krovak_North) = -southing(Krovak).

Note: The current PROJ implementation of Krovak hard-codes colatitudeConeAxis = 30deg17'17.30311" and latitudePseudoStandardParallel = 78deg30'N, which are the values used for the ProjectedCRS S-JTSK (Ferro) / Krovak East North (EPSG:5221). It also hard-codes the parameters of the Bessel ellipsoid typically used for Krovak.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeProjectionCentre** – See *Latitute of projection centre*
- **longitudeOfOrigin** – See *Longitude of origin*
- **colatitudeConeAxis** – See *Co-latitude of cone axis*
- **latitudePseudoStandardParallel** – See *Latitude of pseudo standard*
- **scaleFactorPseudoStandardParallel** – See *Scale factor on pseudo*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createLambertAzimuthalEqualArea**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeNatOrigin, const *common*::*Angle* &longitudeNatOrigin, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Lambert Azimuthal Equal Area projection method.

This method is defined as EPSG:9820.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeNatOrigin** – See *Latitude of natural origin/Center Latitude*
- **longitudeNatOrigin** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createMillerCylindrical**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Miller Cylindrical projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createMercatorVariantA**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Scale* &scale, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Mercator (variant A) projection method.

This is the A variant, also known as Mercator (1SP), defined with the scale factor. Note that latitude of natural origin (centerLat) is a parameter, but unused in the transformation formulas.

This method is defined as EPSG:9804.

Parameters

- `properties` – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- `centerLat` – See *Latitude of natural origin/Center Latitude* . Should be 0.
- `centerLong` – See *Longitude of natural origin/Central Meridian*
- `scale` – See *Scale Factor*
- `falseEasting` – See *False Easting*
- `falseNorthing` – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createMercatorVariantB**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeFirstParallel, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Mercator (variant B) projection method.

This is the B variant, also known as Mercator (2SP), defined with the latitude of the first standard parallel (the second standard parallel is implicitly the opposite value). The latitude of natural origin is fixed to zero.

This method is defined as EPSG:9805.

Parameters

- `properties` – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- `latitudeFirstParallel` – See *Latitude of 1st standard parallel*
- `centerLong` – See *Longitude of natural origin/Central Meridian*
- `falseEasting` – See *False Easting*
- `falseNorthing` – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createPopularVisualisationPseudoMercator**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Popular Visualisation Pseudo Mercator projection method.

Also known as WebMercator. Mostly/only used for Projected CRS EPSG:3857 (WGS 84 / Pseudo-Mercator)

This method is defined as EPSG:1024.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude* . Usually 0
- **centerLong** – See *Longitude of natural origin/Central Meridian* . Usually 0
- **falseEasting** – See *False Easting* . Usually 0
- **falseNorthing** – See *False Northing* . Usually 0

Returns
a new *Conversion*.

static *ConversionNNPtr* **createMollweide**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Mollweide projection method.

There is no equivalent in EPSG.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createNewZealandMappingGrid**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the New Zealand Map Grid projection method.

This method is defined as EPSG:9811.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createObliqueStereographic**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Scale* &scale, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Oblique Stereographic (alternative) projection method.

This method is defined as EPSG:9809.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **scale** – See *Scale Factor*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createOrthographic**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Orthographic projection method.

This method is defined as EPSG:9840.

Note: Before PROJ 7.2, only the spherical formulation was implemented.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createAmericanPolyconic**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the American Polyconic projection method.

This method is defined as EPSG:9818.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createPolarStereographicVariantA**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Scale* &scale, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Polar Stereographic (Variant A) projection method.

This method is defined as EPSG:9810.

This is the variant of polar stereographic defined with a scale factor.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude* . Should be 90 deg ou -90 deg.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **scale** – See *Scale Factor*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createPolarStereographicVariantB**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeStandardParallel, const *common*::*Angle* &longitudeOfOrigin, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Polar Stereographic (Variant B) projection method.

This method is defined as EPSG:9829.

This is the variant of polar stereographic defined with a latitude of standard parallel.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeStandardParallel** – See *Latitude of standard parallel*
- **longitudeOfOrigin** – See *Longitude of origin*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createRobinson**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Robinson projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createSinusoidal**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Sinusoidal projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createStereographic**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Scale* &scale, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Stereographic projection method.

There is no equivalent in EPSG. This method implements the original "Oblique

Stereographic" method described in "Snyder's Map Projections - A Working

manual", which is different from the "Oblique Stereographic (alternative)" method implemented in *createObliqueStereographic()*.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **scale** – See *Scale Factor*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createVanDerGrinten**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Van der Grinten projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createWagnerI**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Wagner I projection method.

There is no equivalent in EPSG.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createWagnerII**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Wagner II projection method.

There is no equivalent in EPSG.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createWagnerIII**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &latitudeTrueScale, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Wagner III projection method.

There is no equivalent in EPSG.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **latitudeTrueScale** – Latitude of true scale.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createWagnerIV**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Wagner IV projection method.

There is no equivalent in EPSG.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createWagnerV**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Wagner V projection method.

There is no equivalent in EPSG.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createWagnerVI**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Wagner VI projection method.

There is no equivalent in EPSG.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createWagnerVII**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Wagner VII projection method.

There is no equivalent in EPSG.

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns
a new *Conversion*.

static *ConversionNNPtr* **createQuadrilateralizedSphericalCube**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLat, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Quadrilateralized Spherical Cube projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLat** – See *Latitude of natural origin/Center Latitude*
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createSphericalCrossTrackHeight**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &pegPointLat, const *common*::*Angle* &pegPointLong, const *common*::*Angle* &pegPointHeading, const *common*::*Length* &pegPointHeight)

Instantiate a conversion based on the Spherical Cross-Track Height projection method.

There is no equivalent in EPSG.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **pegPointLat** – Peg point latitude.
- **pegPointLong** – Peg point longitude.
- **pegPointHeading** – Peg point heading.
- **pegPointHeight** – Peg point height.

Returns

a new *Conversion*.

static *ConversionNNPtr* **createEqualEarth**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &centerLong, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Equal Earth projection method.

This method is defined as EPSG:1078.

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** – See *Longitude of natural origin/Central Meridian*
- **falseEasting** – See *False Easting*
- **falseNorthing** – See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* **createVerticalPerspective**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &topoOriginLat, const *common*::*Angle* &topoOriginLong, const *common*::*Length* &topoOriginHeight, const *common*::*Length* &viewPointHeight, const *common*::*Length* &falseEasting, const *common*::*Length* &falseNorthing)

Instantiate a conversion based on the Vertical Perspective projection method.

This method is defined as EPSG:9838.

The PROJ implementation of the EPSG Vertical Perspective has the current limitations with respect to the method described in EPSG:

- it is a 2D-only method, ignoring the ellipsoidal height of the point to project.
- it has only a spherical development.
- the height of the topocentric origin is ignored, and thus assumed to be 0.

For completeness, PROJ adds the falseEasting and falseNorthing parameter, which are not described in EPSG. They should usually be set to 0.

Since

6.3

Parameters

- `properties` – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- `topoOriginLat` – Latitude of topocentric origin
- `topoOriginLong` – Longitude of topocentric origin
- `topoOriginHeight` – Ellipsoidal height of topocentric origin. Ignored by PROJ (that is assumed to be 0)
- `viewPointHeight` – Viewpoint height with respect to the topocentric/mapping plane. In the case where topoOriginHeight = 0, this is the height above the ellipsoid surface at topoOriginLat, topoOriginLong.
- `falseEasting` – See *False Easting* . (not in EPSG)
- `falseNorthing` – See *False Northing* . (not in EPSG)

Returns

a new *Conversion*.

static *ConversionNNPtr* **createPoleRotationGRIBConvention**(const *util*::*PropertyMap* &properties, const *common*::*Angle* &southPoleLatInUnrotatedCRS, const *common*::*Angle* &southPoleLongInUnrotatedCRS, const *common*::*Angle* &axisRotation)

Instantiate a conversion based on the Pole Rotation method, using the conventions of the GRIB 1 and GRIB 2 data formats.

Those are mentioned in the Note 2 of https://www.nco.ncep.noaa.gov/pmb/docs/grib2/grib2_doc/grib2_temp3-1.shtml

Several conventions for the pole rotation method exists. The parameters provided in this method are remapped to the PROJ ob_tran operation with:

Another implementation of that convention is also in the netcdf-java library: https://github.com/Unidata/netcdf-java/blob/3ce72c0cd167609ed8c69152bb4a004d1daa9273/cdm/core/src/main/java/ucar/unidata/geoloc/projection/RotatedLatLon.java

The PROJ implementation of this method assumes a spherical ellipsoid.

Since

7.0

Parameters

- `properties` – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- `southPoleLatInUnrotatedCRS` – Latitude of the point from the unrotated CRS, expressed in the unrotated CRS, that will become the south pole of the rotated CRS.

- **southPoleLongInUnrotatedCRS** – Longitude of the point from the unrotated CRS, expressed in the unrotated CRS, that will become the south pole of the rotated CRS.
- **axisRotation** – The angle of rotation about the new polar axis (measured clockwise when looking from the southern to the northern pole) of the coordinate system, assuming the new axis to have been obtained by first rotating the sphere through southPoleLongInUnrotatedCRS degrees about the geographic polar axis and then rotating through (90 + southPoleLatInUnrotatedCRS) degrees so that the southern pole moved along the (previously rotated) Greenwich meridian.

Returns
a new *Conversion*.

static *ConversionNNPtr* **createChangeVerticalUnit**(const *util*::*PropertyMap* &properties, const *common*::*Scale* &factor)

Instantiate a conversion based on the Change of Vertical Unit method.

This method is defined as EPSG:1069 [DEPRECATED].

Parameters
- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **factor** – *Conversion* factor

Returns
a new *Conversion*.

static *ConversionNNPtr* **createHeightDepthReversal**(const *util*::*PropertyMap* &properties)

Instantiate a conversion based on the Height Depth Reversal method.

This method is defined as EPSG:1068.

Since
6.3

Parameters
properties – See *General properties* of the conversion. If the name is not provided, it is automatically set.

Returns
a new *Conversion*.

static *ConversionNNPtr* **createAxisOrderReversal**(bool is3D)

Instantiate a conversion based on the Axis order reversal method.

This swaps the longitude, latitude axis.

This method is defined as EPSG:9843 for 2D or EPSG:9844 for Geographic3D horizontal.

Parameters
is3D – Whether this should apply on 3D geographicCRS

Returns
a new *Conversion*.

static *ConversionNNPtr* **createGeographicGeocentric**(const *util*::*PropertyMap* &properties)

Instantiate a conversion based on the Geographic/Geocentric method.

This method is defined as EPSG:9602.

Parameters
properties – See *General properties* of the conversion. If the name is not provided, it is automatically set.

Returns
a new *Conversion*.

class **Transformation** : public osgeo::proj::*operation*::*SingleOperation*

#include <coordinateoperation.hpp> A mathematical operation on coordinates in which parameters are empirically derived from data containing the coordinates of a series of points in both coordinate reference systems.

This computational process is usually "over-determined", allowing derivation of error (or accuracy) estimates for the coordinate transformation. Also, the stochastic nature of the parameters may result in multiple (different) versions of the same coordinate transformations between the same source and target CRSs. Any single coordinate operation in which the input and output coordinates are referenced to different datums (reference frames) will be a coordinate transformation.

Remark

Implements *Transformation* from *ISO 19111:2019*

Public Functions

const *crs*::*CRSNNPtr* &**sourceCRS**()

Return the source *crs::CRS* of the transformation.

Returns

the source CRS.

const *crs*::*CRSNNPtr* &**targetCRS**()

Return the target *crs::CRS* of the transformation.

Returns

the target CRS.

virtual *CoordinateOperationNNPtr* **inverse**() const override

Return the inverse of the coordinate operation.

Throws

`util::UnsupportedOperationException` –

TransformationNNPtr **substitutePROJAlternativeGridNames**(*io*::*DatabaseContextNNPtr* databaseContext) const

Return an equivalent transformation to the current one, but using PROJ alternative grid names.

Public Static Functions

static *TransformationNNPtr* **create**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, const *crs*::*CRSPtr* &interpolationCRSIn, const *OperationMethodNNPtr* &methodIn, const std::vector<*GeneralParameterValueNNPtr*> &values, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation from a vector of *GeneralParameterValue*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **interpolationCRSIn** – Interpolation CRS (might be null)

- **methodIn** – Operation method.
- **values** – Vector of GeneralOperationParameterNNPtr.
- **accuracies** – Vector of positional accuracy (might be empty).

Throws
InvalidOperation –

Returns
new *Transformation*.

static *TransformationNNPtr* **create**(const *util*::*PropertyMap* &propertiesTransformation, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, const *crs*::*CRSPtr* &interpolationCRSIn, const *util*::*PropertyMap* &propertiesOperationMethod, const std::vector<*OperationParameterNNPtr*> &parameters, const std::vector<*ParameterValueNNPtr*> &values, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation and its *OperationMethod*.

Parameters
- **propertiesTransformation** – The *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **interpolationCRSIn** – Interpolation CRS (might be null)
- **propertiesOperationMethod** – The *General properties* of the *OperationMethod*. At minimum the name should be defined.
- **parameters** – Vector of parameters of the operation method.
- **values** – Vector of ParameterValueNNPtr. Constraint: values.size() == parameters.size()
- **accuracies** – Vector of positional accuracy (might be empty).

Throws
InvalidOperation –

Returns
new *Transformation*.

static *TransformationNNPtr* **createGeocentricTranslations**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with Geocentric Translations method.

Parameters
- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **translationXMetre** – Value of the Translation_X parameter (in metre).
- **translationYMetre** – Value of the Translation_Y parameter (in metre).
- **translationZMetre** – Value of the Translation_Z parameter (in metre).
- **accuracies** – Vector of positional accuracy (might be empty).

Returns
new *Transformation*.

static *TransformationNNPtr* **createPositionVector**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre, double rotationXArcSecond, double rotationYArcSecond, double rotationZArcSecond, double scaleDifferencePPM, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with Position vector transformation method.

This is similar to *createCoordinateFrameRotation()*, except that the sign of the rotation terms is inverted.

Parameters

- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **translationXMetre** – Value of the Translation_X parameter (in metre).
- **translationYMetre** – Value of the Translation_Y parameter (in metre).
- **translationZMetre** – Value of the Translation_Z parameter (in metre).
- **rotationXArcSecond** – Value of the Rotation_X parameter (in arc-second).
- **rotationYArcSecond** – Value of the Rotation_Y parameter (in arc-second).
- **rotationZArcSecond** – Value of the Rotation_Z parameter (in arc-second).
- **scaleDifferencePPM** – Value of the Scale_Difference parameter (in parts-per-million).
- **accuracies** – Vector of positional accuracy (might be empty).

Returns

new *Transformation*.

static *TransformationNNPtr* **createCoordinateFrameRotation**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre, double rotationXArcSecond, double rotationYArcSecond, double rotationZArcSecond, double scaleDifferencePPM, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with Coordinate Frame Rotation method.

This is similar to *createPositionVector()*, except that the sign of the rotation terms is inverted.

Parameters

- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **translationXMetre** – Value of the Translation_X parameter (in metre).
- **translationYMetre** – Value of the Translation_Y parameter (in metre).
- **translationZMetre** – Value of the Translation_Z parameter (in metre).
- **rotationXArcSecond** – Value of the Rotation_X parameter (in arc-second).

- **rotationYArcSecond** – Value of the Rotation_Y parameter (in arc-second).
- **rotationZArcSecond** – Value of the Rotation_Z parameter (in arc-second).
- **scaleDifferencePPM** – Value of the Scale_Difference parameter (in parts-per-million).
- **accuracies** – Vector of positional accuracy (might be empty).

Returns
new *Transformation*.

static *TransformationNNPtr* **createTimeDependentPositionVector**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre, double rotationXArcSecond, double rotationYArcSecond, double rotationZArcSecond, double scaleDifferencePPM, double rateTranslationX, double rateTranslationY, double rateTranslationZ, double rateRotationX, double rateRotationY, double rateRotationZ, double rateScaleDifference, double referenceEpochYear, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with Time Dependent position vector transformation method.

This is similar to *createTimeDependentCoordinateFrameRotation()*, except that the sign of the rotation terms is inverted.

This method is defined as EPSG:1053.

Parameters

- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **translationXMetre** – Value of the Translation_X parameter (in metre).
- **translationYMetre** – Value of the Translation_Y parameter (in metre).
- **translationZMetre** – Value of the Translation_Z parameter (in metre).
- **rotationXArcSecond** – Value of the Rotation_X parameter (in arc-second).
- **rotationYArcSecond** – Value of the Rotation_Y parameter (in arc-second).
- **rotationZArcSecond** – Value of the Rotation_Z parameter (in arc-second).
- **scaleDifferencePPM** – Value of the Scale_Difference parameter (in parts-per-million).
- **rateTranslationX** – Value of the rate of change of X-axis translation (in metre/year)
- **rateTranslationY** – Value of the rate of change of Y-axis translation (in metre/year)
- **rateTranslationZ** – Value of the rate of change of Z-axis translation (in metre/year)
- **rateRotationX** – Value of the rate of change of X-axis rotation (in arc-second/year)
- **rateRotationY** – Value of the rate of change of Y-axis rotation (in arc-second/year)
- **rateRotationZ** – Value of the rate of change of Z-axis rotation (in arc-second/year)
- **rateScaleDifference** – Value of the rate of change of scale difference (in PPM/year)
- **referenceEpochYear** – Parameter reference epoch (in decimal year)

- **accuracies** – Vector of positional accuracy (might be empty).

Returns
new *Transformation*.

static *TransformationNNPtr* **createTimeDependentCoordinateFrameRotation**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre, double rotationXArcSecond, double rotationYArcSecond, double rotationZArcSecond, double scaleDifferencePPM, double rateTranslationX, double rateTranslationY, double rateTranslationZ, double rateRotationX, double rateRotationY, double rateRotationZ, double rateScaleDifference, double referenceEpochYear, const std::vector<*metadata*::*PositionalAccur* &accuracies)

Instantiate a transformation with Time Dependent Position coordinate frame rotation transformation method.

This is similar to *createTimeDependentPositionVector()*, except that the sign of the rotation terms is inverted.

This method is defined as EPSG:1056.

Parameters
- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.

- **targetCRSIn** – Target CRS.
- **translationXMetre** – Value of the Translation_X parameter (in metre).
- **translationYMetre** – Value of the Translation_Y parameter (in metre).
- **translationZMetre** – Value of the Translation_Z parameter (in metre).
- **rotationXArcSecond** – Value of the Rotation_X parameter (in arc-second).
- **rotationYArcSecond** – Value of the Rotation_Y parameter (in arc-second).
- **rotationZArcSecond** – Value of the Rotation_Z parameter (in arc-second).
- **scaleDifferencePPM** – Value of the Scale_Difference parameter (in parts-per-million).
- **rateTranslationX** – Value of the rate of change of X-axis translation (in metre/year)
- **rateTranslationY** – Value of the rate of change of Y-axis translation (in metre/year)
- **rateTranslationZ** – Value of the rate of change of Z-axis translation (in metre/year)
- **rateRotationX** – Value of the rate of change of X-axis rotation (in arc-second/year)
- **rateRotationY** – Value of the rate of change of Y-axis rotation (in arc-second/year)
- **rateRotationZ** – Value of the rate of change of Z-axis rotation (in arc-second/year)
- **rateScaleDifference** – Value of the rate of change of scale difference (in PPM/year)
- **referenceEpochYear** – Parameter reference epoch (in decimal year)
- **accuracies** – Vector of positional accuracy (might be empty).

Throws

InvalidOperation –

Returns

new *Transformation*.

static *TransformationNNPtr* **createTOWGS84**(const *crs*::*CRSNNPtr* &sourceCRSIn, const std::vector<double> &TOWGS84Parameters)

Instantiate a transformation from TOWGS84 parameters.

This is a helper of *createPositionVector()* with the source CRS being the GeographicCRS of sourceCRSIn, and the target CRS being EPSG:4326

Parameters

- **sourceCRSIn** – Source CRS.
- **TOWGS84Parameters** – The vector of 3 double values (Translation_X,_Y,_Z) or 7 double values (Translation_X,_Y,_Z, Rotation_X,_Y,_Z, Scale_Difference) passed to *createPositionVector()*

Throws

InvalidOperation –

Returns

new *Transformation*.

static *TransformationNNPtr* **createNTv2**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, const std::string &filename, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with NTv2 method.

Parameters

- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **filename** – NTv2 filename.
- **accuracies** – Vector of positional accuracy (might be empty).

Returns

new *Transformation*.

static *TransformationNNPtr* **createMolodensky**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre, double semiMajorAxisDifferenceMetre, double flattingDifference, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with Molodensky method.

This method is defined as EPSG:9604.

See also:

createAbridgedMolodensky() for a related *method*.

Parameters

- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **translationXMetre** – Value of the Translation_X parameter (in metre).
- **translationYMetre** – Value of the Translation_Y parameter (in metre).
- **translationZMetre** – Value of the Translation_Z parameter (in metre).
- **semiMajorAxisDifferenceMetre** – The difference between the semi-major axis values of the ellipsoids used in the target and source CRS (in metre).
- **flattingDifference** – The difference between the flattening values of the ellipsoids used in the target and source CRS.
- **accuracies** – Vector of positional accuracy (might be empty).

Throws

InvalidOperation –

Returns

new *Transformation*.

static *TransformationNNPtr* **createAbridgedMolodensky**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre, double semiMajorAxisDifferenceMetre, double flattingDifference, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with Abridged Molodensky method.

This method is defined as EPSG:9605.

See also:

createdMolodensky() for a related *method*.

Parameters

- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.

- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **translationXMetre** – Value of the Translation_X parameter (in metre).
- **translationYMetre** – Value of the Translation_Y parameter (in metre).
- **translationZMetre** – Value of the Translation_Z parameter (in metre).
- **semiMajorAxisDifferenceMetre** – The difference between the semi-major axis values of the ellipsoids used in the target and source CRS (in metre).
- **flattingDifference** – The difference between the flattening values of the ellipsoids used in the target and source CRS.
- **accuracies** – Vector of positional accuracy (might be empty).

Throws
InvalidOperation –

Returns
new *Transformation*.

static *TransformationNNPtr* **createGravityRelatedHeightToGeographic3D**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, const *crs*::*CRSPtr* &interpolationCRSIn, const std::string &filename, const std::vector<*metadata*::*PositionalAccuracy* &accuracies)

Instantiate a transformation from GravityRelatedHeight to Geographic3D.

Parameters
- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **interpolationCRSIn** – Interpolation CRS. (might be null)
- **filename** – GRID filename.
- **accuracies** – Vector of positional accuracy (might be empty).

Returns
new *Transformation*.

static *TransformationNNPtr* **createVERTCON**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, const std::string &filename, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with method VERTCON.

Parameters
- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **filename** – GRID filename.
- **accuracies** – Vector of positional accuracy (might be empty).

Returns

new *Transformation*.

static *TransformationNNPtr* **createLongitudeRotation**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, const *common*::*Angle* &offset)

Instantiate a transformation with method Longitude rotation.

This method is defined as EPSG:9601.

Parameters

- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **offset** – Longitude offset to add.

Returns

new *Transformation*.

static *TransformationNNPtr* **createGeographic2DOffsets**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, const *common*::*Angle* &offsetLat, const *common*::*Angle* &offsetLon, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with method Geographic 2D offsets.

This method is defined as EPSG:9619.

Parameters

- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **offsetLat** – Latitude offset to add.
- **offsetLon** – Longitude offset to add.
- **accuracies** – Vector of positional accuracy (might be empty).

Returns

new *Transformation*.

static *TransformationNNPtr* **createGeographic3DOffsets**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, const *common*::*Angle* &offsetLat, const *common*::*Angle* &offsetLon, const *common*::*Length* &offsetHeight, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with method Geographic 3D offsets.

This method is defined as EPSG:9660.

Parameters

- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **offsetLat** – Latitude offset to add.

- **offsetLon** – Longitude offset to add.
- **offsetHeight** – Height offset to add.
- **accuracies** – Vector of positional accuracy (might be empty).

Returns
new *Transformation*.

static *TransformationNNPtr* **createGeographic2DWithHeightOffsets**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, const *common*::*Angle* &offsetLat, const *common*::*Angle* &offsetLon, const *common*::*Length* &offsetHeight, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with method Geographic 2D with height offsets.

This method is defined as EPSG:9618.

Parameters
- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **offsetLat** – Latitude offset to add.
- **offsetLon** – Longitude offset to add.
- **offsetHeight** – Geoid undulation to add.
- **accuracies** – Vector of positional accuracy (might be empty).

Returns
new *Transformation*.

static *TransformationNNPtr* **createVerticalOffset**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, const *common*::*Length* &offsetHeight, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation with method Vertical Offset.

This method is defined as EPSG:9616.

Parameters
- **properties** – See *General properties* of the *Transformation*. At minimum the name should be defined.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **offsetHeight** – Geoid undulation to add.
- **accuracies** – Vector of positional accuracy (might be empty).

Returns
new *Transformation*.

static *TransformationNNPtr* **createChangeVerticalUnit**(const *util*::*PropertyMap* &properties, const *crs*::*CRSNNPtr* &sourceCRSIn, const *crs*::*CRSNNPtr* &targetCRSIn, const *common*::*Scale* &factor, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a transformation based on the Change of Vertical Unit method.

This method is defined as EPSG:1069 [DEPRECATED].

Parameters

- **properties** – See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **sourceCRSIn** – Source CRS.
- **targetCRSIn** – Target CRS.
- **factor** – *Conversion* factor
- **accuracies** – Vector of positional accuracy (might be empty).

Returns

a new *Transformation*.

class **PointMotionOperation** : public osgeo::proj::*operation*::*SingleOperation*

#include <coordinateoperation.hpp> A mathematical operation that describes the change of coordinate values within one coordinate reference system due to the motion of the point between one coordinate epoch and another coordinate epoch.

The motion is due to tectonic plate movement or deformation.

Remark

Implements *PointMotionOperation* from *ISO 19111:2019*

class **ConcatenatedOperation** : public osgeo::proj::*operation*::*CoordinateOperation*

#include <coordinateoperation.hpp> An ordered sequence of two or more single coordinate operations (*SingleOperation*).

The sequence of coordinate operations is constrained by the requirement that the source coordinate reference system of step n+1 shall be the same as the target coordinate reference system of step n.

Remark

Implements *ConcatenatedOperation* from *ISO 19111:2019*

Public Functions

const std::vector<*CoordinateOperationNNPtr*> &**operations**() const

Return the operation steps of the concatenated operation.

Returns

the operation steps.

virtual *CoordinateOperationNNPtr* **inverse**() const override

Return the inverse of the coordinate operation.

Throws

util::UnsupportedOperationException –

virtual std::set<*GridDescription*> **gridsNeeded**(const *io*::*DatabaseContextPtr* &databaseContext, bool considerKnownGridsAsAvailable) const override

Return grids needed by an operation.

Public Static Functions

static *ConcatenatedOperationNNPtr* **create**(const *util*::*PropertyMap* &properties, const std::vector<*CoordinateOperationNNPtr*> &operationsIn, const std::vector<*metadata*::*PositionalAccuracyNNPtr*> &accuracies)

Instantiate a *ConcatenatedOperation*.

Parameters

- **properties** – See *General properties*. At minimum the name should be defined.
- **operationsIn** – Vector of the *CoordinateOperation* steps.
- **accuracies** – Vector of positional accuracy (might be empty).

Throws

InvalidOperation –

Returns

new *Transformation*.

static *CoordinateOperationNNPtr* **createComputeMetadata**(const std::vector<*CoordinateOperationNNPtr*> &operationsIn, bool checkExtent)

Instantiate a *ConcatenatedOperation*, or return a single coordinate operation.

This computes its accuracy from the sum of its member operations, its extent

Parameters

- **operationsIn** – Vector of the *CoordinateOperation* steps.
- **checkExtent** – Whether we should check the non-emptiness of the intersection of the extents of the operations

Throws

InvalidOperation –

class **CoordinateOperationContext**

#include <coordinateoperation.hpp> Context in which a coordinate operation is to be used.

Remark

Implements [*CoordinateOperationFactory* https://sis.apache.org/apidocs/org/apache/sis/referencing/operation/CoordinateOperationContext.html] from Apache SIS

Public Types

enum class **`SourceTargetCRSExtentUse`**

Specify how source and target CRS extent should be used to restrict candidate operations (only taken into account if no explicit area of interest is specified.

Values:

enumerator **`NONE`**

Ignore CRS extent

enumerator **`BOTH`**

Test coordinate operation extent against both CRS extent.

enumerator **`INTERSECTION`**

Test coordinate operation extent against the intersection of both CRS extent.

enumerator **`SMALLEST`**

Test coordinate operation against the smallest of both CRS extent.

enum class **`SpatialCriterion`**

Spatial criterion to restrict candidate operations.

Values:

enumerator **`STRICT_CONTAINMENT`**

The area of validity of transforms should strictly contain the are of interest.

enumerator **`PARTIAL_INTERSECTION`**

The area of validity of transforms should at least intersect the area of interest.

enum class **`GridAvailabilityUse`**

Describe how grid availability is used.

Values:

enumerator **`USE_FOR_SORTING`**

Grid availability is only used for sorting results. Operations where some grids are missing will be sorted last.

enumerator **`DISCARD_OPERATION_IF_MISSING_GRID`**

Completely discard an operation if a required grid is missing.

enumerator **IGNORE_GRID_AVAILABILITY**

Ignore grid availability at all. Results will be presented as if all grids were available.

enumerator **KNOWN_AVAILABLE**

Results will be presented as if grids known to PROJ (that is registered in the grid_alternatives table of its database) were available. Used typically when networking is enabled.

enum class **IntermediateCRSUse**

Describe if and how intermediate CRS should be used

Values:

enumerator **ALWAYS**

Always search for intermediate CRS.

enumerator **IF_NO_DIRECT_TRANSFORMATION**

Only attempt looking for intermediate CRS if there is no direct transformation available.

enumerator **NEVER**

Public Functions

const *io*::*AuthorityFactoryPtr* &**getAuthorityFactory**() const

Return the authority factory, or null.

const *metadata*::*ExtentPtr* &**getAreaOfInterest**() const

Return the desired area of interest, or null.

void **setAreaOfInterest**(const *metadata*::*ExtentPtr* &extent)

Set the desired area of interest, or null.

double **getDesiredAccuracy**() const

Return the desired accuracy (in metre), or 0.

void **setDesiredAccuracy**(double accuracy)

Set the desired accuracy (in metre), or 0.

void **setAllowBallparkTransformations**(bool allow)

Set whether ballpark transformations are allowed.

bool **getAllowBallparkTransformations**() const

Return whether ballpark transformations are allowed.

void **setSourceAndTargetCRSExtentUse**(*SourceTargetCRSExtentUse* use)

Set how source and target CRS extent should be used when considering if a transformation can be used (only takes effect if no area of interest is explicitly defined).

The default is *CoordinateOperationContext::SourceTargetCRSExtentUse::SMALLEST*.

SourceTargetCRSExtentUse **getSourceAndTargetCRSExtentUse**() const

Return how source and target CRS extent should be used when considering if a transformation can be used (only takes effect if no area of interest is explicitly defined).

The default is *CoordinateOperationContext::SourceTargetCRSExtentUse::SMALLEST*.

void **setSpatialCriterion**(*SpatialCriterion* criterion)

Set the spatial criterion to use when comparing the area of validity of coordinate operations with the area of interest / area of validity of source and target CRS.

The default is STRICT_CONTAINMENT.

SpatialCriterion **getSpatialCriterion**() const

Return the spatial criterion to use when comparing the area of validity of coordinate operations with the area of interest / area of validity of source and target CRS.

The default is STRICT_CONTAINMENT.

void **setUsePROJAlternativeGridNames**(bool usePROJNames)

Set whether PROJ alternative grid names should be substituted to the official authority names.

This only has effect is an authority factory with a non-null database context has been attached to this context.

If set to false, it is still possible to obtain later the substitution by using *io::PROJStringFormatter::create()* with a non-null database context.

The default is true.

bool **getUsePROJAlternativeGridNames**() const

Return whether PROJ alternative grid names should be substituted to the official authority names.

The default is true.

void **setDiscardSuperseded**(bool discard)

Set whether transformations that are superseded (but not deprecated) should be discarded.

The default is true.

bool **getDiscardSuperseded**() const

Return whether transformations that are superseded (but not deprecated) should be discarded.

The default is true.

void **setGridAvailabilityUse**(*GridAvailabilityUse* use)

Set how grid availability is used.

The default is USE_FOR_SORTING.

GridAvailabilityUse **getGridAvailabilityUse**() const

Return how grid availability is used.

The default is USE_FOR_SORTING.

void **setAllowUseIntermediateCRS**(*IntermediateCRSUse* use)

Set whether an intermediate pivot CRS can be used for researching coordinate operations between a source and target CRS.

Concretely if in the database there is an operation from A to C (or C to A), and another one from C to B (or B to C), but no direct operation between A and B, setting this parameter to ALWAYS/IF_NO_DIRECT_TRANSFORMATION, allow chaining both operations.

The current implementation is limited to researching one intermediate step.

By default, with the IF_NO_DIRECT_TRANSFORMATION strategy, all potential C candidates will be used if there is no direct transformation.

IntermediateCRSUse **getAllowUseIntermediateCRS**() const

Return whether an intermediate pivot CRS can be used for researching coordinate operations between a source and target CRS.

Concretely if in the database there is an operation from A to C (or C to A), and another one from C to B (or B to C), but no direct operation between A and B, setting this parameter to ALWAYS/IF_NO_DIRECT_TRANSFORMATION, allow chaining both operations.

The default is IF_NO_DIRECT_TRANSFORMATION.

void **setIntermediateCRS**(const std::vector<std::pair<std::string, std::string>> &intermediateCRSAuthCodes)

Restrict the potential pivot CRSs that can be used when trying to build a coordinate operation between two CRS that have no direct operation.

Parameters

intermediateCRSAuthCodes – a vector of (auth_name, code) that can be used as potential pivot RS

const std::vector<std::pair<std::string, std::string>> &**getIntermediateCRS**() const

Return the potential pivot CRSs that can be used when trying to build a coordinate operation between two CRS that have no direct operation.

Public Static Functions

static *CoordinateOperationContextNNPtr* **create**(const *io*::*AuthorityFactoryPtr* &authorityFactory, const *metadata*::*ExtentPtr* &extent, double accuracy)

Creates a context for a coordinate operation.

If a non null authorityFactory is provided, the resulting context should not be used simultaneously by more than one thread.

If authorityFactory->getAuthority() is the empty string, then coordinate operations from any authority will be searched, with the restrictions set in the authority_to_authority_preference database table. If authorityFactory->getAuthority() is set to "any", then coordinate operations from any authority will be searched If authorityFactory->getAuthority() is a non-empty string different of "any", then coordinate operatiosn will be searched only in that authority namespace.

Parameters

- **authorityFactory** – Authority factory, or null if no database lookup is allowed. Use io::authorityFactory::create(context, std::string()) to allow all authorities to be used.
- **extent** – Area of interest, or null if none is known.
- **accuracy** – Maximum allowed accuracy in metre, as specified in or 0 to get best accuracy.

Returns

a new context.

class **CoordinateOperationFactory**

#include <coordinateoperation.hpp> Creates coordinate operations. This factory is capable to find coordinate transformations or conversions between two coordinate reference systems.

Remark

Implements (partially) *CoordinateOperationFactory* from *GeoAPI*

Public Functions

CoordinateOperationPtr **createOperation**(const *crs*::*CRSNNPtr* &sourceCRS, const *crs*::*CRSNNPtr* &targetCRS) const

Find a *CoordinateOperation* from sourceCRS to targetCRS.

This is a helper of *createOperations()*, using a coordinate operation context with no authority factory (so no catalog searching is done), no desired accuracy and no area of interest. This returns the first operation of the result set of *createOperations()*, or null if none found.

Parameters

- **sourceCRS** – source CRS.
- **targetCRS** – source CRS.

Returns

a *CoordinateOperation* or nullptr.

std::vector<*CoordinateOperationNNPtr*> **createOperations**(const *crs*::*CRSNNPtr* &sourceCRS, const *crs*::*CRSNNPtr* &targetCRS, const *CoordinateOperationContextNNPtr* &context) const

Find a list of *CoordinateOperation* from sourceCRS to targetCRS.

The operations are sorted with the most relevant ones first: by descending area (intersection of the transformation area with the area of interest, or intersection of the transformation with the area of use of the CRS), and by increasing accuracy. Operations with unknown accuracy are sorted last, whatever their area.

When one of the source or target CRS has a vertical component but not the other one, the one that has no vertical component is automatically promoted to a 3D version, where its vertical axis is the ellipsoidal height in metres, using the ellipsoid of the base geodetic CRS.

Parameters

- **sourceCRS** – source CRS.
- **targetCRS** – target CRS.
- **context** – Search context.

Returns

a list

Public Static Functions

static *CoordinateOperationFactoryNNPtr* **create**()

Instantiate a *CoordinateOperationFactory*.

10.5.4.9 io namespace

namespace **io**

I/O classes.

osgeo.proj.io namespace.

Typedefs

using **DatabaseContextPtr** = std::shared_ptr<*DatabaseContext*>

Shared pointer of *DatabaseContext*.

using **DatabaseContextNNPtr** = *util*::nn<*DatabaseContextPtr*>

Non-null shared pointer of *DatabaseContext*.

using **WKTNodePtr** = std::unique_ptr<*WKTNode*>

Unique pointer of *WKTNode*.

using **WKTNodeNNPtr** = *util*::nn<*WKTNodePtr*>

Non-null unique pointer of *WKTNode*.

using **WKTFormatterPtr** = std::unique_ptr<*WKTFormatter*>

WKTFormatter unique pointer.

using **WKTFormatterNNPtr** = *util*::nn<*WKTFormatterPtr*>

Non-null *WKTFormatter* unique pointer.

using **PROJStringFormatterPtr** = std::unique_ptr<*PROJStringFormatter*>

PROJStringFormatter unique pointer.

using **PROJStringFormatterNNPtr** = *util*::nn<*PROJStringFormatterPtr*>

Non-null *PROJStringFormatter* unique pointer.

using **JSONFormatterPtr** = std::unique_ptr<*JSONFormatter*>

JSONFormatter unique pointer.

using **JSONFormatterNNPtr** = *util*::nn<*JSONFormatterPtr*>

Non-null *JSONFormatter* unique pointer.

using **IPROJStringExportablePtr** = std::shared_ptr<*IPROJStringExportable*>

Shared pointer of *IPROJStringExportable*.

using **IPROJStringExportableNNPtr** = *util*::nn<*IPROJStringExportablePtr*>

Non-null shared pointer of *IPROJStringExportable*.

using **AuthorityFactoryPtr** = std::shared_ptr<*AuthorityFactory*>

Shared pointer of *AuthorityFactory*.

using **AuthorityFactoryNNPtr** = *util*::nn<*AuthorityFactoryPtr*>

Non-null shared pointer of *AuthorityFactory*.

Functions

static *crs*::*GeodeticCRSNNPtr* **cloneWithProps**(const *crs*::*GeodeticCRSNNPtr* &geodCRS, const *util*::*PropertyMap* &props)

BaseObjectNNPtr **createFromUserInput**(const std::string &text, const *DatabaseContextPtr* &dbContext, bool usePROJ4InitRules)

Instantiate a sub-class of BaseObject from a user specified text.

The text can be a:

- WKT string
- PROJ string
- database code, prefixed by its authority. e.g. “EPSG:4326”
- OGC URN. e.g. “urn:ogc:def:crs:EPSG::4326”, “urn:ogc:def:coordinateOperation:EPSG::1671”, “urn:ogc:def:ellipsoid:EPSG::7001” or “urn:ogc:def:datum:EPSG::6326”
- OGC URN combining references for compound coordinate reference systems e.g. “urn:ogc:def:crs,crs:EPSG::2393,crs:EPSG::5717” We also accept a custom abbreviated syntax EPSG:2393+5717
- OGC URN combining references for references for projected or derived CRSs e.g. for Projected 3D CRS “UTM zone 31N / WGS 84 (3D)” “urn:ogc:def:crs,crs:EPSG::4979,cs:PROJ::ENh,coordinateOperation:EPSG::16031”
- OGC URN combining references for concatenated operations e.g. “urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618”
- an Object name. e.g “WGS 84”, “WGS 84 / UTM zone 31N”. In that case as uniqueness is not guaranteed, the function may apply heuristics to determine the appropriate best match.
- a compound CRS made from two object names separated with ” + “. e.g. “WGS 84 + EGM96 height”
- PROJJSON string

Parameters

- **text** – One of the above mentioned text format
- **dbContext** – Database context, or nullptr (in which case database lookups will not work)

- **usePROJ4InitRules** – When set to true, init=epsg:XXXX syntax will be allowed and will be interpreted according to PROJ.4 and PROJ.5 rules, that is geodeticCRS will have longitude, latitude order and will expect/output coordinates in radians. ProjectedCRS will have easting, northing axis order (except the ones with Transverse Mercator South Orientated projection). In that mode, the epsg:XXXX syntax will be also interprated the same way.

Throws
ParsingException –

BaseObjectNNPtr **createFromUserInput**(const std::string &text, PJ_CONTEXT *ctx)

Instantiate a sub-class of BaseObject from a user specified text.

The text can be a:

- WKT string
- PROJ string
- database code, prefixed by its authority. e.g. "EPSG:4326"
- OGC URN. e.g. "urn:ogc:def:crs:EPSG::4326", "urn:ogc:def:coordinateOperation:EPSG::1671", "urn:ogc:def:ellipsoid:EPSG::7001" or "urn:ogc:def:datum:EPSG::6326"
- OGC URN combining references for compound coordinate reference systems e.g. "urn:ogc:def:crs,crs:EPSG::2393,crs:EPSG::5717" We also accept a custom abbreviated syntax EPSG:2393+5717
- OGC URN combining references for references for projected or derived CRSs e.g. for Projected 3D CRS "UTM zone 31N / WGS 84 (3D)" "urn:ogc:def:crs,crs:EPSG::4979,cs:PROJ::ENh,coordinateOperation:EPSG::16031"
- OGC URN combining references for concatenated operations e.g. "urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618"
- an Object name. e.g "WGS 84", "WGS 84 / UTM zone 31N". In that case as uniqueness is not guaranteed, the function may apply heuristics to determine the appropriate best match.
- a compound CRS made from two object names separated with " + ". e.g. "WGS 84 + EGM96 height"
- PROJJSON string

Parameters

- **text** – One of the above mentioned text format
- **ctx** – PROJ context

Throws
ParsingException –

class **WKTFormatter**

#include <io.hpp> Formatter to WKT strings.

An instance of this class can only be used by a single thread at a time.

Public Types

enum class **Convention_**

WKT variant.

Values:

enumerator **WKT2**

Full WKT2 string, conforming to ISO 19162:2015(E) / OGC 12-063r5 (WKT2:2015) with all possible nodes and new keyword names.

enumerator **_WKT2_2015**

enumerator **WKT2_SIMPLIFIED**

Same as WKT2 with the following exceptions:

- UNIT keyword used.
- ID node only on top element.
- No ORDER element in AXIS element.
- PRIMEM node omitted if it is Greenwich.
- ELLIPSOID.UNIT node omitted if it is UnitOfMeasure::METRE.
- PARAMETER.UNIT / PRIMEM.UNIT omitted if same as AXIS.
- AXIS.UNIT omitted and replaced by a common GEODCRS.UNIT if they are all the same on all axis.

enumerator **_WKT2_2015_SIMPLIFIED**

enumerator **_WKT2_2019**

Full WKT2 string, conforming to ISO 19162:2019 / OGC 18-010, with (WKT2:2019) all possible nodes and new keyword names. Non-normative list of differences:

- _WKT2_2019 uses GEOGCRS / BASEGEOGCRS keywords for GeographicCRS.

enumerator **_WKT2_2018**

Deprecated alias for _WKT2_2019

enumerator **_WKT2_2019_SIMPLIFIED**

_WKT2_2019 with the simplification rule of WKT2_SIMPLIFIED

enumerator **_WKT2_2018_SIMPLIFIED**

Deprecated alias for _WKT2_2019_SIMPLIFIED

enumerator **_WKT1_GDAL**

WKT1 as traditionally output by GDAL, deriving from OGC 01-009. A notable departure from _WKT1_GDAL with respect to OGC 01-009 is that in _WKT1_GDAL, the unit of the PRIMEM value is always degrees.

enumerator **_WKT1_ESRI**

WKT1 as traditionally output by ESRI software, deriving from OGC 99-049.

enum class **OutputAxisRule**

Rule for output AXIS nodes

Values:

enumerator **YES**

Always include AXIS nodes

enumerator **NO**

Never include AXIS nodes

enumerator **_WKT1_GDAL_EPSG_STYLE**

Includes them only on PROJCS node if it uses Easting/Northing ordering. Typically used for _WKT1_GDAL

Public Functions

WKTFormatter &**setMultiLine**(bool multiLine) noexcept

Whether to use multi line output or not.

WKTFormatter &**setIndentationWidth**(int width) noexcept

Set number of spaces for each indentation level (defaults to 4).

WKTFormatter &**setOutputAxis**(*OutputAxisRule* outputAxis) noexcept

Set whether AXIS nodes should be output.

WKTFormatter &**setStrict**(bool strict) noexcept

Set whether the formatter should operate on strict more or not.

The default is strict mode, in which case a *FormattingException* can be thrown. In non-strict mode, a Geographic 3D CRS can be for example exported as _WKT1_GDAL with 3 axes, whereas this is normally not allowed.

bool **isStrict**() const noexcept

Returns whether the formatter is in strict mode.

WKTFormatter &**setAllowEllipsoidalHeightAsVerticalCRS**(bool allow) noexcept

Set whether the formatter should export, in WKT1, a Geographic or Projected 3D CRS as a compound CRS whose vertical part represents an ellipsoidal height.

bool **isAllowedEllipsoidalHeightAsVerticalCRS**() const noexcept

Return whether the formatter should export, in WKT1, a Geographic or Projected 3D CRS as a compound CRS whose vertical part represents an ellipsoidal height.

const std::string &**toString**() const

Returns the WKT string from the formatter.

Public Static Functions

static *WKTFormatterNNPtr* **create**(*Convention_* convention = *Convention_*::*WKT2*, *DatabaseContextPtr* dbContext = nullptr)

Constructs a new formatter.

A formatter can be used only once (its internal state is mutated)

Its default behavior can be adjusted with the different setters.

Parameters

- **convention** – WKT flavor. Defaults to *Convention_::WKT2*
- **dbContext** – Database context, to allow queries in it if needed. This is used for example for _WKT1_ESRI output to do name substitutions.

Returns

new formatter.

static *WKTFormatterNNPtr* **create**(const *WKTFormatterNNPtr* &other)

Constructs a new formatter from another one.

A formatter can be used only once (its internal state is mutated)

Its default behavior can be adjusted with the different setters.

Parameters

other – source formatter.

Returns

new formatter.

class **PROJStringFormatter**

#include <io.hpp> Formatter to PROJ strings.

An instance of this class can only be used by a single thread at a time.

Public Types

enum class **Convention**

PROJ variant.

Values:

enumerator **PROJ_5**

PROJ v5 (or later versions) string.

enumerator **PROJ_4**

PROJ v4 string as output by GDAL exportToProj4()

Public Functions

PROJStringFormatter &**setMultiLine**(bool multiLine) noexcept

Whether to use multi line output or not.

PROJStringFormatter &**setIndentationWidth**(int width) noexcept

Set number of spaces for each indentation level (defaults to 2).

PROJStringFormatter &**setMaxLineLength**(int maxLineLength) noexcept

Set the maximum size of a line (when multiline output is enable). Can be set to 0 for unlimited length.

void **setUseApproxTMerc**(bool flag)

Set whether approximate Transverse Mercator or UTM should be used.

const std::string &**toString**() const

Returns the PROJ string.

Public Static Functions

static *PROJStringFormatterNNPtr* **create**(*Convention* conventionIn = *Convention*::*PROJ_5*, *DatabaseContextPtr* dbContext = nullptr)

Constructs a new formatter.

A formatter can be used only once (its internal state is mutated)

Its default behavior can be adjusted with the different setters.

Parameters
- **conventionIn** – PROJ string flavor. Defaults to *Convention::PROJ_5*
- **dbContext** – Database context (can help to find alternative grid names). May be nullptr

Returns
new formatter.

class **JSONFormatter**

#include <io.hpp> Formatter to JSON strings.

An instance of this class can only be used by a single thread at a time.

Public Functions

JSONFormatter &**setMultiLine**(bool multiLine) noexcept

Whether to use multi line output or not.

JSONFormatter &**setIndentationWidth**(int width) noexcept

Set number of spaces for each indentation level (defaults to 4).

JSONFormatter &**setSchema**(const std::string &schema) noexcept

Set the value of the "$schema" key in the top level object.

If set to empty string, it will not be written.

const std::string &**toString**() const

Return the serialized JSON.

Public Static Functions

static *JSONFormatterNNPtr* **create**(*DatabaseContextPtr* dbContext = nullptr)

Constructs a new formatter.

A formatter can be used only once (its internal state is mutated)

Returns

new formatter.

class **IJSONExportable**

#include <io.hpp> Interface for an object that can be exported to JSON.

Subclassed by *osgeo::proj::crs::CRS*, *osgeo::proj::cs::CoordinateSystem*, *osgeo::proj::cs::CoordinateSystemAxis*, *osgeo::proj::datum::Datum*, *osgeo::proj::datum::DatumEnsemble*, *osgeo::proj::datum::Ellipsoid*, *osgeo::proj::datum::PrimeMeridian*, *osgeo::proj::metadata::Identifier*, *osgeo::proj::operation::CoordinateOperation*, *osgeo::proj::operation::GeneralParameterValue*, *osgeo::proj::operation::OperationMethod*

Public Functions

std::string **exportToJSON**(*JSONFormatter* *formatter) const

Builds a JSON representation. May throw a *FormattingException*

class **FormattingException** : public osgeo::proj::*util*::*Exception*

#include <io.hpp> Exception possibly thrown by *IWKTExportable::exportToWKT()* or *IPROJStringExportable::exportToPROJString()*.

class **ParsingException** : public osgeo::proj::*util*::*Exception*

#include <io.hpp> Exception possibly thrown by *WKTNode::createFrom()* or *WKTParser::createFromWKT()*.

class **IWKTExportable**

#include <io.hpp> Interface for an object that can be exported to WKT.

Subclassed by *osgeo::proj::common::IdentifiedObject*, *osgeo::proj::metadata::Identifier*, *osgeo::proj::operation::GeneralParameterValue*, *osgeo::proj::operation::ParameterValue*

Public Functions

std::string **exportToWKT**(*WKTFormatter* *formatter) const

Builds a WKT representation. May throw a *FormattingException*

class **IPROJStringExportable**

#include <io.hpp> Interface for an object that can be exported to a PROJ string.

Subclassed by *osgeo::proj::crs::BoundCRS*, *osgeo::proj::crs::CompoundCRS*, *osgeo::proj::crs::GeodeticCRS*, *osgeo::proj::crs::ProjectedCRS*, *osgeo::proj::crs::VerticalCRS*, *osgeo::proj::datum::Ellipsoid*, *osgeo::proj::datum::PrimeMeridian*, *osgeo::proj::operation::CoordinateOperation*

Public Functions

std::string **exportToPROJString**(*PROJStringFormatter* *formatter) const

Builds a PROJ string representation.

- For *PROJStringFormatter::Convention::PROJ_5* (the default),
  - For a *crs::CRS*, returns the same as *PROJStringFormatter::Convention::PROJ_4*. It should be noted that the export of a CRS as a PROJ string may cause loss of many important aspects of a CRS definition. Consequently it is discouraged to use it for interoperability in newer projects. The choice of a WKT representation will be a better option.
  - For *operation::CoordinateOperation*, returns a PROJ pipeline.
- For *PROJStringFormatter::Convention::PROJ_4*, format a string compatible with the OGRSpatialReference::exportToProj4() of GDAL <=2.3. It is only compatible of a few CRS objects. The PROJ string will also contain a +type=crs parameter to disambiguate the nature of the string from a CoordinateOperation.
  - For a *crs::GeographicCRS*, returns a proj=longlat string, with ellipsoid / datum / prime meridian information, ignoring axis order and unit information.
  - For a geocentric *crs::GeodeticCRS*, returns the transformation from geographic coordinates into geocentric coordinates.
  - For a *crs::ProjectedCRS*, returns the projection method, ignoring axis order.
  - For a *crs::BoundCRS*, returns the PROJ string of its source/base CRS, amended with towgs84 / nadgrids parameter when the deriving conversion can be expressed in that way.

Parameters

`formatter` – PROJ string formatter.

Throws

`FormattingException` –

Returns

a PROJ string.

class **WKTNode**

#include <io.hpp> Node in the tree-splitted WKT representation.

Public Functions

explicit **WKTNode**(const std::string &valueIn)

Instantiate a *WKTNode*.

Parameters

`valueIn` – the name of the node.

const std::string &**value**() const

Return the value of a node.

const std::vector<*WKTNodeNNPtr*> &**children**() const

Return the children of a node.

void **addChild**(*WKTNodeNNPtr* &&child)

Adds a child to the current node.

Parameters

`child` – child to add. This should not be a parent of this node.

const *WKTNodePtr* &**lookForChild**(const std::string &childName, int occurrence = 0) const noexcept

Return the (occurrence-1)th sub-node of name childName.

Parameters

- **childName** – name of the child.
- **occurrence** – occurrence index (starting at 0)

Returns

the child, or nullptr.

int **countChildrenOfName**(const std::string &childName) const noexcept

Return the count of children of given name.

Parameters

childName – name of the children to look for.

Returns

count

std::string **toString**() const

Return a WKT representation of the tree structure.

Public Static Functions

static *WKTNodeNNPtr* **createFrom**(const std::string &wkt, size_t indexStart = 0)

Instantiate a *WKTNode* hierarchy from a WKT string.

Parameters

- **wkt** – the WKT string to parse.
- **indexStart** – the start index in the wkt string.

Throws

ParsingException –

class **WKTParser**

#include <io.hpp> Parse a WKT string into the appropriate subclass of *util::BaseObject*.

Public Types

enum class **WKTGuessedDialect**

Guessed WKT "dialect"

Values:

enumerator **WKT2_2019**

WKT2:2019

enumerator **WKT2_2018**

Deprecated alias for WKT2_2019

enumerator **WKT2_2015**

WKT2:2015

enumerator **WKT1_GDAL**

WKT1 specification

enumerator **WKT1_ESRI**

ESRI variant of WKT1

enumerator **NOT_WKT**

Not WKT / unrecognized

Public Functions

WKTParser &**attachDatabaseContext**(const *DatabaseContextPtr* &dbContext)

Attach a database context, to allow queries in it if needed.

WKTParser &**setStrict**(bool strict)

Set whether parsing should be done in strict mode.

std::list<std::string> **warningList**() const

Return the list of warnings found during parsing.

Note: The list might be non-empty only is setStrict(false) has been called.

util::*BaseObjectNNPtr* **createFromWKT**(const std::string &wkt)

Instantiate a sub-class of BaseObject from a WKT string.

By default, validation is strict (to the extent of the checks that are actually implemented. Currently only WKT1 strict grammar is checked), and any issue detected will cause an exception to be thrown, unless setStrict(false) is called priorly.

In non-strict mode, non-fatal issues will be recovered and simply listed in *warningList()*. This does not prevent more severe errors to cause an exception to be thrown.

Throws

`ParsingException` –

WKTGuessedDialect **guessDialect**(const std::string &wkt) noexcept

Guess the "dialect" of the WKT string.

class **PROJStringParser**

#include <io.hpp> Parse a PROJ string into the appropriate subclass of *util::BaseObject*.

Public Functions

PROJStringParser &**attachDatabaseContext**(const *DatabaseContextPtr* &dbContext)

Attach a database context, to allow queries in it if needed.

PROJStringParser &**setUsePROJ4InitRules**(bool enable)

Set how init=epsg:XXXX syntax should be interpreted.

Parameters

enable – When set to true, init=epsg:XXXX syntax will be allowed and will be interpreted according to PROJ.4 and PROJ.5 rules, that is geodeticCRS will have longitude, latitude order and will expect/output coordinates in radians. ProjectedCRS will have easting, northing axis order (except the ones with Transverse Mercator South Orientated projection).

std::vector<std::string> **warningList**() const

Return the list of warnings found during parsing.

util::*BaseObjectNNPtr* **createFromPROJString**(const std::string &projString)

Instantiate a sub-class of BaseObject from a PROJ string.

The projString must contain +type=crs for the object to be detected as a CRS instead of a Coordinate-Operation.

Throws

ParsingException –

class **DatabaseContext**

#include <io.hpp> Database context.

A database context should be used only by one thread at a time.

Public Functions

const std::string &**getPath**() const

Return the path to the database.

const char ***getMetadata**(const char *key) const

Return a metadata item.

Value remains valid while this is alive and to the next call to getMetadata

std::set<std::string> **getAuthorities**() const

Return the list of authorities used in the database.

std::vector<std::string> **getDatabaseStructure**() const

Return the list of SQL commands (CREATE TABLE, CREATE TRIGGER, CREATE VIEW) needed to initialize a new database.

Public Static Functions

static *DatabaseContextNNPtr* **create**(const std::string &databasePath = std::string(), const std::vector<std::string> &auxiliaryDatabasePaths = std::vector<std::string>(), PJ_CONTEXT *ctx = nullptr)

Instantiate a database context.

This database context should be used only by one thread at a time.

Parameters

- **databasePath** – Path and filename of the database. Might be empty string for the default rules to locate the default proj.db
- **auxiliaryDatabasePaths** – Path and filename of auxiliary databases. Might be empty.
- **ctx** – Context used for file search.

Throws

FactoryException –

class **AuthorityFactory**

#include <io.hpp> Builds object from an authority database.

A *AuthorityFactory* should be used only by one thread at a time.

Remark

Implements AuthorityFactory from *GeoAPI*

Public Types

enum class **ObjectType**

Object type.

Values:

enumerator **PRIME_MERIDIAN**

Object of type *datum::PrimeMeridian*

enumerator **ELLIPSOID**

Object of type *datum::Ellipsoid*

enumerator **DATUM**

Object of type *datum::Datum* (and derived classes)

enumerator **GEODETIC_REFERENCE_FRAME**

Object of type *datum::GeodeticReferenceFrame* (and derived classes)

enumerator **VERTICAL_REFERENCE_FRAME**

Object of type *datum::VerticalReferenceFrame* (and derived classes)

enumerator **CRS**

Object of type *crs::CRS* (and derived classes)

enumerator **GEODETIC_CRS**

Object of type *crs::GeodeticCRS* (and derived classes)

enumerator **GEOCENTRIC_CRS**

GEODETIC_CRS of type geocentric

enumerator **GEOGRAPHIC_CRS**

Object of type *crs::GeographicCRS* (and derived classes)

enumerator **GEOGRAPHIC_2D_CRS**

GEOGRAPHIC_CRS of type Geographic 2D

enumerator **GEOGRAPHIC_3D_CRS**

GEOGRAPHIC_CRS of type Geographic 3D

enumerator **PROJECTED_CRS**

Object of type *crs::ProjectedCRS* (and derived classes)

enumerator **VERTICAL_CRS**

Object of type *crs::VerticalCRS* (and derived classes)

enumerator **COMPOUND_CRS**

Object of type *crs::CompoundCRS* (and derived classes)

enumerator **COORDINATE_OPERATION**

Object of type *operation::CoordinateOperation* (and derived classes)

enumerator **CONVERSION**

Object of type *operation::Conversion* (and derived classes)

enumerator **TRANSFORMATION**

Object of type *operation::Transformation* (and derived classes)

enumerator **CONCATENATED_OPERATION**

Object of type *operation::ConcatenatedOperation* (and derived classes)

enumerator **DYNAMIC_GEODETIC_REFERENCE_FRAME**

Object of type *datum::DynamicGeodeticReferenceFrame*

enumerator **DYNAMIC_VERTICAL_REFERENCE_FRAME**

Object of type *datum::DynamicVerticalReferenceFrame*

enumerator **DATUM_ENSEMBLE**

Object of type *datum::DatumEnsemble*

Public Functions

util::*BaseObjectNNPtr* **createObject**(const std::string &code) const

Returns an arbitrary object from a code.

The returned object will typically be an instance of Datum, CoordinateSystem, ReferenceSystem or CoordinateOperation. If the type of the object is know at compile time, it is recommended to invoke the most precise method instead of this one (for example createCoordinateReferenceSystem(code) instead of createObject(code) if the caller know he is asking for a coordinate reference system).

If there are several objects with the same code, a *FactoryException* is thrown.

Parameters

code – Object code allocated by authority. (e.g. "4326")

Throws

- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns

object.

common::*UnitOfMeasureNNPtr* **createUnitOfMeasure**(const std::string &code) const

Returns a *common::UnitOfMeasure* from the specified code.

Parameters
`code` – Object code allocated by authority.

Throws
- *`NoSuchAuthorityCodeException`* –
- *`FactoryException`* –

Returns
object.

metadata::*ExtentNNPtr* **createExtent**(const std::string &code) const

Returns a *metadata::Extent* from the specified code.

Parameters
`code` – Object code allocated by authority.

Throws
- *`NoSuchAuthorityCodeException`* –
- *`FactoryException`* –

Returns
object.

datum::*PrimeMeridianNNPtr* **createPrimeMeridian**(const std::string &code) const

Returns a *datum::PrimeMeridian* from the specified code.

Parameters
`code` – Object code allocated by authority.

Throws
- *`NoSuchAuthorityCodeException`* –
- *`FactoryException`* –

Returns
object.

std::string **identifyBodyFromSemiMajorAxis**(double a, double tolerance) const

Identify a celestial body from an approximate radius.

Parameters
- `semi_major_axis` – Approximate semi-major axis.
- `tolerance` – Relative error allowed.

Throws
`FactoryException` –

Returns
celestial body name if one single match found.

datum::*EllipsoidNNPtr* **createEllipsoid**(const std::string &code) const

Returns a *datum::Ellipsoid* from the specified code.

Parameters
`code` – Object code allocated by authority.

Throws
- *`NoSuchAuthorityCodeException`* –
- *`FactoryException`* –

Returns
object.

datum::*DatumNNPtr* **createDatum**(const std::string &code) const

Returns a *datum::Datum* from the specified code.

Parameters
`code` – Object code allocated by authority.

Throws

- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

datum::*DatumEnsembleNNPtr* **createDatumEnsemble**(const std::string &code, const std::string &type = std::string()) const

Returns a *datum::DatumEnsemble* from the specified code.

Parameters
- **code** – Object code allocated by authority.
- **type** – "geodetic_datum", "vertical_datum" or empty string if unknown

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

datum::*GeodeticReferenceFrameNNPtr* **createGeodeticDatum**(const std::string &code) const

Returns a *datum::GeodeticReferenceFrame* from the specified code.

Parameters
code – Object code allocated by authority.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

datum::*VerticalReferenceFrameNNPtr* **createVerticalDatum**(const std::string &code) const

Returns a *datum::VerticalReferenceFrame* from the specified code.

Parameters
code – Object code allocated by authority.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

cs::*CoordinateSystemNNPtr* **createCoordinateSystem**(const std::string &code) const

Returns a *cs::CoordinateSystem* from the specified code.

Parameters
code – Object code allocated by authority.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

crs::*GeodeticCRSNNPtr* **createGeodeticCRS**(const std::string &code) const

Returns a *crs::GeodeticCRS* from the specified code.

Parameters
code – Object code allocated by authority.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

crs::*GeographicCRSNNPtr* **createGeographicCRS**(const std::string &code) const

Returns a *crs::GeographicCRS* from the specified code.

Parameters
code – Object code allocated by authority.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

crs::*VerticalCRSNNPtr* **createVerticalCRS**(const std::string &code) const

Returns a *crs::VerticalCRS* from the specified code.

Parameters
code – Object code allocated by authority.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

operation::*ConversionNNPtr* **createConversion**(const std::string &code) const

Returns a *operation::Conversion* from the specified code.

Parameters
code – Object code allocated by authority.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

crs::*ProjectedCRSNNPtr* **createProjectedCRS**(const std::string &code) const

Returns a *crs::ProjectedCRS* from the specified code.

Parameters
code – Object code allocated by authority.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

crs::*CompoundCRSNNPtr* **createCompoundCRS**(const std::string &code) const

Returns a *crs::CompoundCRS* from the specified code.

Parameters
code – Object code allocated by authority.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

crs::*CRSNNPtr* **createCoordinateReferenceSystem**(const std::string &code) const

Returns a *crs::CRS* from the specified code.

Parameters
`code` – Object code allocated by authority.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

operation::*CoordinateOperationNNPtr* **createCoordinateOperation**(const std::string &code, bool usePROJAlternativeGridNames) const

Returns a *operation::CoordinateOperation* from the specified code.

Parameters
- `code` – Object code allocated by authority.
- `usePROJAlternativeGridNames` – Whether PROJ alternative grid names should be substituted to the official grid names.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
object.

std::vector<*operation*::*CoordinateOperationNNPtr*> **createFromCoordinateReferenceSystemCodes**(const std::string &sourceCRSCode, const std::string &targetCRSCode) const

Returns a list *operation::CoordinateOperation* between two CRS.

The list is ordered with preferred operations first. No attempt is made at inferring operations that are not explicitly in the database.

Deprecated operations are rejected.

Parameters
- `sourceCRSCode` – Source CRS code allocated by authority.
- `targetCRSCode` – Source CRS code allocated by authority.

Throws
- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns
list of coordinate operations

const std::string &**getAuthority**()

Returns the authority name associated to this factory.

Returns
name.

std::set<std::string> **getAuthorityCodes**(const *ObjectType* &type, bool allowDeprecated = true) const

Returns the set of authority codes of the given object type.

Parameters
- `type` – Object type.
- `allowDeprecated` – whether we should return deprecated objects as well.

Throws
`FactoryException` –

Returns
the set of authority codes for spatial reference objects of the given type

std::string **getDescriptionText**(const std::string &code) const

Gets a description of the object corresponding to a code.

Note: In case of several objects of different types with the same code, one of them will be arbitrarily selected. But if a CRS object is found, it will be selected.

Parameters
code – Object code allocated by authority. (e.g. "4326")

Throws
- `NoSuchAuthorityCodeException` –
- `FactoryException` –

Returns
description.

std::list<*CRSInfo*> **getCRSInfoList**() const

Return a list of information on CRS objects.

This is functionnaly equivalent of listing the codes from an authority, instantiating a CRS object for each of them and getting the information from this CRS object, but this implementation has much less overhead.

Throws
`FactoryException` –

std::list<*UnitInfo*> **getUnitList**() const

Return the list of units.

Since
7.1

Throws
`FactoryException` –

const *DatabaseContextNNPtr* &**databaseContext**() const

Returns the database context.

std::vector<*operation*::*CoordinateOperationNNPtr*> **createFromCoordinateReferenceSystemCodes**(const std::string &sourceCRSAuthName, const std::string &sourceCRSCode, const std::string &targetCRSAuthName, const std::string &targetCRSCode, bool usePROJAlternativeGridNames, bool discardIfMissingGrid, bool considerKnownGridsAsAvailable, bool discardSuperseded, bool tryReverseOrder = false, bool reportOnly-

Returns a list *operation::CoordinateOperation* between two CRS.

The list is ordered with preferred operations first. No attempt is made at inferring operations that are not explicitly in the database (see *createFromCRSCodesWithIntermediates()* for that), and only source -> target operations are searched (i.e. if target -> source is present, you need to call this method with the arguments reversed, and apply the reverse transformations).

Deprecated operations are rejected.

If *getAuthority()* returns empty, then coordinate operations from all authorities are considered.

Parameters

- `sourceCRSAuthName` – Authority name of sourceCRSCode
- `sourceCRSCode` – Source CRS code allocated by authority sourceCRSAuthName.
- `targetCRSAuthName` – Authority name of targetCRSCode
- `targetCRSCode` – Source CRS code allocated by authority targetCRSAuthName.
- `usePROJAlternativeGridNames` – Whether PROJ alternative grid names should be substituted to the official grid names.
- `discardIfMissingGrid` – Whether coordinate operations that reference missing grids should be removed from the result set.
- `considerKnownGridsAsAvailable` – Whether known grids should be considered as available (typically when network is enabled).
- `discardSuperseded` – Whether cordinate operations that are superseded (but not deprecated) should be removed from the result set.
- `tryReverseOrder` – whether to search in the reverse order too (and thus inverse results found that way)
- `reportOnlyIntersectingTransformations` – if intersectingExtent1 and intersectingExtent2 should be honored in a strict way.
- `intersectingExtent1` – Optional extent that the resulting operations must intersect.
- `intersectingExtent2` – Optional extent that the resulting operations must intersect.

Throws

- *`NoSuchAuthorityCodeException`* –
- *`FactoryException`* –

Returns

list of coordinate operations

std::vector<*operation*::*CoordinateOperationNNPtr*> **createFromCRSCodesWithIntermediates**(const std::string &sourceCRSAuthName, const std::string &sourceCRSCode, const std::string &targetCRSAuthName, const std::string &targetCRSCode, bool usePROJAlternativeGridNames, bool discardIfMissingGrid, bool considerKnownGridsAsAvailable, bool discardSuperseded, const std::vector<std::pair<std::string, std::string>> &intermediateCRSAuthCodes,

Returns a list *operation::CoordinateOperation* between two CRS, using intermediate codes.

The list is ordered with preferred operations first.

Deprecated operations are rejected.

The method will take care of considering all potential combinations (i.e. contrary to *createFromCoordinateReferenceSystemCodes()*, you do not need to call it with sourceCRS and targetCRS switched)

If *getAuthority()* returns empty, then coordinate operations from all authorities are considered.

Parameters

- **sourceCRSAuthName** – Authority name of sourceCRSCode
- **sourceCRSCode** – Source CRS code allocated by authority sourceCRSAuthName.
- **targetCRSAuthName** – Authority name of targetCRSCode
- **targetCRSCode** – Source CRS code allocated by authority targetCRSAuthName.
- **usePROJAlternativeGridNames** – Whether PROJ alternative grid names should be substituted to the official grid names.
- **discardIfMissingGrid** – Whether coordinate operations that reference missing grids should be removed from the result set.
- **considerKnownGridsAsAvailable** – Whether known grids should be considered as available (typically when network is enabled).
- **discardSuperseded** – Whether cordinate operations that are superseded (but not deprecated) should be removed from the result set.
- **intermediateCRSAuthCodes** – List of (auth_name, code) of CRS that can be used as potential intermediate CRS. If the list is empty, the database will be used to find common CRS in operations involving both the source and target CRS.
- **allowedIntermediateObjectType** – Restrict the type of the intermediate object considered. Only *ObjectType::CRS* and *ObjectType::GEOGRAPHIC_CRS* supported currently
- **allowedAuthorities** – One or several authority name allowed for the two coordinate operations that are going to be searched. When this vector is no empty, it overrides the authority of this object. This is useful for example when the coordinate operations to chain belong to two different allowed authorities.
- **intersectingExtent1** – Optional extent that the resulting operations must intersect.
- **intersectingExtent2** – Optional extent that the resulting operations must intersect.

Throws

- *NoSuchAuthorityCodeException* –
- *FactoryException* –

Returns

list of coordinate operations

std::string **getOfficialNameFromAlias**(const std::string &aliasedName, const std::string &tableName, const std::string &source, bool tryEquivalentNameSpelling, std::string &outTableName, std::string &outAuthName, std::string &outCode) const

Gets the official name from a possibly alias name.

Parameters

- **aliasedName** – Alias name.
- **tableName** – Table name/category. Can help in case of ambiguities. Or empty otherwise.
- **source** – Source of the alias. Can help in case of ambiguities. Or empty otherwise.
- **tryEquivalentNameSpelling** – whether the comparison of aliasedName with the alt_name column of the alias_name table should be done with using *metadata::Identifier::isEquivalentName()* rather than strict string comparison;
- **outTableName** – Table name in which the official name has been found.

- **outAuthName** – Authority name of the official name that has been found.
- **outCode** – Code of the official name that has been found.

Throws
FactoryException –

Returns
official name (or empty if not found).

std::list<*common*::*IdentifiedObjectNNPtr*> **createObjectsFromName**(const std::string &name, const std::vector<*ObjectType*> &allowedObjectTypes = std::vector<*ObjectType*>(), bool approximateMatch = true, size_t limitResultCount = 0) const

Return a list of objects, identified by their name.

Parameters
- **searchedName** – Searched name. Must be at least 2 character long.
- **allowedObjectTypes** – List of object types into which to search. If empty, all object types will be searched.
- **approximateMatch** – Whether approximate name identification is allowed.
- **limitResultCount** – Maximum number of results to return. Or 0 for unlimited.

Throws
FactoryException –

Returns
list of matched objects.

std::list<std::pair<std::string, std::string>> **listAreaOfUseFromName**(const std::string &name, bool approximateMatch) const

Return a list of area of use from their name.

Parameters
- **name** – Searched name.
- **approximateMatch** – Whether approximate name identification is allowed.

Throws
FactoryException –

Returns
list of (auth_name, code) of matched objects.

Public Static Functions

static *AuthorityFactoryNNPtr* **create**(const *DatabaseContextNNPtr* &context, const std::string &authorityName)

Instantiate a *AuthorityFactory*.

The authority name might be set to the empty string in the particular case where createFromCoordinateReferenceSystemCodes(const std::string&,const std::string&,const std::string&,const std::string&) const is called.

Parameters
- **context** – Context.
- **authorityName** – Authority name.

Returns
new *AuthorityFactory*.

struct **CRSInfo**

#include <io.hpp> CRS information

Public Members

std::string **authName**

Authority name

std::string **code**

Code

std::string **name**

Name

ObjectType **type**

Type

bool **deprecated**

Whether the object is deprecated

bool **bbox_valid**

Whereas the west_lon_degree, south_lat_degree, east_lon_degree and north_lat_degree fields are valid.

double **west_lon_degree**

Western-most longitude of the area of use, in degrees.

double **south_lat_degree**

Southern-most latitude of the area of use, in degrees.

double **east_lon_degree**

Eastern-most longitude of the area of use, in degrees.

double **north_lat_degree**

Northern-most latitude of the area of use, in degrees.

std::string **areaName**

Name of the area of use.

std::string **projectionMethodName**

Name of the projection method for a projected CRS. Might be empty even for projected CRS in some cases.

struct **UnitInfo**

#include <io.hpp> Unit information

Public Members

std::string **authName**

Authority name

std::string **code**

Code

std::string **name**

Name

std::string **category**

Category: one of "linear", "linear_per_time", "angular", "angular_per_time", "scale", "scale_per_time" or "time"

double **convFactor**

Conversion factor to the SI unit. It might be 0 in some cases to indicate no known conversion factor.

std::string **projShortName**

PROJ short name (may be empty)

bool **deprecated**

Whether the object is deprecated

class **FactoryException** : public osgeo::proj::*util*::*Exception*

#include <io.hpp> Exception thrown when a factory can't create an instance of the requested object.

Subclassed by *osgeo::proj::io::NoSuchAuthorityCodeException*

class **NoSuchAuthorityCodeException** : public osgeo::proj::*io*::*FactoryException*

#include <io.hpp> Exception thrown when an authority factory can't find the requested authority code.

Public Functions

const std::string &**getAuthority**() const

Returns authority name.

const std::string &**getAuthorityCode**() const

Returns authority code.

10.6 Using PROJ in CMake projects

The recommended way to use the PROJ library in a CMake project is to link to the imported library target `${PROJ_LIBRARIES}` provided by the CMake configuration which comes with the library. Typical usage is:

```
find_package(PROJ)

target_link_libraries(MyApp PRIVATE ${PROJ_LIBRARIES})
```

By adding the imported library target `${PROJ_LIBRARIES}` to the target link libraries, CMake will also pass the include directories to the compiler. This requires that you use CMake version 2.8.11 or later. If you are using an older version of CMake, then add

```
include_directories(${PROJ_INCLUDE_DIRS})
```

The CMake command `find_package` will look for the configuration in a number of places. The lookup can be adjusted for all packages by setting the cache variable or environment variable `CMAKE_PREFIX_PATH`. In particular, CMake will consult (and set) the cache variable `PROJ_DIR`.

The old CMake name for the PROJ project was “PROJ4” and the switch to the name “PROJ” was made with version 7.0. So if you expect your package to work with pre-7.0 versions of PROJ, you will need to use

```
find_package(PROJ4)
target_link_libraries(MyApp PRIVATE ${PROJ4_LIBRARIES})
include_directories(${PROJ4_INCLUDE_DIRS})
```

This will also find version 7.0. This use of the PROJ4 name will be phased out at some point.

10.7 Language bindings

PROJ bindings are available for a number of different development platforms.

10.7.1 Python

pyproj: Python interface (wrapper for PROJ)

10.7.2 Ruby

proj4rb: Bindings for PROJ in ruby

10.7.3 Rust

proj: Rust bindings for the latest stable version of PROJ

10.7.4 Go (Golang)

go-proj: Go bindings and idiomatic wrapper for PROJ

10.7.5 Julia

Proj4.jl: Julia bindings and idiomatic wrapper for PROJ.

10.7.6 TCL

proj4tcl: Bindings for PROJ in tcl (critcl source)

10.7.7 MySQL

fProj4: Bindings for PROJ in MySQL

10.7.8 Excel

proj.xll: Excel add-in for PROJ map projections

10.7.9 Visual Basic

PROJ VB Wrappers: By Eric G. Miller.

10.7.10 Fortran

Fortran-Proj: Bindings for PROJ in Fortran (By João Macedo @likeno)

10.8 Version 4 to 6 API Migration

This is a transition guide for developers wanting to migrate their code to use PROJ version 6.

10.8.1 Code example

The difference between the old and new API is shown here with a few examples. Below we implement the same program with the two different API's. The program reads input longitude and latitude from the command line and convert them to projected coordinates with the Mercator projection.

We start by writing the program for PROJ 4:

```
#include <proj_api.h>

main(int argc, char **argv) {
    projPJ pj_merc, pj_longlat;
    double x, y;
    int p;
```

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```
    if (!(pj_longlat = pj_init_plus("+proj=longlat +ellps=clrk66")) )
        return 1;
    if (!(pj_merc = pj_init_plus("+proj=merc +datum=clrk66 +lat_ts=33")) )
        return 1;

    while (scanf("%lf %lf", &x, &y) == 2) {
        x *= DEG_TO_RAD; /* longitude */
        y *= DEG_TO_RAD; /* latitude */
        p = pj_transform(pj_longlat, pj_merc, 1, 1, &x, &y, NULL);
        printf("%.2f\t%.2f\n", x, y);
    }

    pj_free(pj_longlat);
    pj_free(pj_merc);

    return 0;
}
```

The same program implemented using PROJ 6:

```
#include <proj.h>

main(int argc, char **argv) {
    PJ *P;
    PJ_COORD c, c_out;

    /* NOTE: the use of PROJ strings to describe CRS is strongly discouraged */
    /* in PROJ 6, as PROJ strings are a poor way of describing a CRS, and */
    /* more precise its geodetic datum. */
    /* Use of codes provided by authorities (such as "EPSG:4326", etc...) */
    /* or WKT strings will bring the full power of the "transformation */
    /* engine" used by PROJ to determine the best transformation(s) between */
    /* two CRS. */
    P = proj_create_crs_to_crs(PJ_DEFAULT_CTX,
                               "+proj=longlat +ellps=clrs66",
                               "+proj=merc +ellps=clrk66 +lat_ts=33",
                               NULL);
    if (P==0)
        return 1;

    {
        /* For that particular use case, this is not needed. */
        /* proj_normalize_for_visualization() ensures that the coordinate */
        /* order expected and returned by proj_trans() will be longitude, */
        /* latitude for geographic CRS, and easting, northing for projected */
        /* CRS. If instead of using PROJ strings as above, "EPSG:XXXX" codes */
        /* had been used, this might had been necessary. */
        PJ* P_for_GIS = proj_normalize_for_visualization(PJ_DEFAULT_CTX, P);
        if( 0 == P_for_GIS )  {
            proj_destroy(P);
            return 1;
```

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```
        }
        proj_destroy(P);
        P = P_for_GIS;
    }

    /* For reliable geographic <--> geocentric conversions, z shall not */
    /* be some random value. Also t shall be initialized to HUGE_VAL to */
    /* allow for proper selection of time-dependent operations if one of */
    /* the CRS is dynamic. */
    c.lpzt.z = 0.0;
    c.lpzt.t = HUGE_VAL;

    while (scanf("%lf %lf", &c.lpzt.lam, &c.lpzt.phi) == 2) {
        /* No need to convert to radian */
        c_out = proj_trans(P, PJ_FWD, c);
        printf("%.2f\t%.2f\n", c_out.xy.x, c_out.xy.y);
    }

    proj_destroy(P);

    return 0;
}
```

10.8.2 Function mapping from old to new API

Old API functions	New API functions
pj_fwd	*proj_trans()*
pj_inv	*proj_trans()*
pj_fwd3	*proj_trans()*
pj_inv3	*proj_trans()*
pj_transform	*proj_create_crs_to_crs()* or *proj_create_crs_to_crs_from_pj()* + (proj_normalize_for_visualization() +) *proj_trans()*, *proj_trans_array()* or *proj_trans_generic()*
pj_init	*proj_create()* / *proj_create_crs_to_crs()*
pj_init	*proj_create()* / *proj_create_crs_to_crs()*
pj_free	*proj_destroy()*
pj_is_latlong	proj_get_type()
pj_is_geocent	proj_get_type()
pj_get_def	*proj_pj_info()*
pj_latlong_from_proj	*No direct equivalent*, but can be accomplished by chaining *proj_create()*, proj_crs_get_horizontal_datum() and proj_create_geographic_crs_from_datum()
pj_set_finder	proj_context_set_file_finder()
pj_set_searchpath	proj_context_set_search_paths()
pj_deallocate_grids	*No equivalent*
pj_strerrno	*No equivalent*
pj_get_errno_ref	*proj_errno()*
pj_get_release	*proj_info()*

10.8.3 Backward incompatibilities

Access to the `proj_api.h` is still possible but requires to define the `ACCEPT_USE_OF_DEPRECATED_PROJ_API_H` macro.

The emulation of the now deprecated `+init=epsg:XXXX` syntax in PROJ 6 is not fully compatible with previous versions.

In particular, when used with the `pj_transform()` function, no datum shift term (`towgs84`, `nadgrids`, `geoidgrids`) will be added during the expansion of the `+init=epsg:XXXX` string to `+proj=YYYY ....`. If you still uses `pj_transform()` and want datum shift to be applied, then you need to provide a fully expanded string with appropriate `towgs84`, `nadgrids` or `geoidgrids` terms to `pj_init()`.

To use the `+init=epsg:XXXX` syntax with *`proj_create()`* and then *`proj_create_crs_to_crs()`*, `proj_context_use_proj4_init_rules(ctx, TRUE)` or the `PROJ_USE_PROJ4_INIT_RULES=YES` environment variable must have been previously set. In that context, datum shift will be researched. However they might be different than with PROJ 4 or PROJ 5, since a "late-binding" approach will be used (that is trying to find as much as possible the most direct transformation between the source and target datum), whereas PROJ 4 or PROJ 5 used an "early-binding" approach consisting in always going to EPSG:4326 / WGS 84.

10.8.4 Feedback from downstream projects on the PROJ 6 migration

- PROJ 6 adoption by Spatialite
- On GDA2020, PROJ 6 and QGIS: Lessons learnt and recommendations for handling GDA2020 within geospatial software development

10.9 Version 4 to 5 API Migration

This is a transition guide for developers wanting to migrate their code to use PROJ version 5.

10.9.1 Background

Before we go on, a bit of background is needed. The new API takes a different view of the world than the old because it is needed in order to obtain high accuracy transformations. The old API is constructed in such a way that any transformation between two coordinate reference systems *must* pass through the ill-defined WGS84 reference frame, using it as a hub. The new API does away with this limitation to transformations in PROJ. It is still possible to do that type of transformations but in many cases there will be a better alternative.

The world view represented by the old API is always sufficient if all you care about is meter level accuracy - and in many cases it will provide much higher accuracy than that. But the view that "WGS84 is the *true* foundation of the world, and everything else can be transformed natively to and from WGS84" is inherently flawed.

First and foremost because any time WGS84 is mentioned, you should ask yourself "Which of the six WGS84 realizations are we talking about here?".

Second, because for many (especially legacy) systems, it may not be straightforward to transform to WGS84 (or actually ITRF-something, ETRS-something or NAD-something which appear to be the practical meaning of the term WGS84 in everyday PROJ related work), while centimeter-level accurate transformations may exist between pairs of older systems.

The concept of a hub reference frame ("datum") is not inherently bad, but in many cases you need to handle and select that datum with more care than the old API allows. The primary aim of the new API is to allow just that. And to do that, you must realize that the world is inherently 4 dimensional. You may in many cases assume one or more of the coordinates to be constant, but basically, to obtain geodetic accuracy transformations, you need to work in 4 dimensions.

Now, having described the background for introducing the new API, let's try to show how to use it. First note that in order to go from system A to system B, the old API starts by doing an **inverse** transformation from system A to WGS84, then does a **forward** transformation from WGS84 to system B.

With **cs2cs** being the command line interface to the old API, and **cct** being the same for the new, this example of doing the same thing in both world views will should give an idea of the differences:

```
$ echo 300000 6100000 | cs2cs +proj=utm +zone=33 +ellps=GRS80 +to +proj=utm +zone=32␣
↪+ellps=GRS80
683687.87       6099299.66 0.00


$ echo 300000 6100000 0 0 | cct +proj=pipeline +step +inv +proj=utm +zone=33␣
↪+ellps=GRS80 +step +proj=utm +zone=32 +ellps=GRS80
683687.8667   6099299.6624    0.0000    0.0000
```

Lookout for the `+inv` in the first `+step`, indicating an inverse transform.

10.9.2 Code example

The difference between the old and new API is shown here with a few examples. Below we implement the same program with the two different API's. The program reads input longitude and latitude from the command line and convert them to projected coordinates with the Mercator projection.

We start by writing the program for PROJ v. 4:

```c
#include <proj_api.h>

main(int argc, char **argv) {
    projPJ pj_merc, pj_longlat;
    double x, y;

    if (!(pj_longlat = pj_init_plus("+proj=longlat +ellps=clrk66")) )
        return 1;
    if (!(pj_merc = pj_init_plus("+proj=merc +ellps=clrk66 +lat_ts=33")) )
        return 1;

    while (scanf("%lf %lf", &x, &y) == 2) {
        x *= DEG_TO_RAD; /* longitude */
        y *= DEG_TO_RAD; /* latitude */
        p = pj_transform(pj_longlat, pj_merc, 1, 1, &x, &y, NULL );
        printf("%.2f\t%.2f\n", x, y);
    }

    pj_free(pj_longlat);
    pj_free(pj_merc);

    return 0;
}
```

The same program implemented using PROJ v. 5:

```c
#include <proj.h>
```

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```
main(int argc, char **argv) {
    PJ *P;
    PJ_COORD c;

    P = proj_create(PJ_DEFAULT_CTX, "+proj=merc +ellps=clrk66 +lat_ts=33");
    if (P==0)
        return 1;

    while (scanf("%lf %lf", &c.lp.lam, &c.lp.phi) == 2) {
        c.lp.lam = proj_torad(c.lp.lam);
        c.lp.phi = proj_torad(c.lp.phi);
        c = proj_trans(P, PJ_FWD, c);
        printf("%.2f\t%.2f\n", c.xy.x, c.xy.y);
    }

    proj_destroy(P);
}
```

Looking at the two different programs, there's a few immediate differences that catches the eye. First off, the included header file describing the API has changed from `proj_api.h` to simply `proj.h`. All functions in `proj.h` belongs to the `proj_` namespace.

With the new API also comes new datatypes. E.g. the transformation object `projPJ` which has been changed to a pointer of type `PJ`. This is done to highlight the actual nature of the object, instead of hiding it away behind a typedef. New data types for handling coordinates have also been introduced. In the above example we use the `PJ_COORD`, which is a union of various types. The benefit of this is that it is possible to use the various structs in the union to communicate what state the data is in at different points in the program. For instance as in the above example where the coordinate is read from STDIN as a geodetic coordinate, communicated to the reader of the code by using the `c.lp` struct. After it has been projected we print it to STDOUT by accessing the individual elements in `c.xy` to illustrate that the coordinate is now in projected space. Data types are prefixed with *PJ_*.

The final, and perhaps biggest, change is that the fundamental concept of transformations in PROJ are now handled in a single transformation object (`PJ`) and not by stating the source and destination systems as previously. It is of course still possible to do just that, but the transformation object now captures the whole transformation from source to destination in one. In the example with the old API the source system is described as `+proj=latlon +ellps=clrk66` and the destination system is described as `+proj=merc +ellps=clrk66 +lat_ts=33`. Since the Mercator projection accepts geodetic coordinates as its input, the description of the source in this case is superfluous. We use that to our advantage in the new API and simply state the destination. This is simple at a glance, but is actually a big conceptual change. We are now focused on the path between two systems instead of what the source and destination systems are.

10.9.3 Function mapping from old to new API

Old API functions	New API functions
`pj_fwd`	*proj_trans()*
`pj_inv`	*proj_trans()*
`pj_fwd3`	*proj_trans()*
`pj_inv3`	*proj_trans()*
`pj_transform`	*proj_trans_array()* or *proj_trans_generic()*
`pj_init`	*proj_create()*
`pj_init_plus`	*proj_create()*
`pj_free`	*proj_destroy()*
`pj_is_latlong`	*proj_angular_output()*
`pj_is_geocent`	*proj_angular_output()*
`pj_get_def`	*proj_pj_info()*
`pj_latlong_from_proj`	*No equivalent*
`pj_set_finder`	*No equivalent*
`pj_set_searchpath`	*No equivalent*
`pj_deallocate_grids`	*No equivalent*
`pj_strerrno`	*No equivalent*
`pj_get_errno_ref`	*proj_errno()*
`pj_get_release`	*proj_info()*

The source code for PROJ is maintained in a git repository on GitHub. Additionally, a collection of PROJ-compatible transformation grids are maintained in a separate git repository.

Attention: The `projects.h` header and the functions related to it is considered deprecated from version 5.0.0 and onwards. The header has been removed PROJ in version 6.0.0 released February 1st 2019.

Attention: The nmake build system on Windows is on longer supported in version 6.0.0 on onwards. Use CMake instead.

Attention: The `proj_api.h` header and the functions related to it is considered deprecated from version 5.0.0 and onwards. The header has been removed in version 8.0.0 released March 1st 2021.

Attention: With the introduction of PROJ 5, behavioural changes has been made to existing functionality. Consult *Known differences between versions* for the details.

CHAPTER

ELEVEN

SPECIFICATIONS

PROJ implements a number of extensions to standards, that are described below for the sake of broader interoperability.

11.1 PROJJSON

PROJJSON is a JSON encoding of WKT2:2019 / ISO-19162:2019, which itself implements the model of OGC Topic 2: Referencing by coordinates. Apart from the difference of encodings, the semantics is intended to be exactly the same as WKT2:2019.

PROJJSON is available as input and output of PROJ since PROJ 6.2.

The current version is 0.2.

11.1.1 Schema

A JSON schema of its grammar is available at https://proj.org/schemas/v0.2/projjson.schema.json

11.1.2 History

- v0.2: addition of geoid_model in VerticalCRS object.
- v0.1: initial version for PROJ 6.2

11.1.3 Content

The high level objects are:

- Coordinate Reference Systems (CRS):
  - Common ones:
    - `GeographicCRS`
    - `GeodeticCRS`
    - `ProjectedCRS`
    - `CompoundCRS`
    - `BoundCRS`
  - More esoteric ones:
    - `VerticalCRS`

      * EngineeringCRS
      * TemporalCRS
      * ParametricCRS
      * DerivedGeographicCRS
      * DerivedGeodeticCRS
      * DerivedProjectedCRS
      * DerivedVerticalCRS
      * DerivedEngineeringCRS
      * DerivedTemporalCRS
      * DerivedParametricCRS

- Coordinate operations:
  - Transformation
  - Conversion
  - ConcatenatedOperation
- Others:
  - PrimeMeridian
  - Ellipsoid
  - Datum
  - DatumEnsemble

11.1.4 Examples

11.1.4.1 GeographicCRS

The following invocation

```
projinfo EPSG:4326 -o PROJJSON -q
```

will output:


```
{
    "$schema": "https://proj.org/schemas/v0.1/projjson.schema.json",
    "type": "GeographicCRS",
    "name": "WGS 84",
    "datum": {
        "type": "GeodeticReferenceFrame",
        "name": "World Geodetic System 1984",
        "ellipsoid": {
            "name": "WGS 84",
            "semi_major_axis": 6378137,
            "inverse_flattening": 298.257223563
        }
    },
```


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```
    "coordinate_system": {
        "subtype": "ellipsoidal",
        "axis": [
        {
            "name": "Geodetic latitude",
            "abbreviation": "Lat",
            "direction": "north",
            "unit": "degree"
        },
        {
            "name": "Geodetic longitude",
            "abbreviation": "Lon",
            "direction": "east",
            "unit": "degree"
        }
        ]
    },
    "area": "World",
    "bbox": {
        "south_latitude": -90,
        "west_longitude": -180,
        "north_latitude": 90,
        "east_longitude": 180
    },
    "id": {
        "authority": "EPSG",
        "code": 4326
    }
}
```

11.1.4.2 ProjectedCRS

The following invocation

```
projinfo EPSG:32631 -o PROJJSON -q
```

will output:

```
{
    "$schema": "https://proj.org/schemas/v0.1/projjson.schema.json",
    "type": "ProjectedCRS",
    "name": "WGS 84 / UTM zone 31N",
    "base_crs": {
        "name": "WGS 84",
        "datum": {
            "type": "GeodeticReferenceFrame",
            "name": "World Geodetic System 1984",
            "ellipsoid": {
                "name": "WGS 84",
                "semi_major_axis": 6378137,
                "inverse_flattening": 298.257223563
```

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```
            }
        },
        "coordinate_system": {
            "subtype": "ellipsoidal",
            "axis": [
            {
                "name": "Geodetic latitude",
                "abbreviation": "Lat",
                "direction": "north",
                "unit": "degree"
            },
            {
                "name": "Geodetic longitude",
                "abbreviation": "Lon",
                "direction": "east",
                "unit": "degree"
            }
            ]
        },
        "id": {
            "authority": "EPSG",
            "code": 4326
        }
    },
    "conversion": {
        "name": "UTM zone 31N",
        "method": {
            "name": "Transverse Mercator",
            "id": {
                "authority": "EPSG",
                "code": 9807
            }
        },
        "parameters": [
        {
            "name": "Latitude of natural origin",
            "value": 0,
            "unit": "degree",
            "id": {
            "authority": "EPSG",
            "code": 8801
            }
        },
        {
            "name": "Longitude of natural origin",
            "value": 3,
            "unit": "degree",
            "id": {
            "authority": "EPSG",
            "code": 8802
            }
        },
```

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```
        {
            "name": "Scale factor at natural origin",
            "value": 0.9996,
            "unit": "unity",
            "id": {
            "authority": "EPSG",
            "code": 8805
            }
        },
        {
            "name": "False easting",
            "value": 500000,
            "unit": "metre",
            "id": {
            "authority": "EPSG",
            "code": 8806
            }
        },
        {
            "name": "False northing",
            "value": 0,
            "unit": "metre",
            "id": {
            "authority": "EPSG",
            "code": 8807
            }
        }
        ]
    },
    "coordinate_system": {
        "subtype": "Cartesian",
        "axis": [
        {
            "name": "Easting",
            "abbreviation": "E",
            "direction": "east",
            "unit": "metre"
        },
        {
            "name": "Northing",
            "abbreviation": "N",
            "direction": "north",
            "unit": "metre"
        }
        ]
    },
    "area": "World - N hemisphere - 0°E to 6°E - by country",
    "bbox": {
        "south_latitude": 0,
        "west_longitude": 0,
        "north_latitude": 84,
        "east_longitude": 6
```

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```
    },
    "id": {
        "authority": "EPSG",
        "code": 32631
    }
}
```


11.2 Geodetic TIFF grids (GTG)

New in version 7.0.

11.2.1 Introduction

The Geodetic TIFF grid format has been introduced per *PROJ RFC 4: Remote access to grids and GeoTIFF grids*. It is a profile of the TIFF and GeoTIFF formats that addresses the specific requirements of geodetic grids: horizontal shifts, vertical shifts, velocity grids, etc… It also follows the Cloud Optimized GeoTIFF principles.

Such grids are available on a *CDN of GeoTIFF grids*.

11.2.2 General description

The general principles that guide the following requirements and recommendations are such that files will be properly recognized by PROJ, and also by GDAL which is an easy way to inspect such grid files:

- TIFF 6.0 based (could possibly be BigTIFF without code changes, if we ever need some day to handle grids larger than 4GB)
- GeoTIFF 1.1 for the georeferencing. GeoTIFF 1.1 is a recent standard, compared to the original GeoTIFF 1.0 version, but its backward compatibility is excellent, so that should not cause much trouble to readers that are not official GeoTIFF 1.1 compliant.
- Files hosted on the CDN will use a Geographic 2D CRS for the GeoTIFF GeoKeys. That CRS is intended to be the interpolation CRS as defined in OGC Abstract Specification Topic 2, that is the CRS to which grid values are referred to.

  Given that they will nominally be related to the EPSG dataset, the GeodeticCRSGeoKey will be used to store the EPSG code of the CRS. If the CRS cannot be reliably encoded through that key or other geokeys, the `interpolation_crs_wkt` metadata item detailed afterwards should be used.

  This CRS will be generally the source CRS (for geographic to geographic horizontal shift grids, or geographic to vertical shift grids), but for vertical to vertical CRS adjustment, this will be the geographic CRS to which the grid is referenced. In some very rare cases of geographic to vertical shift grids, the interpolation CRS might be a geographic CRS that is not the same as the source CRS (into which ellipsoidal height are expressed). The only instance we have in mind is for the EPSG:7001 "ETRS89 to NAP height (1)" transformation using the naptrans2008 VDatum-grid which is referenced to Amersfoort EPSG:4289 instead of ETRS89…

  On the reading side, PROJ will ignore that information: the CRS is already stored in the source_crs or interpolation_crs column of the grid_transformation table.

  For geographic to vertical shift files (geoid models), the GeoTIFF 1.1 convention will be used to store the value of the VerticalGeoKey So a geoid model that apply to WGS 84 EPSG:4979 will have GeodeticCRSGeoKey = 4326 and VerticalGeoKey = 4979.

- Files hosted on the CDN will use the GeoTIFF defined ModelTiepointTag and ModelPixelScaleTag TIFF tags to store the coordinates of the upper-left pixel and the resolution of the pixels. On the reading side, they will be required and ModelTransformationTag will be ignored.

Note: Regarding anti-meridian handling, a variety of possibilities exist. We do not attempt to standardize this and files hosted on the CDN will use a georeferencing close to the original data producer. For example, NOAA vertical grids that apply to Conterminous USA might even have a top-left longitude beyond 180 (for consistency with Alaska grids, whose origin is < 180) Anti-meridian handling in PROJ has probably issues. This RFC does not attempt to address them in particular, as they are believed to be orthogonal to the topics it covers, and being mostly implementation issues.

- Files hosted on the CDN will use the GTRasterTypeGeoKey = PixelIsPoint convention. This is the convention used by most existing grid formats currently. Note that GDAL typically use a PixelIsArea convention (but can handle both conventions), so the georeferencing it displays when opening a .gsb or .gtx file appears to have a half-pixel shift regarding to the coordinates stored in the original grid file. On the reading side, PROJ will accept both conventions (for equivalent georeferencing, the value of the origin in a PixelIsArea convention is shifted by a half-pixel towards the upper-left direction). Unspecified behavior if this GeoKey is absent.
- Files hosted on the CDN will be tiled, presumably with 256x256 tiles (small grids that are smaller than 256x256 will use a single strip). On the reading side, PROJ will accept TIFF files with any strip or tile organization. Tiling is expressed by specifying the TileWidth, TileHeight, TileOffsets and TileByteCounts tags. Strip organization is expressed by specifying the RowsPerStrip, StripByteCounts and StripOffsets tags.
- Files hosted on the CDN will use Compression = DEFLATE or LZW (to be determined, possibly with Predictor = 2 or 3) On the reading side, PROJ will accept TIFF files with any compression method (appropriate for the data types and PhotometricInterpretation considered) supported by the libtiff build used by PROJ. Of course uncompressed files will be supported.
- Files hosted on the CDN will use little-endian byte ordering. On the reading side, libtiff will transparently handle both little-endian and big-endian ordering.
- Files hosted on the CDN will use PlanarConfiguration=Separate. The tools described in a later section will order blocks so that blocks needed for a given location are close to each other. On the reading side, PROJ will handle also PlanarConfiguration=Contig.
- Files hosted on the CDN will generally use Float32 (BitsPerSample=32 and SampleFormat=IEEEFP) Files may be created using Signed Int 16 (BitsPerSample =16 and SampleFormat = INT), Unsigned Int 16 (BitsPerSample=16 and SampleFormat=UINT), Signed Int 32 or Unsigned Int 32 generally with an associate scale/offset. On the reading side, only those three data types will be supported as well.
- Files hosted on the CDN will have a PhotometricInterpretation = MinIsBlack. It will be assumed, and ignored on the reading side.
- Files hosted on the CDN will nominally have:
  - SamplesPerPixel = 2 for horizontal shift grid, with the first sample being the longitude offset and the second sample being the latitude offset.
  - SamplesPerPixel = 1 for vertical shift grids.
  - SamplesPerPixel = 3 for deformation models combining horizontal and vertical adjustments.

  And even for the current identified needs of horizontal or vertical shifts, more samples may be present (to indicate for example uncertainties), but will be ignored by PROJ.

  The ExtraSamples tag should be set to a value of SamplesPerPixel - 1 (given the rules that apply for PhotometricInterpretation = MinIsBlack)

- The ImageDescription tag may be used to convey extra information about the name, provenance, version and last updated date of the grid. Will be set when possible for files hosted on the CDN. Ignored by PROJ.
- The Copyright tag may be used to convey extra information about the copyright and license of the grid. Will be set when possible for files hosted on the CDN. Ignored by PROJ.
- The DateTime tag may be used to convey the date at which the file has been created or converted. In case of a file conversion, for example from NTv2, this will be the date at which the conversion has been performed. The `ImageDescription` tag however will contain the latest of the CREATED or UPDATED fields from the NTv2 file. Will be set when possible for files hosted on the CDN. Ignored by PROJ.
- Files hosted on the CDN will use the GDAL_NODATA tag to encode the value of the nodata / missing value, when it applies to the grid.

  If offset and/or scaling is used, the nodata value corresponds to the raw value, before applying offset and scaling. The value found in this tag, if present, will be honoured (to the extent to which current PROJ code makes use of nodata). For floating point data, writers are strongly discouraged to use non-finite values (+/- infinity, NaN) of nodata to maximimize interoperability. The GDAL_NODATA value applies to all samples of a given TIFF IFD.
- Files hosted on the CDN will use the GDAL_METADATA tag to encode extra metadata not supported by baseline or extended TIFF.
  - The root XML node should be `GDALMetadata`
  - Zero, one or several child XML nodes `Item` may be present.
  - A Item should have a `name` attribute, and a child text node with its value. `role` and `sample` attributes may be present for attributes that have a special semantics (recognized by GDAL). The value of *sample* should be a integer value between 0 and number_of_samples - 1.
  - Scale and offset to convert integer raw values to floating point values may be expressed with XML *Item* elements whose name attribute is respectively `SCALE` and `OFFSET`, and their `role` attribute is respectively `scale` and `offset`. The decoded value will be: {offset} + {scale} * raw_value_from_geotiff_file

    For a offset value of 1 and scaling of 2, the following payload should be stored:

    ```
    <GDALMetadata>
        <Item name="OFFSET" sample="0" role="offset">1</Item>
        <Item name="SCALE" sample="0" role="scale">2</Item>
    </GDALMetadata>
    ```
  - The type of the grid must be specified with a *Item* whose `name` is set to `TYPE`.

    Values recognized by PROJ currently are:
    * `HORIZONTAL_OFFSET`: implies the presence of at least two samples. The first sample must contain the latitude offset and the second sample must contain the longitude offset. Corresponds to PROJ *Horizontal grid shift* method.
    * `VERTICAL_OFFSET_GEOGRAPHIC_TO_VERTICAL`: implies the presence of at least one sample. The first sample must contain the vertical adjustment. Must be used when the source/interpolation CRS is a Geographic CRS and the target CRS a Vertical CRS. Corresponds to PROJ *Vertical grid shift* method.
    * `VERTICAL_OFFSET_VERTICAL_TO_VERTICAL`: implies the presence of at least one sample. The first sample must contain the vertical adjustment. Must be used when the source and target CRS are Vertical CRS. Corresponds to PROJ *Vertical grid shift* method.
    * `GEOCENTRIC_TRANSLATION`: implies the presence of at least 3 samples. The first 3 samples must be respectively the geocentric adjustments along the X, Y and Z axis. Must be used when the source and target CRS are geocentric CRS. The interpolation CRS must be a geographic CRS. Corresponds to PROJ *Geocentric grid shift* method.

    * `VELOCITY`: implies the presence of at least 3 samples. The first 3 samples must be respectively the velocities along the E(ast), N(orth), U(p) axis in the local topocentric coordinate system. Corresponds to PROJ *Kinematic datum shifting utilizing a deformation model* method.
    * `DEFORMATION_MODEL`: implies the presence of the `DISPLACEMENT_TYPE` and `UNCERTAINTY_TYPE` metadata items. Corresponds to PROJ *Multi-component time-based deformation model* method.

  For example:

```
<Item name="TYPE">HORIZONTAL_OFFSET</Item>
```

- The description of each sample must be specified with a Item whose `name` attribute is set to `DESCRIPTION` and `role` attribute to `description`.

  Values recognized by PROJ for this Item are currently:

    * `latitude_offset`: valid for TYPE=HORIZONTAL_OFFSET. Sample values should be the value to add a latitude expressed in the CRS encoded in the GeoKeys to obtain a latitude value expressed in the target CRS.
    * `longitude_offset`: valid for TYPE=HORIZONTAL_OFFSET. Sample values should be the value to add a longitude expressed in the CRS encoded in the GeoKeys to obtain a longitude value expressed in the target CRS.
    * `geoid_undulation`: valid for TYPE=VERTICAL_OFFSET_GEOGRAPHIC_TO_VERTICAL. For a source CRS being a geographic CRS and a target CRS being a vertical CRS, sample values should be the value to add to a geoid-related height (that is expressed in the target CRS) to get an ellipsoidal height (that is expressed in the source CRS), also called the geoid undulation. Note the possible confusion related to what is the source CRS and target CRS and the semantics of the value stored (to convert from the source to the target, one must subtract the value contained in the grid). This is the convention used by the EPSG:9665 operation method.
    * `vertical_offset`: valid for TYPE=VERTICAL_OFFSET_VERTICAL_TO_VERTICAL. For a source and target CRS being vertical CRS, sample values should be the value to add to an elevation expressed in the source CRS to obtain a longitude value expressed in the target CRS.
    * `x_translation` / `y_translation` / `z_translation`: valid for TYPE=GEOCENTRIC_TRANSLATION. Sample values should be the value to add to the input geocentric coordinates expressed in the source CRS to geocentric coordinates expressed in the target CRS.
    * `east_velocity` / `north_velocity` / `up_velocity`: valid for TYPE=VELOCITY. Sample values should be the velocity in a linear/time unit in a ENU local topocentric coordinate system.
    * `east_offset` / `north_offset` / `vertical_offset`: valid for TYPE=DEFORMATION_MODEL. For east_offset and north_offset, the unit might be degree or metre. For vertical_offset, the unit must be metre.

  For example:

```
<Item name="DESCRIPTION" sample="0" role="description">latitude_offset</Item>
<Item name="DESCRIPTION" sample="1" role="description">longitude_offset</Item>
```

  Other values may be used (not used by PROJ):

    * `latitude_offset_accuracy`: valid for TYPE=HORIZONTAL_OFFSET. Sample values should be the accuracy of corresponding latitude_offset samples. Generally in metre (if converted from NTv2)
    * `longitude_offset_accuracy`: valid for TYPE=HORIZONTAL_OFFSET. Sample values should be the accuracy of corresponding longitude_offset samples. Generally in metre (if converted from NTv2)

- The sign convention for the values of the `longitude_offset` channel should be indicated with an Item named `positive_value` whose value can be `west` or `east`. NTv2 products originally use a `west` convention, but when converting from them to GeoTIFF, the sign of those samples will be inverted so they use a more natural `east` convention. If this item is absent, the default value is `east`.
- The unit of the values stored in the grid must be specified for each sample through an Item of name `UNITTYPE` and role `unittype` Valid values should be the name of entries from the EPSG `unitofmeasure` table. To maximize interoperability, writers are strongly encouraged to limit themselves to the following values:

  For linear units:

  * `metre` (default value assumed if absent for vertical shift grid files, and value used for files stored on PROJ CDN)
  * `US survey foot`

  For angular units:

  * `degree`
  * `arc-second` (default value assumed if absent for longitude and latitude offset samples of horizontal shift grid files, and value used for files stored on PROJ CDN)

  For velocity units:

  * `millimetres per year`

  The longitude and latitude offset samples should use the same unit. The geocentric translation samples should use the same unit. The velocity samples should use the same unit.

  Example:

```
<Item name="UNITTYPE" sample="0" role="unittype">arc-second</Item>
<Item name="UNITTYPE" sample="1" role="unittype">arc-second</Item>
```

- For TYPE=DEFORMATION_MODEL, the type of the displacement must be specified with a *Item* whose `name` is set to `DISPLACEMENT_TYPE`.

  The accepted values are: `HORIZONTAL`, `VERTICAL`, `3D` or `NONE`
- For TYPE=DEFORMATION_MODEL, the type of the uncertainty must be specified with a *Item* whose `name` is set to `UNCERTAINTY_TYPE`.

  The accepted values are: `HORIZONTAL`, `VERTICAL`, `3D` or `NONE`
- The `target_crs_epsg_code` metadata item should be present. For a horizontal shift grid, this is the EPSG code of the target geographic CRS. For a vertical shift grid, this is the EPSG code of a the target vertical CRS. If the target CRS has no associated EPSG code, `target_crs_wkt` must be used. Ignored by PROJ currently.
- The `target_crs_wkt` metadata item must be present if the `target_crs_epsg_code` cannot be used. Its value should be a valid WKT string according to WKT:2015 or WKT:2019 Ignored by PROJ currently.
- The `source_crs_epsg_code` metadata item must be present if the source and interpolation CRS are not the same (typical use case is vertical CRS to vertical CRS transformation), because the GeoKeys encode the interpolation CRS and not the source CRS. If the source CRS has no associated EPSG code, `source_crs_wkt` must be used. Ignored by PROJ currently.
- The `source_crs_wkt` metadata item must be present if the `source_crs_epsg_code` cannot be used. Its value should be a valid WKT string according to WKT:2015 or WKT:2019. Ignored by PROJ currently.

- The `interpolation_crs_wkt` metadata item may be present if the GeoKeys cannot be used to express reliably the interpolation CRS. Its value should be a valid WKT string according to WKT:2015 or WKT:2019. Ignored by PROJ currently.
- The `recommended_interpolation_method` metadata item may be present to describe the method to use to interpolation values at locations not coincident with nodes stored in the grid file. Potential values: `bilinear`, `bicubic`. Ignored by PROJ currently.
- The `area_of_use` metadata item can be used to indicate plain text information about the area of use of the grid (like "USA - Wisconsin"). In case of multiple subgrids, it should be set only on the first one, but applies to the whole set of grids, not just the first one.
- The `grid_name` metadata item should be present if there are subgrids for this grid (that is grids whose extent is contained in the extent of this grid), or if this is a subgrid. It is intended to be a relatively short identifier Will be ignored by PROJ (this information can be inferred by the grids extent)
- The `parent_grid_name` metadata item should be present if this is a subgrid and its value should be equal to the parent's `grid_name` Will be ignored by PROJ (this information can be inferred by the grids extent)
- The `number_of_nested_grids` metadata item should be present if there are subgrids for this grid (that is grids whose extent is contained in the extent of this grid). Will be ignored by PROJ (this information can be inferred by the grids extent)

11.2.3 Example

https://github.com/OSGeo/PROJ-data/blob/master/fr_ign/fr_ign_ntf_r93.tif has been converted from https://github.com/OSGeo/proj-datumgrid/blob/master/ntf_r93.gsb with https://github.com/OSGeo/PROJ-data/blob/master/grid_tools/ntv2_to_gtiff.py

```
$ tiffinfo ntf_r93.tif

TIFF Directory at offset 0x4e (78)
Image Width: 156 Image Length: 111
Bits/Sample: 32
Sample Format: IEEE floating point
Compression Scheme: AdobeDeflate
Photometric Interpretation: min-is-black
Extra Samples: 3<unspecified, unspecified, unspecified>
Samples/Pixel: 4
Rows/Strip: 111
Planar Configuration: separate image planes
ImageDescription: NTF (EPSG:4275) to RGF93 (EPSG:4171). Converted from ntf_r93.gsb␣
↪(version IGN07_01, last updated on 2007-10-31)
DateTime: 2019:12:09 00:00:00
Copyright: Derived from work by IGN France. Open License https://www.etalab.gouv.fr/wp-
↪content/uploads/2014/05/Open_Licence.pdf
Tag 33550: 0.100000,0.100000,0.000000
Tag 33922: 0.000000,0.000000,0.000000,-5.500000,52.000000,0.000000
Tag 34735: 1,1,1,3,1024,0,1,2,1025,0,1,2,2048,0,1,4275
Tag 42112: <GDALMetadata>
<Item name="grid_name">FRANCE</Item>
<Item name="target_crs_epsg_code">4171</Item>
<Item name="TYPE">HORIZONTAL_OFFSET</Item>
<Item name="UNITTYPE" sample="0" role="unittype">arc-second</Item>
<Item name="DESCRIPTION" sample="0" role="description">latitude_offset</Item>
```

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```
<Item name="positive_value" sample="1">east</Item>
<Item name="UNITTYPE" sample="1" role="unittype">arc-second</Item>
<Item name="DESCRIPTION" sample="1" role="description">longitude_offset</Item>
<Item name="UNITTYPE" sample="2" role="unittype">arc-second</Item>
<Item name="DESCRIPTION" sample="2" role="description">latitude_offset_accuracy</Item>
<Item name="UNITTYPE" sample="3" role="unittype">arc-second</Item>
<Item name="DESCRIPTION" sample="3" role="description">longitude_offset_accuracy</Item>
</GDALMetadata>

Predictor: floating point predictor 3 (0x3)
```

```
$ listgeo ntf_r93.tif

Geotiff_Information:
    Version: 1
    Key_Revision: 1.1
    Tagged_Information:
        ModelTiepointTag (2,3):
            0                0                0
            -5.5             52               0
        ModelPixelScaleTag (1,3):
            0.1              0.1              0
        End_Of_Tags.
    Keyed_Information:
        GTModelTypeGeoKey (Short,1): ModelTypeGeographic
        GTRasterTypeGeoKey (Short,1): RasterPixelIsPoint
        GeodeticCRSGeoKey (Short,1): Code-4275 (NTF)
        End_Of_Keys.
    End_Of_Geotiff.

GCS: 4275/NTF
Datum: 6275/Nouvelle Triangulation Francaise
Ellipsoid: 7011/Clarke 1880 (IGN) (6378249.20,6356515.00)
Prime Meridian: 8901/Greenwich (0.000000/  0d 0' 0.00"E)
Projection Linear Units: User-Defined (1.000000m)

Corner Coordinates:
Upper Left    (  5d30' 0.00"W, 52d 0' 0.00"N)
Lower Left    (  5d30' 0.00"W, 40d54' 0.00"N)
Upper Right   ( 10d 6' 0.00"E, 52d 0' 0.00"N)
Lower Right   ( 10d 6' 0.00"E, 40d54' 0.00"N)
Center        (  2d18' 0.00"E, 46d27' 0.00"N)
```

```
$ gdalinfo ntf_r93.tif

Driver: GTiff/GeoTIFF
Files: ntf_r93.tif
Size is 156, 111
Coordinate System is:
GEOGCRS["NTF",
    DATUM["Nouvelle Triangulation Francaise",
```

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```
        ELLIPSOID["Clarke 1880 (IGN)",6378249.2,293.466021293627,
            LENGTHUNIT["metre",1]]],
    PRIMEM["Greenwich",0,
        ANGLEUNIT["degree",0.0174532925199433]],
    CS[ellipsoidal,2],
        AXIS["geodetic latitude (Lat)",north,
            ORDER[1],
            ANGLEUNIT["degree",0.0174532925199433]],
        AXIS["geodetic longitude (Lon)",east,
            ORDER[2],
            ANGLEUNIT["degree",0.0174532925199433]],
    ID["EPSG",4275]]
Data axis to CRS axis mapping: 2,1
Origin = (-5.550000000000000,52.049999999999997)
Pixel Size = (0.100000000000000,-0.100000000000000)
Metadata:
  AREA_OR_POINT=Point
  grid_name=FRANCE
  target_crs_epsg_code=4171
  TIFFTAG_DATETIME=2019:12:09 00:00:00
  TIFFTAG_IMAGEDESCRIPTION=NTF (EPSG:4275) to RGF93 (EPSG:4171). Converted from ntf_r93.
↪gsb (version IGN07_01, last updated on 2007-10-31)
  TYPE=HORIZONTAL_OFFSET
Image Structure Metadata:
  COMPRESSION=DEFLATE
  INTERLEAVE=BAND
Corner Coordinates:
Upper Left  (  -5.5500000,  52.0500000) (  5d33' 0.00"W, 52d 3' 0.00"N)
Lower Left  (  -5.5500000,  40.9500000) (  5d33' 0.00"W, 40d57' 0.00"N)
Upper Right (  10.0500000,  52.0500000) ( 10d 3' 0.00"E, 52d 3' 0.00"N)
Lower Right (  10.0500000,  40.9500000) ( 10d 3' 0.00"E, 40d57' 0.00"N)
Center      (   2.2500000,  46.5000000) (  2d15' 0.00"E, 46d30' 0.00"N)
Band 1 Block=156x111 Type=Float32, ColorInterp=Gray
  Description = latitude_offset
  Unit Type: arc-second
Band 2 Block=156x111 Type=Float32, ColorInterp=Undefined
  Description = longitude_offset
  Unit Type: arc-second
  Metadata:
    positive_value=east
Band 3 Block=156x111 Type=Float32, ColorInterp=Undefined
  Description = latitude_offset_accuracy
  Unit Type: arc-second
Band 4 Block=156x111 Type=Float32, ColorInterp=Undefined
  Description = longitude_offset_accuracy
  Unit Type: arc-second
```

11.2.4 Multi-grid storage

Formats like NTv2 can contain multiple subgrids. This can be transposed to TIFF by using several IFD chained together with the last 4 bytes (or 8 bytes for BigTIFF) of an IFD pointing to the offset of the next one.

The first IFD should have a full description according to the *General description*. Subsequent IFD might have a more compact description, omitting for example, CRS information if it is identical to the main IFD (which should be the case for the currently envisionned use cases), or Copyright / ImageDescription metadata items.

Each IFD will have its NewSubfileType tag set to 0.

If a low-resolution grid is available, it should be put before subgrids of higher-resolution in the chain of IFD linking. On reading, PROJ will use the value from the highest-resolution grid that contains the point of interest.

For efficient reading from the network, files hosted on the CDN will use a layout similar to the one described in the low level paragraph of the Cloud Optimized GeoTIFF GDAL driver page

The layout for a file converted from NTv2 will for example be:

- TIFF/BigTIFF header/signature and pointer to first IFD (Image File Directory)
- “ghost area” indicating the generated process
- IFD of the first grid, followed by TIFF tags values, excluding the TileOffsets and TileByteCounts arrays
- …
- IFD of the last grid, followed by TIFF tags values, excluding the GDAL_METADATA tag, TileOffsets and TileByteCounts arrays
- TileOffsets and TileByteCounts arrays for first IFD
- …
- TileOffsets and TileByteCounts arrays for last IFD
- Value of GDAL_METADATA tag for IFDs following the first IFD
- First IFD: Data corresponding to latitude offset of Block_0_0
- First IFD: Data corresponding to longitude offset of Block_0_0
- First IFD: Data corresponding to latitude offset of Block_0_1
- First IFD: Data corresponding to longitude offset of Block_0_1
- …
- First IFD: Data corresponding to latitude offset of Block_n_m
- First IFD: Data corresponding to longitude offset of Block_n_m
- …
- Last IFD: Data corresponding to latitude offset of Block_0_0
- Last IFD: Data corresponding to longitude offset of Block_0_0
- Last IFD: Data corresponding to latitude offset of Block_0_1
- Last IFD: Data corresponding to longitude offset of Block_0_1
- …
- Last IFD: Data corresponding to latitude offset of Block_n_m
- Last IFD: Data corresponding to longitude offset of Block_n_m

If longitude_offset_accuracy and latitude_offset_accuracy are present, this will be followed by:

- First IFD: Data corresponding to latitude offset accuracy of Block_0_0
- First IFD: Data corresponding to longitude offset accuracy of Block_0_0
- …
- First IFD: Data corresponding to latitude offset accuracy of Block_n_m
- First IFD: Data corresponding to longitude offset accuracy of Block_n_m
- …
- Last IFD: Data corresponding to latitude offset accuracy of Block_0_0
- Last IFD: Data corresponding to longitude offset accuracy of Block_0_0
- …
- Last IFD: Data corresponding to latitude offset accuracy of Block_n_m
- Last IFD: Data corresponding to longitude offset accuracy of Block_n_m

Note: TIFF has another mechanism to link IFDs, the SubIFD tag. This potentially enables to define a hierarchy of IFDs (similar to HDF5 groups). There is no support for that in most TIFF-using software, notably GDAL, and no compelling need to have a nested hierarchy, so "flat" organization with the standard IFD chaining mechanism is adopted.

11.2.5 Examples of multi-grid dataset

https://github.com/OSGeo/PROJ-data/blob/master/au_icsm/au_icsm_GDA94_GDA2020_conformal.tif has been converted from https://github.com/OSGeo/proj-datumgrid/blob/master/oceania/GDA94_GDA2020_conformal.gsb with https://github.com/OSGeo/PROJ-data/blob/master/grid_tools/ntv2_to_gtiff.py

It contains 5 subgrids. All essential metadata to list the subgrids and their georeferencing is contained within the first 3 KB of the file.

The file size is 4.8 MB using DEFLATE compression and floating-point predictor. To be compared with the 83 MB of the original .gsb file.

https://github.com/OSGeo/PROJ-data/blob/master/ca_nrc/ca_nrc_ntv2_0.tif has been converted from https://github.com/OSGeo/proj-datumgrid/blob/master/north-america/ntv2_0.gsb

It contains 114 subgrids. All essential metadata to list the subgrids and their georeferencing is contained within the first 40 KB of the file.

CHAPTER

TWELVE

COMMUNITY

The PROJ community is what makes the software stand out from its competitors. PROJ is used and developed by group of very enthusiastic, knowledgeable and friendly people. Whether you are a first time user of PROJ or a long-time contributor the community is always very welcoming.

12.1 Communication channels

12.1.1 Mailing list

Users and developers of the library are using the mailing list to discuss all things related to PROJ. The mailing list is the primary forum for asking for help with use of PROJ. The mailing list is also used for announcements, discussions about the development of the library and from time to time interesting discussions on geodesy appear as well. You are more than welcome to join in on the discussions!

The PROJ mailing list can be found at https://lists.osgeo.org/mailman/listinfo/proj

12.1.2 GitHub

GitHub is the development platform we use for collaborating on the PROJ code. We use GitHub to keep track of the changes in the code and to index bug reports and feature requests. We are happy to take contributions in any form, either as code, bug reports, documentation or feature requests. See *Contributing* for more info on how you can help improve PROJ.

The PROJ GitHub page can be found at https://github.com/OSGeo/PROJ

Note: The issue tracker on GitHub is only meant to keep track of bugs, feature request and other things related to the development of PROJ. Please ask your questions about the use of PROJ on the mailing list instead.

12.1.3 Gitter

Gitter is the instant messaging alternative to the mailing list. PROJ has a room under the OSGeo organization. Most of the core developers stop by from time to time for an informal chat. You are more than welcome to join the discussion.

The Gitter room can be found at https://gitter.im/OSGeo/proj.4

12.2 Contributing

PROJ has a wide and varied user base. Some are highly skilled geodesists with a deep knowledge of map projections and reference systems, some are GIS software developers and others are GIS users. All users, regardless of the profession or skill level, has the ability to contribute to PROJ. Here's a few suggestion on how:

- Help PROJ-users that is less experienced than yourself.
- Write a bug report
- Request a new feature
- Write documentation for your favorite map projection
- Fix a bug
- Implement a new feature

In the following sections you can find some guidelines on how to contribute. As PROJ is managed on GitHub most contributions require that you have a GitHub account. Familiarity with issues and the GitHub Flow is an advantage.

12.2.1 Help a fellow PROJ user

The main forum for support for PROJ is the mailing list. You can subscribe to the mailing list here and read the archive here.

If you have questions about the usage of PROJ the mailing list is also the place to go. Please *do not* use the GitHub issue tracker as a support forum. Your question is much more likely to be answered on the mailing list, as many more people follow that than the issue tracker.

12.2.2 Adding bug reports

Bug reports are handled in the issue tracker on PROJ's home on GitHub. Writing a good bug report is not easy. But fixing a poorly documented bug is not easy either, so please put in the effort it takes to create a thorough bug report.

A good bug report includes at least:

- A title that quickly explains the problem
- A description of the problem and how it can be reproduced
- Version of PROJ being used
- Version numbers of any other relevant software being used, e.g. operating system
- A description of what already has been done to solve the problem

The more information that is given up front, the more likely it is that a developer will find interest in solving the problem. You will probably get follow-up questions after submitting a bug report. Please answer them in a timely manner if you have an interest in getting the issue solved.

Finally, please only submit bug reports that are actually related to PROJ. If the issue materializes in software that uses PROJ it is likely a problem with that particular software. Make sure that it actually is a PROJ problem before you submit an issue. If you can reproduce the problem only by using tools from PROJ it is definitely a problem with PROJ.

12.2.3 Feature requests

Got an idea for a new feature in PROJ? Submit a thorough description of the new feature in the issue tracker. Please include any technical documents that can help the developer make the new feature a reality. An example of this could be a publicly available academic paper that describes a new projection. Also, including a numerical test case will make it much easier to verify that an implementation of your requested feature actually works as you expect.

Note that not all feature requests are accepted.

12.2.4 Write documentation

PROJ is in dire need of better documentation. Any contributions of documentation are greatly appreciated. The PROJ documentation is available on proj.org. The website is generated with Sphinx. Contributions to the documentation should be made as Pull Requests on GitHub.

If you intend to document one of PROJ's supported projections please use the *Mercator projection* as a template.

12.2.5 Code contributions

See *Code contributions*

12.2.5.1 Legalese

Committers are the front line gatekeepers to keep the code base clear of improperly contributed code. It is important to the PROJ users, developers and the OSGeo foundation to avoid contributing any code to the project without it being clearly licensed under the project license.

Generally speaking the key issues are that those providing code to be included in the repository understand that the code will be released under the MIT/X license, and that the person providing the code has the right to contribute the code. For the committer themselves understanding about the license is hopefully clear. For other contributors, the committer should verify the understanding unless the committer is very comfortable that the contributor understands the license (for instance frequent contributors).

If the contribution was developed on behalf of an employer (on work time, as part of a work project, etc) then it is important that an appropriate representative of the employer understand that the code will be contributed under the MIT/X license. The arrangement should be cleared with an authorized supervisor/manager, etc.

The code should be developed by the contributor, or the code should be from a source which can be rightfully contributed such as from the public domain, or from an open source project under a compatible license.

All unusual situations need to be discussed and/or documented.

Committers should adhere to the following guidelines, and may be personally legally liable for improperly contributing code to the source repository:

- Make sure the contributor (and possibly employer) is aware of the contribution terms.
- Code coming from a source other than the contributor (such as adapted from another project) should be clearly marked as to the original source, copyright holders, license terms and so forth. This information can be in the file headers, but should also be added to the project licensing file if not exactly matching normal project licensing (COPYING).
- Existing copyright headers and license text should never be stripped from a file. If a copyright holder wishes to give up copyright they must do so in writing to the foundation before copyright messages are removed. If license terms are changed it has to be by agreement (written in email is ok) of the copyright holders.
- Code with licenses requiring credit, or disclosure to users should be added to COPYING.

- When substantial contributions are added to a file (such as substantial patches) the author/contributor should be added to the list of copyright holders for the file.
- If there is uncertainty about whether a change is proper to contribute to the code base, please seek more information from the project steering committee, or the foundation legal counsel.

12.2.6 Additional Resources

- General GitHub documentation
- GitHub pull request documentation

12.2.7 Acknowledgements

The *code contribution* section of this CONTRIBUTING file is inspired by PDAL's and the *legalese* section is modified from GDAL committer guidelines

12.3 Guidelines for PROJ code contributors

This is a guide for PROJ, casual or regular, code contributors.

12.3.1 Code contributions.

Code contributions can be either bug fixes or new features. The process is the same for both, so they will be discussed together in this section.

12.3.1.1 Making Changes

- Create a topic branch from where you want to base your work.
- You usually should base your topic branch off of the master branch.
- To quickly create a topic branch: `git checkout -b my-topic-branch`
- Make commits of logical units.
- Check for unnecessary whitespace with `git diff --check` before committing.
- Make sure your commit messages are in the proper format.
- Make sure you have added the necessary tests for your changes.
- Make sure that all tests pass

12.3.1.2 Submitting Changes

- Push your changes to a topic branch in your fork of the repository.
- Submit a pull request to the PROJ repository in the OSGeo organization.
- If your pull request fixes/references an issue, include that issue number in the pull request. For example:

```
Wiz the bang

Fixes #123.
```

- PROJ developers will look at your patch and take an appropriate action.

12.3.1.3 Coding conventions

Programming language

PROJ was originally developed in ANSI C. Today PROJ is mostly developed in C++11, with a few parts of the code base still being C. Most of the older parts of the code base is effectively C with a few modifications so that it compiles better as C++.

Coding style

The parts of the code base that has started its life as C++ is formatted with `clang-format` using the script `scripts/reformat_cpp.sh`. This is mostly contained to the code in *src/iso19111/* but a few other *.cpp*-files are covered as well.

For the rest of the code base, which has its origin in C, we don't enforce any particular coding style, but please try to keep it as simple as possible. If improving existing code, please try to conform with the style of the locally surrounding code.

Whitespace

Throughout the PROJ code base you will see differing whitespace use. The general rule is to keep whitespace in whatever form it is in the file you are currently editing. If the file has a mix of tabs and space please convert the tabs to space in a separate commit before making any other changes. This makes it a lot easier to see the changes in diffs when evaluating the changed code. New files should use spaces as whitespace.

12.3.2 Tools

12.3.2.1 Reformatting C++ code

The script in `scripts/reformat_cpp.sh` will reformat C++ code in accordance to the project preference.

If you are writing a new `.cpp`-file it should be added to the list in the reformatting script.

12.3.2.2 cppcheck static analyzer

You can run locally `scripts/cppcheck.sh` that is a wrapper script around the cppcheck utility. This tool is used as part of the quality control of the code.

cppcheck can have false positives. In general, it is preferable to rework the code a bit to make it more 'obvious' and avoid those false positives. When not possible, you can add a comment in the code like

```
/* cppcheck-suppress duplicateBreak */
```

in the preceding line. Replace duplicateBreak with the actual name of the violated rule emitted by cppcheck.

12.3.2.3 CLang Static Analyzer (CSA)

CSA is run by the `travis/csa` build configuration. You may also run it locally.

Preliminary step: install clang. For example:

```
wget http://releases.llvm.org/6.0.0/clang+llvm-6.0.0-x86_64-linux-gnu-ubuntu-16.04.tar.xz
tar xJf clang+llvm-6.0.0-x86_64-linux-gnu-ubuntu-16.04.tar.xz
mv clang+llvm-6.0.0-x86_64-linux-gnu-ubuntu-16.04 clang+llvm-6
```

Run configure under the scan-build utility of clang:

```
./clang+llvm-6/bin/scan-build ./configure
```

Build under scan-build:

```
./clang+llvm-6/bin/scan-build make [-j8]
```

If CSA finds errors, they will be emitted during the build. And in which case, at the end of the build process, scan-build will emit a warning message indicating errors have been found and how to display the error report. This is with something like

```
./clang+llvm-6/bin/scan-view /tmp/scan-build-2018-03-15-121416-17476-1
```

This will open a web browser with the interactive report.

CSA may also have false positives. In general, this happens when the code is non-trivial / makes assumptions that hard to check at first sight. You will need to add extra checks or rework it a bit to make it more "obvious" for CSA. This will also help humans reading your code !

12.3.2.4 Typo detection and fixes

Run `scripts/fix_typos.sh`

12.3.2.5 Include What You Use (IWYU)

Managing C includes is a pain. IWYU makes updating headers a bit easier. IWYU scans the code for functions that are called and makes sure that the headers for all those functions are present and in sorted order. However, you cannot blindly apply IWYU to PROJ. It does not understand ifdefs, other platforms, or the order requirements of PROJ internal headers. So the way to use it is to run it on a copy of the source and merge in only the changes that make sense. Additions of standard headers should always be safe to merge. The rest require careful evaluation. See the IWYU documentation for motivation and details.

IWYU docs

12.4 Code of Conduct

The PROJ project has adopted the Contributor Covenant Code of Conduct. Everyone who participates in the PROJ community is expected to follow the code of conduct as written below.

12.4.1 Our Pledge

In the interest of fostering an open and welcoming environment, we as contributors and maintainers pledge to make participation in our project and our community a harassment-free experience for everyone, regardless of age, body size, disability, ethnicity, sex characteristics, gender identity and expression, level of experience, education, socio-economic status, nationality, personal appearance, race, religion, or sexual identity and orientation.

12.4.2 Our Standards

Examples of behavior that contributes to creating a positive environment include:

- Using welcoming and inclusive language
- Being respectful of differing viewpoints and experiences
- Gracefully accepting constructive criticism
- Focusing on what is best for the community
- Showing empathy towards other community members

Examples of unacceptable behavior by participants include:

- The use of sexualized language or imagery and unwelcome sexual attention or advances
- Trolling, insulting/derogatory comments, and personal or political attacks
- Public or private harassment
- Publishing others' private information, such as a physical or electronic address, without explicit permission
- Other conduct which could reasonably be considered inappropriate in a professional setting

12.4.3 Our Responsibilities

Project maintainers are responsible for clarifying the standards of acceptable behavior and are expected to take appropriate and fair corrective action in response to any instances of unacceptable behavior.

Project maintainers have the right and responsibility to remove, edit, or reject comments, commits, code, wiki edits, issues, and other contributions that are not aligned to this Code of Conduct, or to ban temporarily or permanently any contributor for other behaviors that they deem inappropriate, threatening, offensive, or harmful.

12.4.4 Scope

This Code of Conduct applies within all project spaces, and it also applies when an individual is representing the project or its community in public spaces. Examples of representing a project or community include using an official project e-mail address, posting via an official social media account, or acting as an appointed representative at an online or offline event. Representation of a project may be further defined and clarified by project maintainers.

12.4.5 Enforcement

Instances of abusive, harassing, or otherwise unacceptable behavior may be reported by contacting the project team at kristianevers@gmail.com. All complaints will be reviewed and investigated and will result in a response that is deemed necessary and appropriate to the circumstances. The project team is obligated to maintain confidentiality with regard to the reporter of an incident. Further details of specific enforcement policies may be posted separately.

Project maintainers who do not follow or enforce the Code of Conduct in good faith may face temporary or permanent repercussions as determined by other members of the project's leadership.

12.4.6 Attribution

This Code of Conduct is adapted from the Contributor Covenant, version 1.4, available at https://www.contributor-covenant.org/version/1/4/code-of-conduct.html

For answers to common questions about this code of conduct, see https://www.contributor-covenant.org/faq

12.5 Request for Comments

A PROJ RFC describes a major change in the technological underpinnings of PROJ, major additions to functionality, or changes in the direction of the project.

12.5.1 PROJ RFC 1: Project Committee Guidelines

Author
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Contact
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Status
Passed

Last Updated
2018-06-08

12.5.1.1 Summary

This document describes how the PROJ Project Steering Committee (PSC) determines membership, and makes decisions on all aspects of the PROJ project - both technical and non-technical.

Examples of PSC management responsibilities:

- setting the overall development road map
- developing technical standards and policies (e.g. coding standards, file naming conventions, etc…)
- ensuring regular releases (major and maintenance) of PROJ software
- reviewing RFC for technical enhancements to the software
- project infrastructure (e.g. GitHub, continuous integration hosting options, etc…)
- formalization of affiliation with external entities such as OSGeo
- setting project priorities, especially with respect to project sponsorship
- creation and oversight of specialized sub-committees (e.g. project infrastructure, training)

In brief the project team votes on proposals on the proj mailing list. Proposals are available for review for at least two days, and a single veto is sufficient delay progress though ultimately a majority of members can pass a proposal.

12.5.1.2 List of PSC Members

(up-to-date as of 2018-06)

- Kristian Evers @kbevers (DK) **Chair**
- Howard Butler @hobu (USA)
- Charles Karney @cffk (USA)
- Thomas Knudsen @busstoptaktik (DK)
- Even Rouault @rouault (FR)
- Kurt Schwehr @schwehr (USA)
- Frank Warmerdam @warmerdam (USA) **Emeritus**

12.5.1.3 Detailed Process

- Proposals are written up and submitted on the proj mailing list for discussion and voting, by any interested party, not just committee members.
- Proposals need to be available for review for at least two business days before a final decision can be made.
- Respondents may vote "+1" to indicate support for the proposal and a willingness to support implementation.
- Respondents may vote "-1" to veto a proposal, but must provide clear reasoning and alternate approaches to resolving the problem within the two days.
- A vote of -0 indicates mild disagreement, but has no effect. A 0 indicates no opinion. A +0 indicate mild support, but has no effect.
- Anyone may comment on proposals on the list, but only members of the Project Steering Committee's votes will be counted.
- A proposal will be accepted if it receives +2 (including the author) and no vetoes (-1).

- If a proposal is vetoed, and it cannot be revised to satisfy all parties, then it can be resubmitted for an override vote in which a majority of all eligible voters indicating +1 is sufficient to pass it. Note that this is a majority of all committee members, not just those who actively vote.
- Upon completion of discussion and voting the author should announce whether they are proceeding (proposal accepted) or are withdrawing their proposal (vetoed).
- The Chair gets a vote.
- The Chair is responsible for keeping track of who is a member of the Project Steering Committee (perhaps as part of a PSC file in CVS).
- Addition and removal of members from the committee, as well as selection of a Chair should be handled as a proposal to the committee.
- The Chair adjudicates in cases of disputes about voting.

RFC Origin

PROJ RFC and Project Steering Committee is derived from similar governance bodies in both the GDAL and MapServer software projects.

12.5.1.4 When is Vote Required?

- Any change to committee membership (new members, removing inactive members)
- Changes to project infrastructure (e.g. tool, location or substantive configuration)
- Anything that could cause backward compatibility issues.
- Adding substantial amounts of new code.
- Changing inter-subsystem APIs, or objects.
- Issues of procedure.
- When releases should take place.
- Anything dealing with relationships with external entities such as OSGeo
- Anything that might be controversial.

12.5.1.5 Observations

- The Chair is the ultimate adjudicator if things break down.
- The absolute majority rule can be used to override an obstructionist veto, but it is intended that in normal circumstances vetoers need to be convinced to withdraw their veto. We are trying to reach consensus.

12.5.1.6 Committee Membership

The PSC is made up of individuals consisting of technical contributors (e.g. developers) and prominent members of the PROJ user community. There is no set number of members for the PSC although the initial desire is to set the membership at 6.

Adding Members

Any member of the proj mailing list may nominate someone for committee membership at any time. Only existing PSC committee members may vote on new members. Nominees must receive a majority vote from existing members to be added to the PSC.

Stepping Down

If for any reason a PSC member is not able to fully participate then they certainly are free to step down. If a member is not active (e.g. no voting, no IRC or email participation) for a period of two months then the committee reserves the right to seek nominations to fill that position. Should that person become active again (hey, it happens) then they would certainly be welcome, but would require a nomination.

12.5.1.7 Membership Responsibilities

Guiding Development

Members should take an active role guiding the development of new features they feel passionate about. Once a change request has been accepted and given a green light to proceed does not mean the members are free of their obligation. PSC members voting "+1" for a change request are expected to stay engaged and ensure the change is implemented and documented in a way that is most beneficial to users. Note that this applies not only to change requests that affect code, but also those that affect the web site, technical infrastructure, policies and standards.

Mailing List Participation

PSC members are expected to be active on the proj mailing list, subject to Open Source mailing list etiquette. Non-developer members of the PSC are not expected to respond to coding level questions on the developer mailing list, however they are expected to provide their thoughts and opinions on user level requirements and compatibility issues when RFC discussions take place.

12.5.1.8 Updates

June 2018

RFC 1 was ratified by the following members

12.5.2 PROJ RFC 2: Initial integration of "GDAL SRS barn" work

Author
Even Rouault

Contact
even.rouault at spatialys.com

Status
Adopted, implemented in PROJ 6.0

Initial version
2018-10-09

Last Updated
2018-10-31

12.5.2.1 Summary

This RFC is the result of a first phase of the GDAL Coordinate System Barn Raising efforts. In its current state, this work mostly consists of:

- a C++ implementation of the ISO-19111:2018 / OGC Topic 2 "Referencing by coordinates" classes to represent Datums, Coordinate systems, CRSs (Coordinate Reference Systems) and Coordinate Operations.
- methods to convert between this C++ modeling and WKT1, WKT2 and PROJ string representations of those objects
- management and query of a SQLite3 database of CRS and Coordinate Operation definition
- a C API binding part of those capabilities

12.5.2.2 Related standards

Consult Applicable standards

(They will be linked from the PROJ documentation)

12.5.2.3 Details

Structure in packages / namespaces

The C++ implementation of the (upcoming) ISO-19111:2018 / OGC Topic 2 "Referencing by coordinates" classes follows this abstract modeling as much as possible, using package names as C++ namespaces, abstract classes and method names. A new BoundCRS class has been added to cover the modeling of the WKT2 BoundCRS construct, that is a generalization of the WKT1 TOWGS84 concept. It is strongly recommended to have the ISO-19111 standard open to have an introduction for the concepts when looking at the code. A few classes have also been inspired by the GeoAPI

The classes are organized into several namespaces:

- **osgeo::proj::util**
  A set of base types from ISO 19103, GeoAPI and other PROJ "technical" specific classes

  Template optional<T>, classes BaseObject, IComparable, BoxedValue, ArrayOfBaseObject, PropertyMap, LocalName, NameSpace, GenericName, NameFactory, CodeList, Exception, InvalidValueTypeException, UnsupportedOperationException

- **osgeo::proj::metadata:**
  Common classes from ISO 19115 (Metadata) standard

  Classes Citation, GeographicExtent, GeographicBoundingBox, TemporalExtent, VerticalExtent, Extent, Identifier, PositionalAccuracy,

- **osgeo::proj::common:**
  Common classes: UnitOfMeasure, Measure, Scale, Angle, Length, DateTime, DateEpoch, IdentifiedObject, ObjectDomain, ObjectUsage

- **osgeo::proj::cs:**
  Coordinate systems and their axis

  Classes AxisDirection, Meridian, CoordinateSystemAxis, CoordinateSystem, SphericalCS, EllipsoidalCS, VerticalCS, CartesianCS, OrdinalCS, ParametricCS, TemporalCS, DateTimeTemporalCS, TemporalCountCS, TemporalMeasureCS

- **osgeo::proj::datum:**
  Datum (the relationship of a coordinate system to the body)

  Classes Ellipsoid, PrimeMeridian, Datum, DatumEnsemble, GeodeticReferenceFrame, DynamicGeodeticReferenceFrame, VerticalReferenceFrame, DynamicVerticalReferenceFrame, TemporalDatum, EngineeringDatum, ParametricDatum

- **osgeo::proj::crs:**
  CRS = coordinate reference system = coordinate system with a datum

  Classes CRS, GeodeticCRS, GeographicCRS, DerivedCRS, ProjectedCRS, VerticalCRS, CompoundCRS, BoundCRS, TemporalCRS, EngineeringCRS, ParametricCRS, DerivedGeodeticCRS, DerivedGeographicCRS, DerivedProjectedCRS, DerivedVerticalCRS

- **osgeo::proj::operation:**
  Coordinate operations (relationship between any two coordinate reference systems)

  Classes CoordinateOperation, GeneralOperationParameter, OperationParameter, GeneralParameterValue, ParameterValue, OperationParameterValue, OperationMethod, InvalidOperation, SingleOperation, Conversion, Transformation, PointMotionOperation, ConcatenatedOperation

- **osgeo::proj::io:**
  I/O classes: WKTFormatter, PROJStringFormatter, FormattingException, ParsingException, IWKTExportable, IPROJStringExportable, WKTNode, WKTParser, PROJStringParser, DatabaseContext, AuthorityFactory, FactoryException, NoSuchAuthorityCodeException

What does what?

The code to parse WKT and PROJ strings and build ISO-19111 objects is contained in io.cpp

The code to format WKT and PROJ strings from ISO-19111 objects is mostly contained in the related exportToWKT() and exportToPROJString() methods overridden in the applicable classes. io.cpp contains the general mechanics to build such strings.

Regarding WKT strings, three variants are handled in import and export:

- WKT2_2018: variant corresponding to the upcoming ISO-19162:2018 standard
- WKT2_2015: variant corresponding to the current ISO-19162:2015 standard
- WKT1_GDAL: variant corresponding to the way GDAL understands the OGC 01-099 and OGC 99-049 standards

Regarding PROJ strings, two variants are handled in import and export:

- PROJ5: variant used by PROJ >= 5, possibly using pipeline constructs, and avoiding +towgs84 / +nadgrids legacy constructs. This variant honours axis order and input/output units. That is the pipeline for the conversion of EPSG:4326 to EPSG:32631 will assume that the input coordinates are in latitude, longitude order, with degrees.
- PROJ4: variant used by PROJ 4.x

The raw query of the proj.db database and the upper level construction of ISO-19111 objects from the database contents is done in factory.cpp

A few design principles

Methods generally take and return xxxNNPtr objects, that is non-null shared pointers (pointers with internal reference counting). The advantage of this approach is that the user has not to care about the life-cycle of the instances (and this makes the code leak-free by design). The only point of attention is to make sure no reference cycles are made. This is the case for all classes, except the CoordinateOperation class that point to CRS for sourceCRS and targetCRS members, whereas DerivedCRS point to a Conversion instance (which derives from CoordinateOperation). This issue was detected in the ISO-19111 standard. The solution adopted here is to use std::weak_ptr in the CoordinateOperation class to avoid the cycle. This design artefact is transparent to users.

Another important design point is that all ISO19111 objects are immutable after creation, that is they only have getters that do not modify their states. Consequently they could possibly use in a thread-safe way. There are however classes like PROJStringFormatter, WKTFormatter, DatabaseContext, AuthorityFactory and CoordinateOperationContext whose instances are mutable and thus can not be used by multiple threads at once.

Example how to build the EPSG:4326 / WGS84 Geographic2D definition from scratch:

```
auto greenwich = PrimeMeridian::create(
    util::PropertyMap()
        .set(metadata::Identifier::CODESPACE_KEY,
            metadata::Identifier::EPSG)
        .set(metadata::Identifier::CODE_KEY, 8901)
        .set(common::IdentifiedObject::NAME_KEY, "Greenwich"),
    common::Angle(0));
// actually predefined as PrimeMeridian::GREENWICH constant

auto ellipsoid = Ellipsoid::createFlattenedSphere(
    util::PropertyMap()
        .set(metadata::Identifier::CODESPACE_KEY, metadata::Identifier::EPSG)
        .set(metadata::Identifier::CODE_KEY, 7030)
        .set(common::IdentifiedObject::NAME_KEY, "WGS 84"),
    common::Length(6378137),
    common::Scale(298.257223563));
// actually predefined as Ellipsoid::WGS84 constant

auto datum = GeodeticReferenceFrame::create(
    util::PropertyMap()
        .set(metadata::Identifier::CODESPACE_KEY, metadata::Identifier::EPSG)
        .set(metadata::Identifier::CODE_KEY, 6326)
        .set(common::IdentifiedObject::NAME_KEY, "World Geodetic System 1984");
    ellipsoid
    util::optional<std::string>(), // anchor
    greenwich);
// actually predefined as GeodeticReferenceFrame::EPSG_6326 constant
```

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```
auto geogCRS = GeographicCRS::create(
    util::PropertyMap()
        .set(metadata::Identifier::CODESPACE_KEY, metadata::Identifier::EPSG)
        .set(metadata::Identifier::CODE_KEY, 4326)
        .set(common::IdentifiedObject::NAME_KEY, "WGS 84"),
    datum,
    cs::EllipsoidalCS::createLatitudeLongitude(scommon::UnitOfMeasure::DEGREE));
// actually predefined as GeographicCRS::EPSG_4326 constant
```

Algorithmic focus

On the algorithmic side, a somewhat involved logic is the CoordinateOperationFactory::createOperations() in coordinateoperation.cpp that takes a pair of source and target CRS and returns a set of possible coordinate operations (either single operations like a Conversion or a Transformation, or concatenated operations). It uses the intrinsic structure of those objects to create the coordinate operation pipeline. That is, if going from a ProjectedCRS to another one, by doing first the inverse conversion from the source ProjectedCRS to its base GeographicCRS, then finding the appropriate transformation(s) from this base GeographicCRS to the base GeographicCRS of the target CRS, and then applying the conversion from this base GeographicCRS to the target ProjectedCRS. At each step, it queries the database to find if one or several transformations are available. The resulting coordinate operations are filtered, and sorted, with user provided hints:

- desired accuracy
- area of use, defined as a bounding box in longitude, latitude space (its actual CRS does not matter for the intended use)
- if no area of use is defined, if and how the area of use of the source and target CRS should be used. By default, the smallest area of use is used. The rationale is for example when transforming between a national ProjectedCRS and a world-scope GeographicCRS to use the are of use of this ProjectedCRS to select the appropriate datum shifts.
- how the area of use of the candidate transformations and the desired area of use (either explicitly or implicitly defined, as explained above) are compared. By default, only transformations whose area of use is fully contained in the desired area of use are selected. It is also possible to relax this test by specifying that only an intersection test must be used.
- whether PROJ transformation grid names should be substituted to the official names, when a match is found in the *grid_alternatives* table of the database. Defaults to true
- whether the availability of those grids should be used to filter and sort the results. By default, the transformations using grids available in the system will be presented first.

The results are sorted, with the most relevant ones appearing first in the result vector. The criteria used are in that order

- grid actual availability: operations referencing grids not available will be listed after ones with available grids
- grid potential availability: operation referencing grids not known at all in the proj.db will be listed after operations with grids known, but not available.
- known accuracy: operations with unknown accuracies will be listed after operations with known accuracy
- area of use: operations with smaller area of use (the intersection of the operation area of used with the desired area of use) will be listed after the ones with larger area of use
- accuracy: operations with lower accuracy will be listed after operations with higher accuracy (caution: lower accuracy actually means a higher numeric value of the accuracy property, since it is a precision in metre)

All those settings can be specified in the CoordinateOperationContext instance passed to createOperations().

An interesting example to understand how those parameters play together is to use *projinfo -s EPSG:4267 -t EPSG:4326* (NAD27 to WGS84 conversions), and see how specifying desired area of use, spatial criterion, grid availability, etc. affects the results.

The following command currently returns 78 results:

```
projinfo -s EPSG:4267 -t EPSG:4326 --summary --spatial-test intersects
```

The createOperations() algorithm also does a kind of "CRS routing". A typical example is if wanting to transform between CRS A and CRS B, but no direct transformation is referenced in proj.db between those. But if there are transformations between A <-> C and B <-> C, then it is possible to build a concatenated operation A -> C -> B. The typical example is when C is WGS84, but the implementation is generic and just finds a common pivot from the database. An example of finding a non-WGS84 pivot is when searching a transformation between EPSG:4326 and EPSG:6668 (JGD2011 - Japanese Geodetic Datum 2011), which has no direct transformation registered in the EPSG database . However there are transformations between those two CRS and JGD2000 (and also Tokyo datum, but that one involves less accurate transformations)

```
projinfo -s EPSG:4326 -t EPSG:6668  --grid-check none --bbox 135.42,34.84,142.14,41.58 --
↪summary

Candidate operations found: 7
unknown id, Inverse of JGD2000 to WGS 84 (1) + JGD2000 to JGD2011 (1), 1.2 m, Japan -␣
↪northern Honshu
unknown id, Inverse of JGD2000 to WGS 84 (1) + JGD2000 to JGD2011 (2), 2 m, Japan␣
↪excluding northern main province
unknown id, Inverse of Tokyo to WGS 84 (108) + Tokyo to JGD2011 (2), 9.2 m, Japan␣
↪onshore excluding northern main province
unknown id, Inverse of Tokyo to WGS 84 (108) + Tokyo to JGD2000 (2) + JGD2000 to JGD2011␣
↪(1), 9.4 m, Japan - northern Honshu
unknown id, Inverse of Tokyo to WGS 84 (2) + Tokyo to JGD2011 (2), 13.2 m, Japan -␣
↪onshore mainland and adjacent islands
unknown id, Inverse of Tokyo to WGS 84 (2) + Tokyo to JGD2000 (2) + JGD2000 to JGD2011␣
↪(1), 13.4 m, Japan - northern Honshu
unknown id, Inverse of Tokyo to WGS 84 (1) + Tokyo to JGD2011 (2), 29.2 m, Asia - Japan␣
↪and South Korea
```

12.5.2.4 Code repository

The current state of the work can be found in the iso19111 branch of rouault/proj.4 repository , and is also available as a GitHub pull request at https://github.com/OSGeo/proj.4/pull/1040

Here is a not-so-usable comparison with a fixed snapshot of master branch

12.5.2.5 Database

Content

The database contains CRS and coordinate operation definitions from the EPSG database (IOGP's EPSG Geodetic Parameter Dataset) v9.5.3, IGNF registry (French National Geographic Institute), ESRI database, as well as a few customizations.

Building (for PROJ developers creating the database)

The building of the database is a several stage process:

Construct SQL scripts for EPSG

The first stage consists in constructing .sql scripts mostly with CREATE TABLE and INSERT statements to create the database structure and populate it. There is one .sql file for each database table, populated with the content of the EPSG database, automatically generated with the build_db.py script, which processes the PostgreSQL dumps issued by IOGP. A number of other scripts are dedicated to manual editing, for example grid_alternatives.sql file that binds official grid names to PROJ grid names

Concert UTF8 SQL to sqlite3 db

The second stage is done automatically by the make process. It pipes the .sql script, in the right order, to the sqlite3 binary to generate a first version of the proj.db SQLite3 database.

Add extra registries

The third stage consists in creating additional .sql files from the content of other registries. For that process, we need to bind some definitions of those registries to those of the EPSG database, to be able to link to existing objects and detect some boring duplicates. The ignf.sql file has been generated using the build_db_create_ignf.py script from the current data/IGNF file that contains CRS definitions (and implicit transformations to WGS84) as PROJ.4 strings. The esri.sql file has been generated using the build_db_from_esri.py script, from the .csv files in https://github.com/Esri/projection-engine-db-doc/tree/master/csv

Finalize proj.db

The last stage runs make again to incorporate the new .sql files generated in the previous stage (so the process of building the database involves a kind of bootstrapping…)

Building (for PROJ users)

The make process just runs the second stage mentioned above from the .sql files. The resulting proj.db is currently 5.3 MB large.

Structure

The database is structured into the following tables and views. They generally match a ISO-19111 concept, and is generally close to the general structure of the EPSG database. Regarding identification of objects, where the EPSG database only contains a 'code' numeric column, the PROJ database identifies objects with a (auth_name, code) tuple of string values, allowing several registries to be combined together.

- **Technical:**
  - *authority_list*: view enumerating the authorities present in the database. Currently: EPSG, IGNF, PROJ
  - *metadata*: a few key/value pairs, for example to indicate the version of the registries imported in the database
  - *object_view*: synthetic view listing objects (ellipsoids, datums, CRS, coordinate operations…) code and name, and the table name where they are further described
  - *alias_names*: list possible alias for the *name* field of object table
  - *link_from_deprecated_to_non_deprecated*: to handle the link between old ESRI to new ESRI/EPSG codes
- **Common:**
  - *unit_of_measure*: table with UnitOfMeasure definitions.
  - *area*: table with area-of-use (bounding boxes) applicable to CRS and coordinate operations.
- **Coordinate systems:**
  - *axis*: table with CoordinateSystemAxis definitions.
  - *coordinate_system*: table with CoordinateSystem definitions.
- **Ellipsoid and datums:**
  - *ellipsoid*: table with ellipsoid definitions.
  - *prime_meridian*: table with PrimeMeridian definitions.
  - *geodetic_datum*: table with GeodeticReferenceFrame definitions.
  - *vertical_datum*: table with VerticalReferenceFrame definitions.
- **CRS:**
  - *geodetic_crs*: table with GeodeticCRS and GeographicCRS definitions.
  - *projected_crs*: table with ProjectedCRS definitions.
  - *vertical_crs*: table with VerticalCRS definitions.
  - *compound_crs*: table with CompoundCRS definitions.
- **Coordinate operations:**
  - *coordinate_operation_view*: view giving a number of common attributes shared by the concrete tables implementing CoordinateOperation

- *conversion*: table with definitions of Conversion (mostly parameter and values of Projection)
- *concatenated_operation*: table with definitions of ConcatenatedOperation.
- *grid_transformation*: table with all grid-based transformations.
- *grid_packages*: table listing packages in which grids can be found. ie "proj-datumgrid", "proj-datumgrid-europe", …
- *grid_alternatives*: table binding official grid names to PROJ grid names. e.g "Und_min2.5x2.5_egm2008_isw=82_WGS84_TideFree.gz" –> "egm08_25.gtx"
- *helmert_transformation*: table with all Helmert-based transformations.
- *other_transformation*: table with other type of transformations.

The main departure with the structure of the EPSG database is the split of the various coordinate operations over several tables. This was done mostly for human-readability as the EPSG organization of coordoperation, coordoperationmethod, coordoperationparam, coordoperationparamusage, coordoperationparamvalue tables makes it hard to grasp at once all the parameters and values for a given operation.

12.5.2.6 Utilities

A new *projinfo* utility has been added. It enables the user to enter a CRS or coordinate operation by a AUTHORITY:CODE, PROJ string or WKT string, and see it translated in the different flavors of PROJ and WKT strings. It also enables to build coordinate operations between two CRSs.

Usage

```
usage: projinfo [-o formats] [-k crs|operation] [--summary] [-q]
                [--bbox min_long,min_lat,max_long,max_lat]
                [--spatial-test contains|intersects]
                [--crs-extent-use none|both|intersection|smallest]
                [--grid-check none|discard_missing|sort]
                [--boundcrs-to-wgs84]
                {object_definition} | (-s {srs_def} -t {srs_def})

-o: formats is a comma separated combination of: all,default,PROJ4,PROJ,WKT_ALL,WKT2_
↪2015,WKT2_2018,WKT1_GDAL
    Except 'all' and 'default', other format can be preceded by '-' to disable them
```

Examples

Specify CRS by AUTHORITY:CODE

```
$ projinfo EPSG:4326

PROJ string:
+proj=pipeline +step +proj=longlat +ellps=WGS84 +step +proj=unitconvert +xy_in=rad +xy_
↪out=deg +step +proj=axisswap +order=2,1

WKT2_2015 string:
```

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```
GEODCRS["WGS 84",
    DATUM["World Geodetic System 1984",
        ELLIPSOID["WGS 84",6378137,298.257223563,
            LENGTHUNIT["metre",1]]],
    PRIMEM["Greenwich",0,
        ANGLEUNIT["degree",0.0174532925199433]],
    CS[ellipsoidal,2],
        AXIS["geodetic latitude (Lat)",north,
            ORDER[1],
            ANGLEUNIT["degree",0.0174532925199433]],
        AXIS["geodetic longitude (Lon)",east,
            ORDER[2],
            ANGLEUNIT["degree",0.0174532925199433]],
    AREA["World"],
    BBOX[-90,-180,90,180],
    ID["EPSG",4326]]
```

Specify CRS by PROJ string and specify output formats

```
$ projinfo -o PROJ4,PROJ,WKT1_GDAL,WKT2_2018 "+title=IGN 1972 Nuku Hiva - UTM fuseau 7␣
↪Sud +proj=tmerc +towgs84=165.7320,216.7200,180.5050,-0.6434,-0.4512,-0.0791,7.420400␣
↪+a=6378388.0000 +rf=297.0000000000000 +lat_0=0.000000000 +lon_0=-141.000000000 +k_0=0.
↪99960000 +x_0=500000.000 +y_0=10000000.000 +units=m +no_defs"

PROJ string:
Error when exporting to PROJ string: BoundCRS cannot be exported as a PROJ.5 string, but␣
↪its baseCRS might

PROJ.4 string:
+proj=utm +zone=7 +south +ellps=intl +towgs84=165.732,216.72,180.505,-0.6434,-0.4512,-0.
↪0791,7.4204

WKT2_2018 string:
BOUNDCRS[
    SOURCECRS[
        PROJCRS["IGN 1972 Nuku Hiva - UTM fuseau 7 Sud",
            BASEGEOGCRS["unknown",
                DATUM["unknown",
                    ELLIPSOID["International 1909 (Hayford)",6378388,297,
                        LENGTHUNIT["metre",1,
                            ID["EPSG",9001]]]],
                PRIMEM["Greenwich",0,
                    ANGLEUNIT["degree",0.0174532925199433],
                    ID["EPSG",8901]]],
            CONVERSION["unknown",
                METHOD["Transverse Mercator",
                    ID["EPSG",9807]],
                PARAMETER["Latitude of natural origin",0,
                    ANGLEUNIT["degree",0.0174532925199433],
                    ID["EPSG",8801]],
```

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```
            PARAMETER["Longitude of natural origin",-141,
                ANGLEUNIT["degree",0.0174532925199433],
                ID["EPSG",8802]],
            PARAMETER["Scale factor at natural origin",0.9996,
                SCALEUNIT["unity",1],
                ID["EPSG",8805]],
            PARAMETER["False easting",500000,
                LENGTHUNIT["metre",1],
                ID["EPSG",8806]],
            PARAMETER["False northing",10000000,
                LENGTHUNIT["metre",1],
                ID["EPSG",8807]]],
        CS[Cartesian,2],
            AXIS["(E)",east,
                ORDER[1],
                LENGTHUNIT["metre",1,
                    ID["EPSG",9001]]],
            AXIS["(N)",north,
                ORDER[2],
                LENGTHUNIT["metre",1,
                    ID["EPSG",9001]]]]],
TARGETCRS[
    GEOGCRS["WGS 84",
        DATUM["World Geodetic System 1984",
            ELLIPSOID["WGS 84",6378137,298.257223563,
                LENGTHUNIT["metre",1]]],
        PRIMEM["Greenwich",0,
            ANGLEUNIT["degree",0.0174532925199433]],
        CS[ellipsoidal,2],
            AXIS["latitude",north,
                ORDER[1],
                ANGLEUNIT["degree",0.0174532925199433]],
            AXIS["longitude",east,
                ORDER[2],
                ANGLEUNIT["degree",0.0174532925199433]],
        ID["EPSG",4326]]],
ABRIDGEDTRANSFORMATION["Transformation from unknown to WGS84",
    METHOD["Position Vector transformation (geog2D domain)",
        ID["EPSG",9606]],
    PARAMETER["X-axis translation",165.732,
        ID["EPSG",8605]],
    PARAMETER["Y-axis translation",216.72,
        ID["EPSG",8606]],
    PARAMETER["Z-axis translation",180.505,
        ID["EPSG",8607]],
    PARAMETER["X-axis rotation",-0.6434,
        ID["EPSG",8608]],
    PARAMETER["Y-axis rotation",-0.4512,
        ID["EPSG",8609]],
    PARAMETER["Z-axis rotation",-0.0791,
        ID["EPSG",8610]],
    PARAMETER["Scale difference",1.0000074204,
```

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```
            ID["EPSG",8611]]]]

WKT1_GDAL:
PROJCS["IGN 1972 Nuku Hiva - UTM fuseau 7 Sud",
    GEOGCS["unknown",
        DATUM["unknown",
            SPHEROID["International 1909 (Hayford)",6378388,297],
            TOWGS84[165.732,216.72,180.505,-0.6434,-0.4512,-0.0791,7.4204]],
        PRIMEM["Greenwich",0,
            AUTHORITY["EPSG","8901"]],
        UNIT["degree",0.0174532925199433,
            AUTHORITY["EPSG","9122"]],
        AXIS["Longitude",EAST],
        AXIS["Latitude",NORTH]],
    PROJECTION["Transverse_Mercator"],
    PARAMETER["latitude_of_origin",0],
    PARAMETER["central_meridian",-141],
    PARAMETER["scale_factor",0.9996],
    PARAMETER["false_easting",500000],
    PARAMETER["false_northing",10000000],
    UNIT["metre",1,
        AUTHORITY["EPSG","9001"]],
    AXIS["Easting",EAST],
    AXIS["Northing",NORTH]]
```

Find transformations between 2 CRS

Between "Poland zone I" (based on Pulkovo 42 datum) and "UTM WGS84 zone 34N"

Summary view:

```
$ projinfo -s EPSG:2171 -t EPSG:32634 --summary

Candidate operations found: 1
unknown id, Inverse of Poland zone I + Pulkovo 1942(58) to WGS 84 (1) + UTM zone 34N, 1␣
↪m, Poland - onshore
```

Display of pipelines:

```
$ PROJ_LIB=data src/projinfo -s EPSG:2171 -t EPSG:32634 -o PROJ

PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1 +step +inv +proj=sterea +lat_0=50.625␣
↪+lon_0=21.0833333333333 +k=0.9998 +x_0=4637000 +y_0=5647000 +ellps=krass +step␣
↪+proj=cart +ellps=krass +step +proj=helmert +x=33.4 +y=-146.6 +z=-76.3 +rx=-0.359 +ry=-
↪0.053 +rz=0.844 +s=-0.84 +convention=position_vector +step +inv +proj=cart␣
↪+ellps=WGS84 +step +proj=utm +zone=34 +ellps=WGS84
```

12.5.2.7 Impacted files

New files (excluding makefile.am, CMakeLists.txt and other build infrastructure artefacts):

- **include/proj/: Public installed C++ headers**
  - common.hpp: declarations of osgeo::proj::common namespace.
  - coordinateoperation.hpp: declarations of osgeo::proj::operation namespace.
  - coordinatesystem.hpp: declarations of osgeo::proj::cs namespace.
  - crs.hpp: declarations of osgeo::proj::crs namespace.
  - datum.hpp: declarations of osgeo::proj::datum namespace.
  - io.hpp: declarations of osgeo::proj::io namespace.
  - metadata.hpp: declarations of osgeo::proj::metadata namespace.
  - util.hpp: declarations of osgeo::proj::util namespace.
  - nn.hpp: Code from https://github.com/dropbox/nn to manage Non-nullable pointers for C++
- **include/proj/internal: Private non-installed C++ headers**
  - coordinateoperation_internal.hpp: classes InverseCoordinateOperation, InverseConversion, InverseTransformation, PROJBasedOperation, and functions to get conversion mappings between WKT and PROJ syntax
  - coordinateoperation_constants.hpp: Select subset of conversion/transformation EPSG names and codes for the purpose of translating them to PROJ strings
  - coordinatesystem_internal.hpp: classes AxisDirectionWKT1, AxisName and AxisAbbreviation
  - internal.hpp: a few helper functions, mostly to do string-based operations
  - io_internal.hpp: class WKTConstants
  - helmert_constants.hpp: Helmert-based transformation & parameters names and codes.
  - lru_cache.hpp: code from https://github.com/mohaps/lrucache11 to have a generic Least-Recently-Used cache of objects
- **src/:**
  - c_api.cpp: C++ API mapped to C functions
  - common.cpp: implementation of common.hpp
  - coordinateoperation.cpp: implementation of coordinateoperation.hpp
  - coordinatesystem.cpp: implementation of coordinatesystem.hpp
  - crs.cpp: implementation of crs.hpp
  - datum.cpp: implementation of datum.hpp
  - factory.cpp: implementation of AuthorityFactory class (from io.hpp)
  - internal.cpp: implementation of internal.hpp
  - io.cpp: implementation of io.hpp
  - metadata.cpp: implementation of metadata.hpp

- static.cpp: a number of static constants (like pre-defined well-known ellipsoid, datum and CRS), put in the right order for correct static initializations
- util.cpp: implementation of util.hpp
- projinfo.cpp: new 'projinfo' binary
- general.dox: generic introduction documentation.

• **data/sql/:**
  - area.sql: generated by build_db.py
  - axis.sql: generated by build_db.py
  - begin.sql: hand generated (trivial)
  - commit.sql: hand generated (trivial)
  - compound_crs.sql: generated by build_db.py
  - concatenated_operation.sql: generated by build_db.py
  - conversion.sql: generated by build_db.py
  - coordinate_operation.sql: generated by build_db.py
  - coordinate_system.sql: generated by build_db.py
  - crs.sql: generated by build_db.py
  - customizations.sql: hand generated (empty)
  - ellipsoid.sql: generated by build_db.py
  - geodetic_crs.sql: generated by build_db.py
  - geodetic_datum.sql: generated by build_db.py
  - grid_alternatives.sql: hand-generated. Contains links between official registry grid names and PROJ ones
  - grid_transformation.sql: generated by build_db.py
  - grid_transformation_custom.sql: hand-generated
  - helmert_transformation.sql: generated by build_db.py
  - ignf.sql: generated by build_db_create_ignf.py
  - esri.sql: generated by build_db_from_esri.py
  - metadata.sql: hand-generated
  - other_transformation.sql: generated by build_db.py
  - prime_meridian.sql: generated by build_db.py
  - proj_db_table_defs.sql: hand-generated. Database structure: CREATE TABLE / CREATE VIEW / CREATE TRIGGER
  - projected_crs.sql: generated by build_db.py
  - unit_of_measure.sql: generated by build_db.py
  - vertical_crs.sql: generated by build_db.py
  - vertical_datum.sql: generated by build_db.py

• **scripts/:**

  - build_db.py : generate .sql files from EPSG database dumps
  - build_db_create_ignf.py: generates data/sql/ignf.sql
  - build_db_from_esri.py: generates data/sql/esri.sql
  - doxygen.sh: generates Doxygen documentation
  - gen_html_coverage.sh: generates HTML report of the coverage for –coverage build
  - filter_lcov_info.py: utility used by gen_html_coverage.sh
  - reformat.sh: used by reformat_cpp.sh
  - reformat_cpp.sh: reformat all .cpp/.hpp files according to LLVM-style formatting rules
- **tests/unit/**
  - test_c_api.cpp: test of src/c_api.cpp
  - test_common.cpp: test of src/common.cpp
  - test_util.cpp: test of src/util.cpp
  - test_crs.cpp: test of src/crs.cpp
  - test_datum.cpp: test of src/datum.cpp
  - test_factory.cpp: test of src/factory.cpp
  - test_io.cpp: test of src/io.cpp
  - test_metadata.cpp: test of src/metadata.cpp
  - test_operation.cpp: test of src/operation.cpp

12.5.2.8 C API

proj.h has been extended to bind a number of C++ classes/methods to a C API.

The main structure is an opaque PJ_OBJ* roughly encapsulating a osgeo::proj::BaseObject, that can represent a CRS or a CoordinateOperation object. A number of the C functions will work only if the right type of underlying C++ object is used with them. Misuse will be properly handled at runtime. If a user passes a PJ_OBJ* representing a coordinate operation to a pj_obj_crs_xxxx() function, it will properly error out. This design has been chosen over creating a dedicate PJ_xxx object for each C++ class, because such an approach would require adding many conversion and free functions for little benefit.

This C API is incomplete. In particular, it does not allow to build ISO19111 objects at hand. However it currently permits a number of actions:

- building CRS and coordinate operations from WKT and PROJ strings, or from the proj.db database
- exporting CRS and coordinate operations as WKT and PROJ strings
- querying main attributes of those objects
- finding coordinate operations between two CRS.

test_c_api.cpp should demonstrates simple usage of the API (note: for the conveniency of writing the tests in C++, test_c_api.cpp wraps the C PJ_OBJ* instances in C++ 'keeper' objects that automatically call the pj_obj_unref() function at function end. In a pure C use, the caller must use pj_obj_unref() to prevent leaks.)

12.5.2.9 Documentation

All public C++ classes and methods and C functions are documented with Doxygen.

Current snapshot of Class list

Spaghetti inheritance diagram

A basic integration of the Doxygen XML output into the general PROJ documentation (using reStructuredText format) has been done with the Sphinx extension Breathe, producing:

- One section with the C++ API
- One section with the C API

12.5.2.10 Testing

Nearly all exported methods are tested by a unit test. Global line coverage of the new files is 92%. Those tests represent 16k lines of codes.

12.5.2.11 Build requirements

The new code leverages on a number of C++11 features (auto keyword, constexpr, initializer list, std::shared_ptr, lambda functions, etc.), which means that a C++11-compliant compiler must be used to generate PROJ:

- gcc >= 4.8
- clang >= 3.3
- Visual Studio >= 2015.

Compilers tested by the Travis-CI and AppVeyor continuous integration environments:

- GCC 4.8
- mingw-w64-x86-64 4.8
- clang 5.0
- Apple LLVM version 9.1.0 (clang-902.0.39.2)
- MSVC 2015 32 and 64 bit
- MSVC 2017 32 and 64 bit

The libsqlite3 >= 3.7 development package must also be available. And the sqlite3 binary must be available to build the proj.db files from the .sql files.

12.5.2.12 Runtime requirements

- libc++/libstdc++/MSVC runtime consistent with the compiler used
- libsqlite3 >= 3.7

12.5.2.13 Backward compatibility

At this stage, no backward compatibility issue is foreseen, as no existing functional C code has been modified to use the new capabilities

12.5.2.14 Future work

The work described in this RFC will be pursued in a number of directions. Non-exhaustively:

- Support for ESRI WKT1 dialect (PROJ currently ingest the ProjectedCRS in esri.sql in that dialect, but there is no mapping between it and EPSG operation and parameter names, so conversion to PROJ strings does not always work.
- closer integration with the existing code base. In particular, the +init=dict:code syntax should now go first to the database (then the *epsg* and *IGNF* files can be removed). Similarly proj_create_crs_to_crs() could use the new capabilities to find an appropriate coordinate transformation.
- and whatever else changes are needed to address GDAL and libgeotiff needs

12.5.2.15 Adoption status

The RFC has been adopted with support from PSC members Kurt Schwehr, Kristian Evers, Howard Butler and Even Rouault.

12.5.3 PROJ RFC 3: Dependency management

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Status
Adopted

Last Updated
2019-01-16

12.5.3.1 Summary

This document defines a set of guidelines for dependency management in PROJ. With PROJ being a core component in many downstream software packages clearly stating which dependencies the library has is of great value. This document concern both programming language standards as well as minimum required versions of library dependencies and build tools.

It is proposed to adopt a rolling update scheme that ensures that PROJ is sufficiently accessible, even on older systems, as well as keeping up with the technological evolution. The scheme is divided in two parts, one concerning versions of used programming languages within PROJ and the other concerning software packages that PROJ depend on.

With adoption of this RFC, versions used for

1. programming languages will always be at least two revisions behind the most recent standard
2. software packages will always be at least two years old (patch releases are exempt)

A change in programming language standard can only be introduced with a new major version release of PROJ. Changes for software package dependencies can be introduced with minor version releases of PROJ. Changing the version requirements for a dependency needs to be approved by the PSC.

Following the above rule set will ensure that all but the most conservative users of PROJ will be able to build and use the most recent version of the library.

In the sections below details concerning programming languages and software dependencies are outlined. The RFC is concluded with a bootstrapping section that details the state of dependencies after the accept of the RFC.

12.5.3.2 Background

PROJ has traditionally been written in C89. Until recently, no formal requirements of e.g. build systems has been defined and formally accepted by the project. *RFC2* formally introduces dependencies on C++11 and SQLite 3.7.

In this RFC a rolling update of version or standard requirements is described. The reasoning behind a rolling update scheme is that it has become increasingly evident that C89 is becoming outdated and creating a less than optimal development environment for contributors. It has been noted that the most commonly used compilers all now support more recent versions of C, so the strict usage of C89 is no longer as critical as it used to be.

Similarly, rolling updates to other tools and libraries that PROJ depend on will ensure that the code base can be kept modern and in line with the rest of the open source software ecosphere.

12.5.3.3 C and C++

Following *RFC2* PROJ is written in both C and C++. At the time of writing the core library is C based and the code described in RFC2 is written in C++. While the core library is mostly written in C it is compiled as C++. Minor sections of PROJ, like the geodesic algorithms are still compiled as C since there is no apparent benefit of compiling with a C++ compiler. This may change in the future.

Both the C and C++ standards are updated with regular intervals. After an update of a standard it takes time for compiler manufacturers to implement the standards fully, which makes adaption of new standards potentially troublesome if done too soon. On the other hand, waiting too long to adopt new standards will eventually make the code base feel old and new contributors are more likely to stay away because they don't want to work using tools of the past. With a rolling update scheme both concerns can be managed by always staying behind the most recent standard, but not so far away that potential contributors are scared away. Keeping a policy of always lagging behind be two iterations of the standard is thought to be the best comprise between the two concerns.

C comes in four ISO standardised varieties: C89, C99, C11, C18. In this document we refer to their informal names for ease of reading. C++ exists in five varieties: C++98, C++03, C++11, C++14, C++17. Before adoption of this RFC PROJ uses C89 and C++11. For C, that means that the used standard is three iterations behind the most recent standard. C++ is two iterations behind. Following the rules in this RFC the required C standard used in PROJ is at allowed to be two iterations behind the most recent standard. That means that a change to C99 is possible, as long as the PROJ PSC acknowledges such a change.

When a new standard for either C or C++ is released PROJ should consider changing its requirement to the next standard in the line. For C++ that means a change in standard roughly every three years, for C the periods between standard updates is expected to be longer. Adaptation of new programming language standards should be coordinated with a major version release of PROJ.

12.5.3.4 Software dependencies

At the time of writing PROJ is dependent on very few external packages. In fact only one runtime dependency is present: SQLite. Building PROJ also requires one of two external dependencies for configuration: Autotools or CMake.

As with programming language standards it is preferable that software dependencies are a bit behind the most recent development. For this reason it is required that the minimum version supported in PROJ dependencies is at least two years old, preferably more. It is not a requirement that the minimum version of dependencies is always kept strictly two years behind current development, but it is allowed in case future development of PROJ warrants an update. Changes in minimum version requirements are allowed to happen with minor version releases of PROJ.

At the time of writing the minimum version required for SQLite it 3.7 which was released in 2010. CMake currently is required to be at least at version 2.8.3 which was also released in 2010.

12.5.3.5 Bootstrapping

This RFC comes with a set of guidelines for handling dependencies for PROJ in the future. Up until now dependencies hasn't been handled consistently, with some dependencies not being approved formally by the projects governing body. Therefore minimum versions of PROJ dependencies is proposed so that at the acception of this RFC PROJ will have the following external requirements:

- C99 (was C89)
- C++11 (already approved in *RFC2*)
- SQLite 3.7 (already approved in *RFC2*)
- CMake 3.5 (was 2.8.3)

12.5.3.6 Adoption status

The RFC was adopted on 2018-01-19 with +1's from the following PSC members

- Kristian Evers
- Even Rouault
- Thomas Knudsen
- Howard Butler

12.5.4 PROJ RFC 4: Remote access to grids and GeoTIFF grids

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Status
Adopted

Implementation target
PROJ 7

Last Updated
2020-01-10

12.5.4.1 Motivation

PROJ 6 brings undeniable advances in the management of coordinate transformations between datums by relying and applying information available in the PROJ database. PROJ's rapid evolution from a cartographic projections library with a little bit of geodetic capability to a full geodetic transformation and description environment has highlighted the importance of the support data. Users desire the convenience of software doing the right thing with the least amount of fuss, and survey organizations wish to deliver their models across as wide a software footprint as possible. To get results with the highest precision, a grid file that defines a model that provides dimension shifts is often needed. The proj-datumgrid project centralizes grids available under an open data license and bundles them in different archives split along major geographical regions of the world .

It is assumed that a PROJ user has downloaded and installed grid files that are referred to in the PROJ database. These files can be quite large in aggregate, and packaging support by major distribution channels is somewhat uneven due to their size, sometimes ambiguous licensing story, and difficult-to-track versioning and lineage. It is not always clear to the user, especially to those who may not be so familiar with geodetic operations, that the highest precision transformation may not always being applied if grid data is not available. Users want both convenience and correctness, and management of the shift files can be challenging to those who may not be aware of their importance to the process.

The computing environment in which PROJ operates is also changing. Because the shift data can be so large (currently more than 700 MB of uncompressed data, and growing), deployment of high accuracy operations can be limited due to deployment size constraints (serverless operations, for example). Changing to a delivery format that supports incremental access over a network along with convenient access and compression will ease the resource burden the shift files present while allowing the project to deliver transformation capability with the highest known precision provided by the survey organizations.

Adjustment grids also tend to be provided in many different formats depending on the organization and country that produced them. In PROJ, we have over time "standardized" on using horizontal shift grids as NTv2 and vertical shift grids using GTX. Both have poor general support as dedicated formats, limited metadata capabilities, and neither are not necessarily "cloud optimized" for incremental access across a network.

12.5.4.2 Summary of work planned by this RFC

- Grids will be hosted by one or several Content Delivery Networks (CDN)
- Grid loading mechanism will be reworked to be able to download grids or parts of grids from a online repository. When opted in, users will no longer have to manually fetch grid files and place them in PROJ_LIB. Full and accurate capability of the software will no longer require hundreds of megabytes of grid shift files in advance, even if only just a few of them are needed for the transformations done by the user.
- Local caching of grid files, or even part of files, so that users end up mirroring what they actually use.
- A grid shift format, for both horizontal and vertical shift grids (and in potential future steps, for other needs, such as deformation models) will be implemented.

The use of grids locally available will of course still be available, and will be the default behavior.

12.5.4.3 Network access to grids

curl will be an optional build dependency of PROJ, added in autoconf and cmake build systems. It can be disabled at build time, but this must be an explicit setting of configure/cmake as the resulting builds have less functionality. When curl is enabled at build time, download of grids themselves will not be enabled by default at runtime. It will require explicit consent of the user, either through the API (`proj_context_set_enable_network()`) through the PROJ_NETWORK=ON environment variable, or the `network = on` setting of proj.ini.

Regarding the minimum version of libcurl required, given GDAL experience that can build with rather ancient libcurl for similar functionality, we can aim for libcurl >= 7.29.0 (as being available in RHEL 7).

An alternate pluggable network interface can also be set by the user in case support for libcurl was not built in, or if for the desired context of use, the user wishes to provide the network implementation (a typical use case could be QGIS that would use its QT-based networking facilities to solve issues with SSL, proxy, authentication, etc.)

A text configuration file, installed in ${installation_prefix}/share/proj/proj.ini (or ${PROJ_LIB}/proj.ini) will contain the URL of the CDN that will be used. The user may also override this setting with the `proj_context_set_url_endpoint()` or through the PROJ_NETWORK_ENDPOINT environment variable.

The rationale for putting proj.ini in that location is that it is a well-known place by PROJ users, with the existing PROJ_LIB mechanics for systems like Windows where hardcoded paths at runtime aren't generally usable.

C API

The preliminary C API for the above is:

```
/** Enable or disable network access.
*
* @param ctx PROJ context, or NULL
* @return TRUE if network access is possible. That is either libcurl is
*         available, or an alternate interface has been set.
*/
int proj_context_set_enable_network(PJ_CONTEXT* ctx, int enable);

/** Define URL endpoint to query for remote grids.
*
* This overrides the default endpoint in the PROJ configuration file or with
* the PROJ_NETWORK_ENDPOINT environment variable.
*
* @param ctx PROJ context, or NULL
* @param url Endpoint URL. Must NOT be NULL.
*/
void proj_context_set_url_endpoint(PJ_CONTEXT* ctx, const char* url);

/** Opaque structure for PROJ. Implementations might cast it to their
 * structure/class of choice. */
typedef struct PROJ_NETWORK_HANDLE PROJ_NETWORK_HANDLE;

/** Network access: open callback
*
* Should try to read the size_to_read first bytes at the specified offset of
* the file given by URL url,
* and write them to buffer. *out_size_read should be updated with the actual
* amount of bytes read (== size_to_read if the file is larger than size_to_read).
* During this read, the implementation should make sure to store the HTTP
* headers from the server response to be able to respond to
* proj_network_get_header_value_cbk_type callback.
*
* error_string_max_size should be the maximum size that can be written into
* the out_error_string buffer (including terminating nul character).
*
* @return a non-NULL opaque handle in case of success.
*/
typedef PROJ_NETWORK_HANDLE* (*proj_network_open_cbk_type)(
```

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```
                                                            PJ_CONTEXT* ctx,
                                                            const char* url,
                                                            unsigned long long offset,
                                                            size_t size_to_read,
                                                            void* buffer,
                                                            size_t* out_size_read,
                                                            size_t error_string_max_size,
                                                            char* out_error_string,
                                                            void* user_data);

/** Network access: close callback */
typedef void (*proj_network_close_cbk_type)(PJ_CONTEXT* ctx,
                                            PROJ_NETWORK_HANDLE* handle,
                                            void* user_data);

/** Network access: get HTTP headers */
typedef const char* (*proj_network_get_header_value_cbk_type)(
                                            PJ_CONTEXT* ctx,
                                            PROJ_NETWORK_HANDLE* handle,
                                            const char* header_name,
                                            void* user_data);

/** Network access: read range
*
* Read size_to_read bytes from handle, starting at offset, into
* buffer.
* During this read, the implementation should make sure to store the HTTP
* headers from the server response to be able to respond to
* proj_network_get_header_value_cbk_type callback.
*
* error_string_max_size should be the maximum size that can be written into
* the out_error_string buffer (including terminating nul character).
*
* @return the number of bytes actually read (0 in case of error)
*/
typedef size_t (*proj_network_read_range_type)(
                                            PJ_CONTEXT* ctx,
                                            PROJ_NETWORK_HANDLE* handle,
                                            unsigned long long offset,
                                            size_t size_to_read,
                                            void* buffer,
                                            size_t error_string_max_size,
                                            char* out_error_string,
                                            void* user_data);

/** Define a custom set of callbacks for network access.
*
* All callbacks should be provided (non NULL pointers).
*
* @param ctx PROJ context, or NULL
* @param open_cbk Callback to open a remote file given its URL
* @param close_cbk Callback to close a remote file.
```

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```
* @param get_header_value_cbk Callback to get HTTP headers
* @param read_range_cbk Callback to read a range of bytes inside a remote file.
* @param user_data Arbitrary pointer provided by the user, and passed to the
* above callbacks. May be NULL.
* @return TRUE in case of success.
*/
int proj_context_set_network_callbacks(
    PJ_CONTEXT* ctx,
    proj_network_open_cbk_type open_cbk,
    proj_network_close_cbk_type close_cbk,
    proj_network_get_header_value_cbk_type get_header_value_cbk,
    proj_network_read_range_type read_range_cbk,
    void* user_data);
```

To make network access efficient, PROJ will internally have a in-memory cache of file ranges to only issue network requests by chunks of 16 KB or multiple of them, to limit the number of HTTP GET requests and minimize latency caused by network access. This is very similar to the behavior of the GDAL /vsicurl/ I/O layer. The plan is to mostly copy GDAL's vsicurl implementation inside PROJ, with needed adjustments and proper namespacing of it.

A retry strategy (typically a delay with an exponential back-off and some random jitter) will be added to account for intermittent network or server-side failure.

URL building

The PROJ database has a `grid_transformation` grid whose column `grid_name` (and possibly `grid2_name`) contain the name of the grid as indicated by the authority having registered the transformation (typically EPSG). As those grid names are not generally directly usable by PROJ, the PROJ database has also a `grid_alternatives` table that link original grid names to the ones used by PROJ. When network access will be available and needed due to lack of a local grid, the full URL will be the endpoint from the configuration or set by the user, the basename of the PROJ usable filename, and the "tif" suffix. So if the CDN is at http://example.com and the name from `grid_alternatives` is egm96_15.gtx, then the URL will be http://example.com/egm96_15.tif

Grid loading

The following files will be affected, in one way or another, by the above describes changes: nad_cvt.cpp, nad_intr.cpp, nad_init.cpp, grid_info.cpp, grid_list.cpp, apply_gridshift.cpp, apply_vgridshift.cpp.

In particular the current logic that consists to ingest all the values of a grid/subgrid in the ct->cvs array will be completely modified, to enable access to grid values at a specified (x,y) location.

proj_create_crs_to_crs() / proj_create_operations() impacts

Once network access is available, all grids known to the PROJ database (grid_transformation + grid_alternatives table) will be assumed to be available, when computing the potential pipelines between two CRS.

Concretely, this will be equivalent to calling *proj_operation_factory_context_set_grid_availability_use()* with the `use` argument set to a new enumeration value

```
/** Results will be presented as if grids known to PROJ (that is
* registered in the grid_alternatives table of its database) were
* available. Used typically when networking is enabled.
```

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```
*/
PROJ_GRID_AVAILABILITY_KNOWN_AVAILABLE
```

Local on-disk caching of remote grids

As many workflows will tend to use the same grids over and over, a local on-disk caching of remote grids will be added. The cache will be a single SQLite3 database, in a user-writable directory shared by all applications using PROJ.

Its total size will be configurable, with a default maximum size of 100 MB in proj.ini. The cache will also keep the timestamp of the last time it checked various global properties of the file (its size, Last-Modified and ETag headers). A time-to-live parameter, with a default of 1 day in proj.ini, will be used to determine whether the CDN should be hit to verify if the information in the cache is still up-to-date.

```
/** Enable or disable the local cache of grid chunks
*
* This overrides the setting in the PROJ configuration file.
*
* @param ctx PROJ context, or NULL
* @param enabled TRUE if the cache is enabled.
*/
void proj_grid_cache_set_enable(PJ_CONTEXT *ctx, int enabled);

/** Override, for the considered context, the path and file of the local
* cache of grid chunks.
*
* @param ctx PROJ context, or NULL
* @param fullname Full name to the cache (encoded in UTF-8). If set to NULL,
*                 caching will be disabled.
*/
void proj_grid_cache_set_filename(PJ_CONTEXT* ctx, const char* fullname);

/** Override, for the considered context, the maximum size of the local
* cache of grid chunks.
*
* @param ctx PROJ context, or NULL
* @param max_size_MB Maximum size, in mega-bytes (1024*1024 bytes), or
*                    negative value to set unlimited size.
*/
void proj_grid_cache_set_max_size(PJ_CONTEXT* ctx, int max_size_MB);

/** Override, for the considered context, the time-to-live delay for
* re-checking if the cached properties of files are still up-to-date.
*
* @param ctx PROJ context, or NULL
* @param ttl_seconds Delay in seconds. Use negative value for no expiration.
*/
void proj_grid_cache_set_ttl(PJ_CONTEXT* ctx, int ttl_seconds);

/** Clear the local cache of grid chunks.
 *
 * @param ctx PROJ context, or NULL.
```

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```
 */
void proj_grid_cache_clear(PJ_CONTEXT* ctx);
```

The planned database structure is:

```
-- General properties on a file
CREATE TABLE properties(
 url          TEXT PRIMARY KEY NOT NULL,
 lastChecked  TIMESTAMP NOT NULL,
 fileSize     INTEGER NOT NULL,
 lastModified TEXT,
 etag         TEXT
);

-- Store chunks of data. To avoid any potential fragmentation of the
-- cache, the data BLOB is always set to the maximum chunk size of 16 KB
-- (right padded with 0-byte)
-- The actual size is stored in chunks.data_size
CREATE TABLE chunk_data(
 id        INTEGER PRIMARY KEY AUTOINCREMENT CHECK (id > 0),
 data      BLOB NOT NULL
);

-- Record chunks of data by (url, offset)
CREATE TABLE chunks(
 id        INTEGER PRIMARY KEY AUTOINCREMENT CHECK (id > 0),
 url       TEXT NOT NULL,
 offset    INTEGER NOT NULL,
 data_id   INTEGER NOT NULL,
 data_size INTEGER NOT NULL,
 CONSTRAINT fk_chunks_url FOREIGN KEY (url) REFERENCES properties(url),
 CONSTRAINT fk_chunks_data FOREIGN KEY (data_id) REFERENCES chunk_data(id)
);
CREATE INDEX idx_chunks ON chunks(url, offset);

-- Doubly linked list of chunks. The next link is to go to the least-recently
-- used entries.
CREATE TABLE linked_chunks(
 id        INTEGER PRIMARY KEY AUTOINCREMENT CHECK (id > 0),
 chunk_id  INTEGER NOT NULL,
 prev      INTEGER,
 next      INTEGER,
 CONSTRAINT fk_links_chunkid FOREIGN KEY (chunk_id) REFERENCES chunks(id),
 CONSTRAINT fk_links_prev FOREIGN KEY (prev) REFERENCES linked_chunks(id),
 CONSTRAINT fk_links_next FOREIGN KEY (next) REFERENCES linked_chunks(id)
);
CREATE INDEX idx_linked_chunks_chunk_id ON linked_chunks(chunk_id);

-- Head and tail pointers of the linked_chunks. The head pointer is for
-- the most-recently used chunk.
-- There should be just one row in this table.
CREATE TABLE linked_chunks_head_tail(
```

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```
  head       INTEGER,
  tail       INTEGER,
  CONSTRAINT lht_head FOREIGN KEY (head) REFERENCES linked_chunks(id),
  CONSTRAINT lht_tail FOREIGN KEY (tail) REFERENCES linked_chunks(id)
);
INSERT INTO linked_chunks_head_tail VALUES (NULL, NULL);
```

The chunks table will store 16 KB chunks (or less for terminating chunks). The linked_chunks and linked_chunks_head_tail table swill act as a doubly linked list of chunks, with the least recently used ones at the end of the list, which will be evicted when the cache saturates.

The directory used to locate this database will be ${XDG_DATA_HOME}/proj (per https://specifications.freedesktop.org/basedir-spec/basedir-spec-latest.html) where ${XDG_DATA_HOME} defaults to ${HOME}/.local/share on Unix builds and ${LOCALAPPDATA} on Windows builds. Exact details to be sorted out, but https://github.com/ActiveState/appdirs/blob/a54ea98feed0a7593475b94de3a359e9e1fe8fdb/appdirs.py#L45-L97 can be a good reference.

As this database might be accessed by several threads or processes at the same time, the code accessing to it will carefully honour SQLite3 errors regarding to locks, to do appropriate retries if another thread/process is currently locking the database. Accesses requiring a modification of the database will start with a BEGIN IMMEDIATE transaction so as to acquire a write lock.

Note: This database should be hosted on a local disk, not a network one. Otherwise SQLite3 locking issues are to be expected.

CDN provider

Amazon Public Datasets has offered to be a storage and CDN provider.

The program covers storage and egress (bandwidth) of the data. They generally don't allow usage of CloudFront (their CDN) as part of the program (we would usually look to have it covered by credits), but in this instance, they would be fine to provide it. They'd only ask that we keep the CloudFront URL "visible" (as appropriate for the use case) so people can see where the data is hosted in case they go looking. Their terms can be seen at https://aws.amazon.com/service-terms/ and CloudFront has its own, small section. Those terms may change a bit from time to time for minor changes. Major changing service terms is assumed to be unfrequent. There are also the Public Dataset Program terms at http://aws.amazon.com/public-datasets/terms/. Those also do not effectively change over time and are renewed on a 2 year basis.

Criteria for grid hosting

The grids hosted on the CDN will be exactly the ones collected, currently and in the future, by the proj-datumgrid initiative. In particular, new grids are accepted as long as they are released under a license that is compatible with the Open Source Definition and the source of the grid is clearly stated and verifiable. Suitable licenses include:

- Public domain
- X/MIT
- BSD 2/3/4 clause
- CC0
- CC-BY (v3.0 or later)

- CC-BY-SA (v3.0 or later)

For new grids to be transparently used by the proj_create_crs_to_crs() mechanics, they must be registered in the PROJ database (proj.db) in the `grid_transformation` and `grid_alternatives` table. The nominal path to have a new record in the grid_transformation is to have a transformation being registered in the EPSG dataset (if there is no existing one), which will be subsequently imported into the PROJ database.

Versioning, historical preservation of grids

The policy regarding this should be similar to the one applied to proj-datumgrid, which even if not formalized, is around the following lines:

- Geodetic agencies release regularly new version of grids. Typically for the USA, NOAA has released GEOID99, GEOID03, GEOID06, GEOID09, GEOID12A, GEOID12B, GEOID18 for the NAVD88 to NAD83/NAD83(2011) vertical adjustments. Each of these grids is considered by EPSG and PROJ has a separate object, with distinct filenames. The release of a new version does not cause the old grid to be automatically removed. That said, due to advertized accuracies and supersession rules of the EPSG dataset, the most recent grid will generally be used for a CRS -> CRS transformation if the user uses proj_create_crs_to_crs() (with the exception that if a VERT_CRS WKT includes a GEOID_MODEL known to PROJ, an old version of the grid will be used). If the user specifies a whole pipeline with an explicit grid name, it will be of course strictly honoured. As time goes, the size of the datasets managed by proj-datumgrid will be increasing, we will have to explore on we managed that for the distributed .zip / .tar.gz archives. This should not be a concern for CDN hosted content.
- In case software-related conversion errors from the original grid format to the one used by PROJ (be it GTX, NTv2 or GeoTIFF) would happen, the previous erroneous version of the dataset would be replaced by the corrected one. In that situation, this might have an effect with the local on-disk caching of remote grids. We will have to see with the CDN providers used if we can use for example the ETag HTTP header on the client to detect a change, so that old cached content is not erroneously reused (if not possible, we'll have to use some text file listing the grid names and their current md5sum)

12.5.4.4 Grids in GeoTIFF format

Limitations of current formats

Several formats exist depending on the ad-hoc needs and ideas of the original data producer. It would be appropriate to converge on a common format able to address the different use cases.

- Not tiled. Tiling is a nice to have property for cloud-friendly access to large files.
- No support for compression
- The NTv2 structures is roughly: header of main grid, data of main grid, header of subgrid 1, data of subgrid 1, header of subgrid 2, data of subgrid 2, etc.Due to the headers being scattered through the file, it is not possibly to retrieve with a single HTTP GET request all header information.
- GTX format has no provision to store metadata besides the minimum georeferencing of the grid. NTv2 is a bit richer, but no extensible metadata possible.

Discussion on choice of format

We have been made recently aware of other initiatives from the industry to come with a common format to store geodetic adjustment data. Some discussions have happen recently within the OGC CRS Working group. Past efforts include the Esri's proposed Geodetic data Grid eXchange Format, GGXF, briefly mentioned at page 86 of https://iag.dgfi.tum.de/fileadmin/IAG-docs/Travaux2015/01_Travaux_Template_Comm_1_tvd.pdf and page 66 of ftp://ftp.iaspei.org/pub/meetings/2010-2019/2015-Prague/IAG-Geodesy.pdf The current trend of those works would be to use a netCDF / HDF5 container.

So, for the sake of completeness, we list hereafter a few potential candidate formats and their pros and cons.

TIFF/GeoTIFF

Strong points:

- TIFF is a well-known and widespread format.
- The GeoTIFF encoding is a widely industry supported scheme to encode georeferencing. It is now a OGC standard
- There are independent initiatives to share grids as GeoTIFF, like that one
- TIFF can contain multiple images (IFD: Image File Directory) chained together. This is the mechanism used for multiple-page scanned TIFF files, or in the geospatial field to store multi-resolution/pyramid rasters. So it can be used with sub-grids as in the NTv2 format.
- Extensive experience with the TIFF format, and its appropriateness for network access, in particular through the Cloud Optimized GeoTIFF initiative whose layout can make use of sub-grids efficient from a network access perspective, because grid headers can be put at the beginning of the file, and so being retrieved in a single HTTP GET request.
- TIFF can be tiled.
- TIFF can be compressed. Commonly found compression formats are DEFLATE, LZW, combined with differential integer or floating point predictors
- A TIFF image can contain a configurable number of channels/bands/samples. In the rest of the document, we will use the sample terminology for this concept.
- TIFF sample organization can be configured: either the values of different samples are packed together (PlanarConfiguration = Contig), or put in separate tiles/strips (PlanarConfiguration = Separate)
- libtiff is a dependency commonly found in binary distributions of the "ecosystem" to which PROJ belongs too
- libtiff benefits from many years of efforts to increase its security, for example being integrated to the oss-fuzz initiative. Given the potential fetching of grids, using security tested components is an important concern.
- Browser-side: there are "ports" of libtiff/libgeotiff in the browser such as https://geotiffjs.github.io/ which could potentially make a port of PROJ easier.

Weak points:

- we cannot use libgeotiff, since it depends itself on PROJ (to resolve CRS or components of CRS from their EPSG codes). That said, for PROJ intended use, we only need to decode the ModelTiepointTag and ModelPixelScaleTag TIFF tags, so this can be done "at hand"
- the metadata capabilities of TIFF baseline are limited. The TIFF format comes with a predefined set of metadata items whose keys have numeric values. That said, GDAL has used for the last 20 years or so a dedicated tag, GDAL_METADATA of code 42112 that holds a XML-formatted string being able to store arbitrary key-pair values.

netCDF v3

Strong points:

- The binary format description as given in OGC 10-092r3 is relatively simple, but it would still probably be necessary to use libnetcdf-c to access it
- Metadata can be stored easily in netCDF attributes

Weak points:

- No compression in netCDF v3
- No tiling in netCDF v3
- Multi-samples variables are located in different sections of the files (correspond to TIFF PlanarConfiguration = Separate)
- No natural way of having hierarchical / multigrids. They must be encoded as separate variables
- georeferencing in netCDF is somewhat less standardized than TIFF/GeoTIFF. The generally used model is the conventions for CF (Climate and Forecast) metadata but there is nothing really handy in them for simple georeferencing with the coordinate of the upper-left pixel and the resolution. The practice is to write explicit lon and lat variables with all values taken by the grid. GDAL has for many years supported a simpler syntax, using a GeoTransform attribute.
- From the format description, its layout could be relatively cloud friendly, except that libnetcdf has no API to plug an alternate I/O layer.
- Most binary distributions of netCDF nowadays are based on libnetcdf v4, which implies the HDF5 dependency.
- From a few issues we identified a few years ago regarding crashes on corrupted datasets, we contacted libnetcdf upstream, but they did not seem to be interested in addressing those security issues.

netCDF v4 / HDF5

Note: The netCDF v4 format is a profile of the HDF5 file format.

Strong points:

- Compression supported (ZLIB and SZIP predefined)
- Tiling (chunking) supported
- Values of Multi-sample variables can be interleaved together (similarly to TIFF PlanarConfiguration = Contig) by using compound data types.
- Hierarchical organization with groups
- While the netCDF API does not provide an alternate I/O layer, this is possible with the HDF5 API.
- Grids can be indexed by more than 2 dimensions (for current needs, we don't need more than 2D support)

Weak points:

- The HDF 5 File format is more complex than netCDF v3, and likely more than TIFF. We do not have in-depth expertise of it to assess its cloud-friendliness.
- The ones mentioned for netCDF v3 regarding georeferencing and security apply.

GeoPackage

As PROJ has already a SQLite3 dependency, GeoPackage could be examined as a potential solution.

Strong points:

- SQLite3 dependency
- OGC standard
- Multi-grid capabilities
- Tiling
- Compression
- Metadata capabilities

Weak points:

- GeoPackage mostly address the RGB(A) Byte use case, or via the tile gridded data extension, single-sample non-Byte data. No native support for multi-sample non-Byte data: each sample should be put in a separate raster table.
- Experience shows that SQLite3 layout (at least the layout adopted when using the standard libsqlite3) is not cloud friendly. Indices may be scattered in different places of the file.

Conclusions

The 2 major contenders regarding our goals and constraints are GeoTIFF and HDF5. Given past positive experience and its long history, GeoTIFF remains our preferred choice.

Format description

The format description is available in a dedicated *Geodetic TIFF grids (GTG)* document.

Tooling

A script will be developed to accept a list of individual grids to combine together into a single file.

A ntv2_to_gtiff.py convenience script will be created to convert NTv2 grids, including their subgrids, to the above described GeoTIFF layout.

A validation Python script will be created to check that a file meets the above described requirements and recommendations.

Build requirements

The minimum libtiff version will be 4.0 (RHEL 7 ships with libtiff 4.0.3). To be able to read grids stored on the CDN, libtiff will need to build against zlib to have DEFLATE and LZW support, which is met by all known binary distributions of libtiff.

The libtiff dependency can be disabled at build time, but this must be an explicit setting of configure/cmake as the resulting builds have less functionality.

12.5.4.5 Dropping grid catalog functionality

While digging through existing code, I more or less discovered that the PROJ code base has the concept of a grid catalog. This is a feature apparently triggered by using the +catalog=somefilename.csv in a PROJ string, where the CSV file list grid names, their extent, priority and date. It seems to be an alternative to using +nadgrids with multiple grids, with the extra ability to interpolate shift values between several grids if a +date parameter is provided and the grid catalog mentions a date for each grids. It was added in June 2012 per commit fcb186942ec8532655ff6cf4cc990e5da669a3bc

This feature is likely unknown to most users as there is no known documentation for it (neither in current documentation, nor in historic one). It is not either tested by PROJ tests, so its working status is unknown. It would likely make implementation of this RFC easier if this was removed. This would result in completely dropping the gridcatalog.cpp and gc_reader.cpp files, their call sites and the catalog_name and datum_date parameter from the PJ structure.

In case similar functionality would be be needed, it might be later reintroduced as an extra mode of *Horizontal grid shift*, or using a dedicated transformation method, similarly to the *Kinematic datum shifting utilizing a deformation model* one, and possibly combining the several grids to interpolate among in the same file, with a date metadata item.

12.5.4.6 Backward compatibility issues

None anticipated, except the removal of the (presumably little used) grid catalog functionality.

12.5.4.7 Potential future related work

The foundations set in the definition of the GeoTIFF grid format should hopefully be reused to extend them to support deformation models (was initially discussed per https://github.com/OSGeo/PROJ/issues/1001).

Definition of such an extension is out of scope of this RFC.

12.5.4.8 Documentation

- New API function will be documented.
- A dedicated documentation page will be created to explain the working of network-based access.
- A dedicated documentation page will be created to describe the GeoTIFF based grid format. Mostly reusing above material.

12.5.4.9 Testing

Number of GeoTIFF formulations (tiled vs untiled, PlanarConfiguration Separate vs Contig, data types, scale+offset vs not, etc.) will be tested.

For testing of network capabilities, a mix of real hits to the CDN and use of the alternate pluggable network interface to test edge cases will be used.

12.5.4.10 Proposed implementation

A proposed implementation is available at https://github.com/OSGeo/PROJ/pull/1817

Tooling scripts are currently available at https://github.com/rouault/sample_proj_gtiff_grids/ (will be ultimately stored in PROJ repository)

12.5.4.11 Adoption status

The RFC was adopted on 2020-01-10 with +1's from the following PSC members

- Kristian Evers
- Even Rouault
- Thomas Knudsen
- Howard Butler
- Kurt Schwehr

12.5.5 PROJ RFC 5: Adopt GeoTIFF-based grids for grids delivered with PROJ

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Status
Adopted

Implementation target
PROJ 7

Last Updated
2020-01-28

12.5.5.1 Motivation

This RFC is a continuation of *PROJ RFC 4: Remote access to grids and GeoTIFF grids*. With RFC4, PROJ can, upon request of the user, download grids from a CDN in a progressive way. There is also API, such as `proj_download_file()` to be able to download a GeoTIFF grid in the user writable directory. The content of the CDN at https://cdn.proj.org is https://github.com/OSGeo/PROJ-data , which has the same content as https://github.com/OSGeo/proj-datumgrid converted in GeoTIFF files. In the current state, we could have a somewhat inconsistency between users relying on the proj-datumgrid, proj-datumgrid-[world,northamerica,oceania,europe] packages of mostly NTv2 and GTX files, and what is shipped through the CDN. Maintaining two repositories is also a maintenance burden in the long term.

It is thus desirable to have a single source of truth, and we propose it to be based on the GeoTIFF grids.

12.5.5.2 Summary of work planned by this RFC and related decisions

- https://github.com/OSGeo/PROJ-data/ will be used, starting with PROJ 7.0, to create "static" grid packages.
- For now, a single package of, mostly GeoTIFF grids (a few text files for PROJ init style files, as well as a few edge cases for deformation models where grids have not been converted), will be delivered. Its size at the time of writing is 486 MB (compared to 1.5 GB of uncompressed NTv2 + GTX content, compressed to ~ 700 MB currently)
- The content of this archive will be flat, i.e. no subdirectories
- Each file will be named according to the following pattern `${agency_name}_${filename}[.ext]`. For example fr_ign_ntf_r93.tif This convention should allow packagers, if the need arise, to be able to split the monolithic package in smaller ones, based on criterion related to the country.

  The agency name is the one you can see from the directory names at https://github.com/OSGeo/PROJ-data/. `${agency_name}` itself is structure like `${two_letter_country_code_of_agency_nationality}_${some_abbreviation}` (with the exception of eur_nkg, for the Nordic Geodetic Commission which isn't affiliated to a single country but to some European countries, and follows the general scheme)
- https://github.com/OSGeo/proj-datumgrid and related packages will only be maintained during the remaining lifetime of PROJ 6.x. After that, the repository will no longer receive any update and will be put in archiving state (see https://help.github.com/en/github/creating-cloning-and-archiving-repositories/about-archiving-repositories)
- PROJ database `grid_alternatives` table will be updated to point to the new TIFF filenames. It will also maintain the old names as used by current proj-datumgrid packages to be able to provide backward compatibility when a PROJ string refers to a grid by its previous name.
- Upon adoption of this RFC, new grids referenced by PROJ database will only point to GeoTIFF grid names.
- Related to the above point, if a PROJ string refers to a grid name, let's say foo.gsb. This grid will first be looked for in all the relevant locations under this name. If no match is found, then a lookup in the `grid_alternatives` table will be done to retrieve the potential new name (GeoTIFF file), and if there's such match, a new look-up in the file system will be done with the name of this GeoTIFF file.
- The `package_name` column of grid_alternatives will no longer be filled. And `url` will be filled with the direct URL to the grid in the CDN, for example: https://cdn.proj.org/fr_ign_ntf_r93.tif
- The Python scripts to convert grids (NTv2, GTX) to GeoTIFF currently available at https://github.com/rouault/sample_proj_gtiff_grids/ will be moved to a grid_tools/ subdirectories of https://github.com/OSGeo/PROJ-data/ Documentation for those utilities will be added to PROJ documentation.
- Obviously, all the above assumes PROJ builds to have libtiff enabled. Non-libtiff builds are not considered as nominal PROJ builds (if a PROJ master build is attempted and libtiff is not detected, it fails. The user has to explicitly ask to disable TIFF support), and users deciding to go through that route will have to deal with the consequences (that is that grid-based transformations generated by PROJ will likely be non working)

12.5.5.3 Backward compatibility

This change is considered to be *mostly* backward compatible. There might be impacts for software using `proj_coordoperation_get_grid_used()` and assuming that the url returned is one of the proj-datumgrid-xxx files at https://download.osgeo.org. As mentioned in https://lists.osgeo.org/pipermail/proj/2020-January/009274.html , this assumption was not completely bullet-proof either. There will be impacts on software checking the value of PROJ pipeline strings resulting `proj_create_crs_to_crs()`. The new grid names will now be returned (the most impacted software will likely be PROJ's own test suite)

Although discouraged, people not using the new proj-datumgrid-geotiff-XXX.zip archives, should still be able to use the old archives made of NTv2/GTX files, at least as long as the PROJ database does not only point to a GeoTIFF grid. So this might be a short-term partly working solution, but at time goes, it will become increasingly non-working. The nominal combination will be PROJ 7.0 + proj-datumgrid-geotiff-1.0.zip

12.5.5.4 Testing

PROJ test suite will have to be adapted for the new TIFF based filenames.

Mechanism to auto-promote existing NTv2/GTX names to TIFF ones will be exercised.

12.5.5.5 Proposed implementation

https://github.com/OSGeo/PROJ/pull/1891 and https://github.com/OSGeo/PROJ-data/pull/5

12.5.5.6 Adoption status

The RFC was adopted on 2020-01-28 with +1's from the following PSC members

- Kristian Evers
- Even Rouault
- Thomas Knudsen
- Howard Butler
- Kurt Schwehr

12.5.6 PROJ RFC 6: Triangulation-based transformations

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Status
Adopted

Implementation target
PROJ 7.2

Last Updated
2020-09-02

12.5.6.1 Summary

This RFC adds a new transformation method, `tinshift` (TIN stands for Triangulated Irregular Network)

The motivation for this work is to be able to handle the official transformations created by National Land Survey of Finland, for:

- horizontal transformation between the KKJ and ETRS89 horizontal datums
- vertical transformations between N43 and N60 heights, and N60 and N2000 heights.

Such transformations are somehow related to traditional grid-based transformations, except that the correction values are hold by the vertices of the triangulation, instead of being at nodes of a grid.

Triangulation are in a number of cases the initial product of a geodesic adjustment, with grids being a derived product. The Swiss grids have for example derived products of an original triangulation.

Grid-based transformations remain very convenient to use because accessing correction values is really easy and efficient, so triangulation-based transformations are not meant as replacing them, but more about it being a complement, that is sometimes necessary to be able to replicate the results of a officially vetted transformation to a millimetric or better precision (speaking here about reproducibility of numeric results, rather than the physical accuracy of the transformation that might rather be centimetric). It is always possible to approach the result of the triangulation with a grid, but that may require to adopt a small grid step, and thus generate a grid that can be much larger than the original triangulation.

12.5.6.2 Details

Transformation

A new transformation method, `tinshift`, is added. It takes one mandatory argument, `file`, that points to a JSON file, which contains the triangulation and associated metadata. Input and output coordinates must be geographic or projected. Depending on the content of the JSON file, horizontal, vertical or both components of the coordinates may be transformed.

The transformation is used like:

```
$ echo 3210000.0000 6700000.0000 0 2020 | cct +proj=tinshift +file=./triangulation_kkj.
↪json

209948.3217     6697187.0009    0.0000     2020
```

The transformation is invertible, with the same computational complexity than the forward transformation.

Algorithm

Internally, `tinshift` ingest the whole file into memory. It is considered that triangulation should be small enough for that. The above mentioned KKJ to ETRS89 triangulation fits into 65 KB of JSON, for 1449 triangles and 767 vertices.

When a point is transformed, one must find the triangle into which it falls into. Instead of iterating over all triangles, we build a in-memory quadtree to speed-up the identification of candidates triangles. On the above mentioned KKJ -> ETRS89 triangulation, this speeds up the whole transformation by a factor of 10. The quadtree structure is a very good compromise between the performance gain it brings and the simplicity of its implementation (we have ported the implementation coming from GDAL, inherit from the one used for shapefile .spx spatial indices).

To determine if a point falls into a triangle, one computes its 3 barycentric coordinates from its projected coordinates, λ_i for $i = 1, 2, 3$. They are real values (in the [0,1] range for a point inside the triangle), giving the weight of each of the 3 vertices of the triangles.

Once those weights are known, interpolating the target horizontal coordinate is a matter of doing the linear combination of those weights with the target horizontal coordinates at the 3 vertices of the triangle (Xt_i and Yt_i):

$$X_{target} = Xt_1 * \lambda_1 + Xt_2 * \lambda_2 + Xt_3 * \lambda_3$$
$$Y_{target} = Yt_1 * \lambda_1 + Yt_2 * \lambda_2 + Yt_3 * \lambda_3$$

This interpolation is exact at the vertices of the triangulation, and has linear properties inside each triangle. It is completely equivalent to other formulations of triangular interpolation, such as

$$X_{target} = A + X_{source} * B + Y_{source} * C$$
$$Y_{target} = D + X_{source} * E + Y_{source} * F$$

where the A, B, C, D, E, F constants (for a given triangle) are found by solving the 2 systems of 3 linear equations, constraint by the source and target coordinate pairs of the 3 vertices of the triangle:

$$Xt_i = A + Xs_i * B + Ys_i * C$$
$$Yt_i = D + Xs_i * E + Ys_i * F$$

Note: From experiments, the interpolation using barycentric coordinates is slightly more numerically robust when interpolating projected coordinates of amplitude of the order of 1e5 / 1e6, due to computations involving differences of coordinates. Whereas the formulation with the A, B, C, D, E, F tends to have big values for the A and D constants, and values clause to 0 for C and E, and close to 1 for B and F. However, the difference between the two approaches is negligible for practical purposes (below micrometre precision)

Similarly for a vertical coordinate transformation, where $Zoff_i$ is the vertical offset at each vertex of the triangle:

$$Z_{target} = Z_{source} + Zoff_1 * \lambda_1 + Zoff_2 * \lambda_2 + Zoff_3 * \lambda_3$$

Constraints on the triangulation

No check is done on the consistence of the triangulation. It is highly recommended that triangles do not overlap each other (when considering the source coordinates or the forward transformation, or the target coordinates for the inverse transformation), otherwise which triangle will be selected is unspecified. Besides that, the triangulation does not need to have particular properties (like being a Delaunay triangulation)

File format

To the best of our knowledge, there are no established file formats to convey geodetic transformations as triangulations. Potential similar formats to store TINs are ITF or XMS. Both of them would need to be extended in order to handle datum shift information, since they are both intended for mostly DEM use.

We thus propose a text-based format, using JSON as a serialization. Using a text-based format could potentially be thought as a limitation performance-wise compared to binary formats, but for the size of triangulations considered (a few thousands triangles / vertices), there is no issue. Loading such file is a matter of 20 milliseconds or so. For reference, loading a triangulation of about 115 000 triangles and 71 000 vertices takes 450 ms.

Using JSON provides generic formatting and parsing rules, and convenience to create it from Python script for examples. This could also be easily generated "at hand" by non-JSON aware writers.

For generic metadata, we reuse closely what has been used for the Deformation model master file

Below a minimal example, from the KKJ to ETRS89 transformation, with just a single triangle:

```
{
    "file_type": "triangulation_file",
    "format_version": "1.0",
    "name": "Name",
    "version": "Version",
    "publication_date": "2018-07-01T00:00:00Z",
    "license": "Creative Commons Attribution 4.0 International",
    "description": "Test triangulation",
    "authority": {
        "name": "Authority name",
        "url": "http://example.com",
        "address": "Address",
        "email": "test@example.com"
    },
    "links": [
    {
        "href": "https://example.com/about.html",
        "rel": "about",
        "type": "text/html",
        "title": "About"
    },
    {
        "href": "https://example.com/download",
        "rel": "source",
        "type": "application/zip",
        "title": "Authoritative source"
    },
    {
        "href": "https://creativecommons.org/licenses/by/4.0/",
        "rel": "license",
        "type": "text/html",
        "title": "Creative Commons Attribution 4.0 International license"
    },
    {
        "href": "https://example.com/metadata.xml",
        "rel": "metadata",
        "type": "application/xml",
    "title": " ISO 19115 XML encoded metadata regarding the triangulation"
        }
    ],
    "input_crs": "EPSG:2393",
    "target_crs": "EPSG:3067",
    "transformed_components": [ "horizontal" ],
    "vertices_columns": [ "source_x", "source_y", "target_x", "target_y" ],
    "triangles_columns": [ "idx_vertex1", "idx_vertex2", "idx_vertex3" ],
    "vertices": [ [3244102.707, 6693710.937, 244037.137, 6690900.686],
                  [3205290.722, 6715311.822, 205240.895, 6712492.577],
                  [3218328.492, 6649538.429, 218273.648, 6646745.973] ],
    "triangles": [ [0, 1, 2] ]
}
```

So after the generic metadata, we define the input and output CRS (informative only), and that the transformation affects horizontal components of coordinates. We name the columns of the `vertices` and `triangles` arrays. We defined the source and target coordinates of each vertex, and define a triangle by referring to the index of its vertices in the `vertices` array.

More formally, the specific items for the triangulation file are:

input_crs
String identifying the CRS of source coordinates in the vertices. Typically `EPSG:XXXX`. If the transformation is for vertical component, this should be the code for a compound CRS (can be EPSG:XXXX+YYYY where XXXX is the code of the horizontal CRS and YYYY the code of the vertical CRS). For example, for the KKJ->ETRS89 transformation, this is EPSG:2393 (`KKJ / Finland Uniform Coordinate System`). The input coordinates are assumed to be passed in the "normalized for visualisation" / "GIS friendly" order, that is longitude, latitude for geographic coordinates and easting, northing for projected coordinates.

output_crs
String identifying the CRS of target coordinates in the vertices. Typically `EPSG:XXXX`. If the transformation is for vertical component, this should be the code for a compound CRS (can be EPSG:XXXX+YYYY where XXXX is the code of the horizontal CRS and YYYY the code of the vertical CRS). For example, for the KKJ->ETRS89 transformation, this is EPSG:3067 ("ETRS89 / TM35FIN(E,N)"). The output coordinates will be returned in the "normalized for visualisation" / "GIS friendly" order, that is longitude, latitude for geographic coordinates and easting, northing for projected coordinates.

transformed_components
Array which may contain one or two strings: "horizontal" when horizontal components of the coordinates are transformed and/or "vertical" when the vertical component is transformed.

vertices_columns
Specify the name of the columns of the rows in the `vertices` array. There must be exactly as many elements in `vertices_columns` as in a row of `vertices`. The following names have a special meaning: `source_x`, `source_y`, `target_x`, `target_y`, `source_z`, `target_z` and `offset_z`. `source_x` and `source_y` are compulsory. `source_x` is for the source longitude (in degree) or easting. `source_y` is for the source latitude (in degree) or northing. `target_x` and `target_y` are compulsory when `horizontal` is specified in `transformed_components`. (`source_z` and `target_z`) or `offset_z` are compulsory when `vertical` is specified in `transformed_components`

triangles_columns
Specify the name of the columns of the rows in the `triangles` array. There must be exactly as many elements in `triangles_columns` as in a row of `triangles`. The following names have a special meaning: `idx_vertex1`, `idx_vertex2`, `idx_vertex3`. They are compulsory.

vertices
An array whose items are themselves arrays with as many columns as described in `vertices_columns`.

triangles
An array whose items are themselves arrays with as many columns as described in `triangles_columns`. The value of the `idx_vertexN` columns must be indices (between 0 and len(`vertices`-1) of items of the `vertices` array.

Code impacts

The following new files are added in src/transformations:

- tinshift.cpp: PROJ specific code for defining the new operation. Takes care of the input and output coordinate conversions (between input_crs and triangulation_source_crs, and triangulation_target_crs and output_crs), when needed.
- tinshift.hpp: Header-based implementation. This file contains the API.
- tinshift_exceptions.hpp: Exceptions that can be raised during file parsing

- tinshift_impl.hpp: Implementation of file loading, triangle search and interpolation.

This is the approach that has been followed for the deformation model implementation, and which makes it easier to do unit test.

src/quadtree.hpp contains a quadtree implementation.

Performance indications

Tested on Intel(R) Core(TM) i7-6700HQ CPU @ 2.60GHz, transforming 4 million points

For the KKJ to ETRS89 transformation (1449 triangles and 767 vertices), 4.4 million points / sec can be transformed.

For comparison, the Helmert-based KKJ to ETRS89 transformation operates at 1.6 million points / sec.

A triangulation with about 115 000 triangles and 71 000 vertices operates at 2.2 million points / sec (throughput on more points would be better since the initial loading of the triangulation is non-negligible here)

12.5.6.3 Backward compatibility

New functionality fully backward compatible.

12.5.6.4 Testing

The PROJ test suite will be enhanced to test the new transformation, with a new .gie file, and a C++ unit test to test at a lower level.

12.5.6.5 Documentation

- The tinshift method will be documented.
- The JSON format will be documented under https://proj.org/specifications/
- A JSON schema will also be provided.

12.5.6.6 Proposed implementation

An initial implementation is available at https://github.com/rouault/PROJ/tree/tinshift

12.5.6.7 References

Finnish coordinate transformation (automated translation to English)

12.5.6.8 Adoption status

The RFC was adopted on 2020-09-02 with +1's from the following PSC members

- Kristian Evers
- Charles Karney
- Thomas Knudsen
- Even Rouault

12.5.6.9 Funding

This work is funded by National Land Survey of Finland

12.6 Conference

FOSS4G 2021 is the leading annual conference for free and open source geospatial software. It will include presentations related to PROJ, and some of the PROJ development community will be attending. It is the event for those interested in PROJ, other FOSS geospatial technologies and the community around them. The conference will due to COVID-19 be held in a virtual setting September 27th - October 2nd, 2021.

CHAPTER

THIRTEEN

FAQ

13.1 Which file formats does PROJ support?

The *command line applications* that come with PROJ only support text input and output (apart from **proj** which accepts a simple binary data stream as well). **proj**, **cs2cs** and **cct** expects text files with one coordinate per line with each coordinate dimension in a separate column.

Note: If your data is stored in a common geodata file format chances are that you can use GDAL as a frontend to PROJ and transform your data with the **ogr2ogr** application.

13.2 Can I transform from *abc* to *xyz*?

Probably. PROJ supports transformations between most coordinate reference systems registered in the EPSG registry, as well as a number of other coordinate reference systems. The best way to find out is to test it with the **projinfo** application. Here's an example checking if there's a transformation between ETRS89/UTM32N (EPSG:25832) and ETRS89/DKTM1 (EPSG:4093):

```
$ ./projinfo -s EPSG:25832 -t EPSG:4093 -o PROJ
Candidate operations found: 1
-------------------------------------
Operation No. 1:

unknown id, Inverse of UTM zone 32N + DKTM1, 0 m, World

PROJ string:
+proj=pipeline
  +step +inv +proj=utm +zone=32 +ellps=GRS80
  +step +proj=tmerc +lat_0=0 +lon_0=9 +k=0.99998 +x_0=200000 +y_0=-5000000
        +ellps=GRS80
```

See the **projinfo** *documentation* for more info on how to use it.

13.3 Coordinate reference system *xyz* is not in the EPSG registry, what do I do?

Generally PROJ will accept coordinate reference system descriptions in the form of WKT, WKT2 and PROJ strings. If you are able to describe your desired CRS in either of those formats there's a good chance that PROJ will be able to make sense of it.

If it is important to you that a given CRS is added to the EPSG registry, you should contact your local geodetic authority and ask them to submit the CRS for inclusion in the registry.

13.4 I found a bug in PROJ, how do I get it fixed?

Please report bugs that you find to the issue tracker on GitHub. *Here's how*.

If you know how to program you can also try to fix it yourself. You are welcome to ask for guidance on one of the *communication channels* used by the project.

13.5 How do I contribute to PROJ?

Any contributions from the PROJ community is welcome. See *Contributing* for more details.

13.6 How do I calculate distances/directions on the surface of the earth?

These are called geodesic calculations. There is a page about it here: *Geodesic calculations*.

13.7 What is the best format for describing coordinate reference systems?

A coordinate reference system (CRS) can in PROJ be described in several ways: As PROJ strings, Well-Known Text (WKT) and as spatial reference ID's (such as EPSG codes). Generally, WKT or SRID's are preferred over PROJ strings as they can contain more information about a given CRS. Conversions between WKT and PROJ strings will in most cases cause a loss of information, potentially leading to erroneous transformations.

For compatibility reasons PROJ supports several WKT dialects (see `projinfo -o`). If possible WKT2 should be used.

13.8 Why is the axis ordering in PROJ not consistent?

PROJ respects the axis ordering as it was defined by the authority in charge of a given coordinate reference system. This is in accordance to the ISO19111 standard [ISO19111]. Unfortunately most GIS software on the market doesn't follow this standard. Before version 6, PROJ did not respect the standard either. This causes some problems while the rest of the industry conforms to the standard. PROJ intends to spearhead this effort, hopefully setting a good example for the rest of the geospatial industry.

Customarily in GIS the first component in a coordinate tuple has been aligned with the east/west direction and the second component with the north/south direction. For many coordinate reference systems this is also what is defined by the authority. There are however exceptions, especially when dealing with coordinate systems that don't align with the cardinal directions of a compass. For example it is not obvious which coordinate component aligns to which axis in a skewed coordinate system with a 45 degrees angle against the north direction. Similarly, a geocentric cartesian coordinate system usually has the z-component aligned with the rotational axis of the earth and hence the axis points towards north. Both cases are incompatible with the convention of always having the x-component be the east/west axis, the y-component the north/south axis and the z-component the up/down axis.

In most cases coordinate reference systems with geodetic coordinates expect the input ordered as latitude/longitude (typically with the EPSG dataset), however, internally PROJ expects an longitude/latitude ordering for all projections. This is generally hidden for users but in a few cases it is exposed at the surface level of PROJ, most prominently in the **proj** utility which expects longitude/latitude ordering of input date (unless *proj -r* is used).

In case of doubt about the axis order of a specific CRS **projinfo** is able to provide an answer. Simply look up the CRS and examine the axis specification of the Well-Known Text output:

```
projinfo EPSG:4326
PROJ.4 string:
+proj=longlat +datum=WGS84 +no_defs +type=crs

WKT2:2019 string:
GEOGCRS["WGS 84",
    DATUM["World Geodetic System 1984",
        ELLIPSOID["WGS 84",6378137,298.257223563,
            LENGTHUNIT["metre",1]]],
    PRIMEM["Greenwich",0,
        ANGLEUNIT["degree",0.0174532925199433]],
    CS[ellipsoidal,2],
        AXIS["geodetic latitude (Lat)",north,
            ORDER[1],
            ANGLEUNIT["degree",0.0174532925199433]],
        AXIS["geodetic longitude (Lon)",east,
            ORDER[2],
            ANGLEUNIT["degree",0.0174532925199433]],
    USAGE[
        SCOPE["unknown"],
        AREA["World"],
        BBOX[-90,-180,90,180]],
    ID["EPSG",4326]]
```

13.9 Why am I getting the error "Cannot find proj.db"?

The file *proj.db* must be readable for the library to properly function. Like other *resource files*, it is located using a set of search paths. In most cases, the following paths are checked in order:

- A path provided by the environment variable *PROJ_LIB*.
- A path built into PROJ as its resource installation directory (typically ../share/proj relative to the PROJ library).
- The current directory.

Note that if you're using conda, activating an environment sets *PROJ_LIB* to a resource directory located in that environment.

13.10 What happened to PROJ.4?

The first incarnation of PROJ saw the light of day in 1983. Back then it was simply known as PROJ. Eventually a new version was released, known as PROJ.2 in order to distinguish between the two versions. Later on both PROJ.3 and PROJ.4 was released. By the time PROJ.4 was released the software had matured enough that a new major version release wasn't an immediate necessity. PROJ.4 was around for more than 25 years before it again became time for an update. This left the project in a bit of a conundrum regarding the name. For the majority of the life-time of the product it was known as PROJ.4, but with the release of version 5 the name was no longer aligned with the version number. As a consequence, it was decided to decouple the name from the version number and once again simply call the software PROJ.

Use of name PROJ.4 is now strictly reserved for describing legacy behavior of the software, e.g. "PROJ.4 strings" as seen in **projinfo** output.

CHAPTER

FOURTEEN

GLOSSARY

Ballpark transformation

For a transformation between two geographic CRS, a ballpark transformation is a coordinate operation that only takes into account potential difference of axis orders (long-lat vs lat-long), units (degree vs grads) and prime meridian (Greenwich vs Paris/Rome/other historic prime meridians). It does not attempt any datum shift, hence the "ballpark" qualifier in its name. Its accuracy is unknown, and could lead in some cases to errors of a few hundreds of metres.

For a transformation between two vertical CRS or a vertical CRS and a geographic CRS, a ballpark transformation only takes into account potential different in units (e.g. metres vs feet). Its accuracy is unknown, and could lead in some cases to errors of a few tens of metres.

Note: The term "Ballpark transformation" is specific to PROJ.

Pseudocylindrical Projection

Pseudocylindrical projections have the mathematical characteristics of

$$x = f(\lambda, \phi)$$
$$y = g(\phi)$$

where the parallels of latitude are straight lines, like cylindrical projections, but the meridians are curved toward the center as they depart from the equator. This is an effort to minimize the distortion of the polar regions inherent in the cylindrical projections.

Pseudocylindrical projections are almost exclusively used for small scale global displays and, except for the Sinusoidal projection, only derived for a spherical Earth. Because of the basic definition none of the pseudocylindrical projections are conformal but many are equal area.

To further reduce distortion, pseudocylindrical are often presented in interrupted form that are made by joining several regions with appropriate central meridians and false easting and clipping boundaries. Interrupted Homolosine constructions are suited for showing respective global land and oceanic regions, for example. To reduce the lateral size of the map, some uses remove an irregular, North-South strip of the mid-Atlantic region so that the western tip of Africa is plotted north of the eastern tip of South America.

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