PROJ coordinate transformation software library

Release 6.3.1

PROJ contributors

February 2020
7 Coordinate operations

7.1 Projections

7.1.1 Albers Equal Area

7.1.2 Azimuthal Equidistant

7.1.3 Airy

7.1.4 Aitoff

7.1.5 Modified Stereographic of Alaska

7.1.6 Apian Globular I

7.1.7 August Epicycloidal

7.1.8 Bacon Globular

7.1.9 Bertin 1953

7.1.10 Bipolar conic of western hemisphere

7.1.1.1 Options

7.1.2.1 Options

7.1.3.1 Options

7.1.4.1 Parameters

7.1.5.1 Options

7.1.6.1 Options

7.1.7.1 Parameters

7.1.8.1 Parameters

7.1.9.1 Usage

7.1.9.2 Parameters

7.1.9.3 Further reading

7.1.10 Bipolar conic of western hemisphere

6.1 cct

6.1.1 Synopsis

6.1.2 Description

6.1.3 Examples

6.1.4 Background

6.2 cs2cs

6.2.1 Synopsis

6.2.2 Description

6.2.3 Examples

6.2.3.1 Using PROJ strings

6.2.3.2 Using EPSG codes

6.3 geod

6.3.1 Synopsis

6.3.2 Description

6.3.3 Examples

6.3.4 Further reading

6.4 gie

6.4.1 Synopsis

6.4.2 Description

6.4.3 Examples

6.4.4 gie command language

6.4.5 Background

6.5 proj

6.5.1 Synopsis

6.5.2 Description

6.5.3 Example

6.6 projinfo

6.6.1 Synopsis

6.6.2 Description

6.6.3 Examples

6.6.3.2 Using EPSG codes

6.6.3.1 Using PROJ strings

6.6.3.2 Using EPSG codes

6.6.3.1 Using PROJ strings

6.6.3.2 Using EPSG codes
7.1.31 Usage .......................................................... 104
7.1.31.1 Parameters .............................................. 104
7.1.31.2 Further reading ........................................... 104
7.1.32 Euler .......................................................... 105
7.1.32.1 Parameters .............................................. 105
7.1.33 Fahey .......................................................... 106
7.1.33.1 Parameters .............................................. 107
7.1.34 Foucaut ....................................................... 107
7.1.34.1 Parameters .............................................. 108
7.1.35 Foucaut Sinusoidal ......................................... 108
7.1.35.1 Parameters .............................................. 109
7.1.36 Gall (Gall Stereographic) ................................. 109
7.1.36.1 Usage .................................................... 109
7.1.36.2 Parameters .............................................. 110
7.1.36.3 Mathematical definition ......................... 111
7.1.36.4 Further reading ........................................ 111
7.1.37 Geostationary Satellite View ......................... 111
7.1.37.1 Usage .................................................... 113
7.1.37.2 Parameters .............................................. 114
7.1.38 Ginsburg VIII (TsNIIGAiK) ............................... 114
7.1.38.1 Parameters .............................................. 114
7.1.39 General Sinusoidal Series ............................. 116
7.1.39.1 Parameters .............................................. 116
7.1.40 Gnomonic ................................................... 116
7.1.40.1 Parameters .............................................. 116
7.1.41 Goode Homolosine ....................................... 118
7.1.41.1 Parameters .............................................. 118
7.1.42 Mod. Stererographics of 48 U.S. .................... 119
7.1.42.1 Parameters .............................................. 119
7.1.43 Mod. Stereographics of 50 U.S. .................... 119
7.1.43.1 Parameters .............................................. 119
7.1.44 Hammer & Eckert-Greifendorff ...................... 120
7.1.44.1 Parameters .............................................. 121
7.1.45 Hatano Asymmetrical Equal Area .................. 121
7.1.45.1 Parameters .............................................. 121
7.1.46 HEALPix .................................................... 123
7.1.46.1 Usage .................................................... 124
7.1.46.2 Parameters .............................................. 124
7.1.46.3 Further reading ........................................ 124
7.1.47 rHEALPix .................................................. 125
7.1.47.1 Usage .................................................... 126
7.1.47.2 Parameters .............................................. 126
7.1.47.3 Further reading ........................................ 126
7.1.48 Interrupted Goode Homolosine ..................... 127
7.1.48.1 Parameters .............................................. 127
7.1.49 International Map of the World Polyconic ........ 127
7.1.49.1 Parameters .............................................. 127
7.1.50 Icosahedral Snyder Equal Area ..................... 129
7.1.50.1 Parameters .............................................. 129
7.1.51 Kavraisky V ............................................... 130
7.1.51.1 Parameters .............................................. 130
7.1.52 Kavraisky VII ............................................. 131
7.1.52.1 Parameters .............................................. 131
7.1.53 Krovak ...................................................... 132
7.1.53.1 Parameters .................................................. 132
7.1.54 Laborde ......................................................... 133
7.1.54.1 Parameters .................................................. 133
7.1.55 Lambert Azimuthal Equal Area ................................ 135
7.1.55.1 Parameters .................................................. 135
7.1.56 Lagrange ......................................................... 136
7.1.56.1 Parameters .................................................. 137
7.1.57 Larrivee ......................................................... 137
7.1.57.1 Parameters .................................................. 137
7.1.58 Laskowski ....................................................... 139
7.1.58.1 Parameters .................................................. 139
7.1.59 Lambert Conformal Conic ................................... 140
7.1.59.1 Parameters .................................................. 141
7.1.59.2 Further reading ............................................. 142
7.1.60 Lambert Conformal Conic Alternative ....................... 142
7.1.60.1 Parameters .................................................. 142
7.1.61 Lambert Equal Area Conic ................................... 143
7.1.61.1 Parameters .................................................. 143
7.1.62 Lee Oblated Stereographic .................................. 144
7.1.62.1 Parameters .................................................. 144
7.1.63 Loximuthal ...................................................... 144
7.1.63.1 Parameters .................................................. 144
7.1.64 Space oblique for LANDSAT .................................. 146
7.1.64.1 Parameters .................................................. 146
7.1.65 McBryde-Thomas Flat-Polar Sine (No. 1) ....................... 147
7.1.65.1 Parameters .................................................. 147
7.1.66 McBryde-Thomas Flat-Pole Sine (No. 2) ....................... 148
7.1.66.1 Parameters .................................................. 149
7.1.67 McBride-Thomas Flat-Polar Parabolic ......................... 149
7.1.67.1 Parameters .................................................. 149
7.1.68 McBryde-Thomas Flat-Polar Quartic ........................ 150
7.1.68.1 Parameters .................................................. 150
7.1.69 McBryde-Thomas Flat-Polar Sinusoidal ....................... 151
7.1.69.1 Parameters .................................................. 151
7.1.70 Mercator ........................................................ 152
7.1.70.1 Usage ......................................................... 153
7.1.70.2 Parameters .................................................. 153
7.1.70.3 Mathematical definition ................................... 154
7.1.70.4 Further reading ............................................. 155
7.1.71 Miller Oblated Stereographic ................................ 155
7.1.71.1 Parameters .................................................. 156
7.1.72 Miller Cylindrical ............................................. 156
7.1.72.1 Usage ......................................................... 156
7.1.72.2 Parameters .................................................. 157
7.1.72.3 Mathematical definition ................................... 158
7.1.72.4 Further reading ............................................. 158
7.1.73 Space oblique for MISR ........................................ 158
7.1.73.1 Parameters .................................................. 158
7.1.74 Mollweide ....................................................... 160
7.1.74.1 Parameters .................................................. 160
7.1.75 Murdoch I ....................................................... 161
7.1.75.1 Parameters .................................................. 161
7.1.76 Murdoch II ...................................................... 162
7.1.76.1 Parameters .................................................. 162
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1.125</td>
<td>Usage</td>
<td>229</td>
</tr>
<tr>
<td>7.1.125</td>
<td>Parameters</td>
<td>229</td>
</tr>
<tr>
<td>7.1.125</td>
<td>Further reading</td>
<td>230</td>
</tr>
<tr>
<td>7.1.126</td>
<td>van der Grinten I</td>
<td>230</td>
</tr>
<tr>
<td>7.1.126</td>
<td>Parameters</td>
<td>231</td>
</tr>
<tr>
<td>7.1.127</td>
<td>van der Grinten II</td>
<td>231</td>
</tr>
<tr>
<td>7.1.127</td>
<td>Parameters</td>
<td>231</td>
</tr>
<tr>
<td>7.1.128</td>
<td>van der Grinten III</td>
<td>233</td>
</tr>
<tr>
<td>7.1.128</td>
<td>Parameters</td>
<td>233</td>
</tr>
<tr>
<td>7.1.129</td>
<td>van der Grinten IV</td>
<td>234</td>
</tr>
<tr>
<td>7.1.129</td>
<td>Parameters</td>
<td>234</td>
</tr>
<tr>
<td>7.1.130</td>
<td>Vitkovsky I</td>
<td>235</td>
</tr>
<tr>
<td>7.1.130</td>
<td>Parameters</td>
<td>235</td>
</tr>
<tr>
<td>7.1.131</td>
<td>Wagner I (Kavraisky VI)</td>
<td>236</td>
</tr>
<tr>
<td>7.1.131</td>
<td>Parameters</td>
<td>236</td>
</tr>
<tr>
<td>7.1.132</td>
<td>Wagner II</td>
<td>237</td>
</tr>
<tr>
<td>7.1.132</td>
<td>Parameters</td>
<td>237</td>
</tr>
<tr>
<td>7.1.133</td>
<td>Wagner III</td>
<td>238</td>
</tr>
<tr>
<td>7.1.133</td>
<td>Parameters</td>
<td>238</td>
</tr>
<tr>
<td>7.1.134</td>
<td>Wagner IV</td>
<td>239</td>
</tr>
<tr>
<td>7.1.134</td>
<td>Parameters</td>
<td>239</td>
</tr>
<tr>
<td>7.1.135</td>
<td>Wagner V</td>
<td>240</td>
</tr>
<tr>
<td>7.1.135</td>
<td>Parameters</td>
<td>240</td>
</tr>
<tr>
<td>7.1.136</td>
<td>Wagner VI</td>
<td>241</td>
</tr>
<tr>
<td>7.1.136</td>
<td>Parameters</td>
<td>241</td>
</tr>
<tr>
<td>7.1.137</td>
<td>Wagner VII</td>
<td>242</td>
</tr>
<tr>
<td>7.1.138</td>
<td>Web Mercator / Pseudo Mercator</td>
<td>242</td>
</tr>
<tr>
<td>7.1.138</td>
<td>Usage</td>
<td>243</td>
</tr>
<tr>
<td>7.1.138</td>
<td>Parameters</td>
<td>243</td>
</tr>
<tr>
<td>7.1.138</td>
<td>Mathematical definition</td>
<td>243</td>
</tr>
<tr>
<td>7.1.138</td>
<td>Further reading</td>
<td>244</td>
</tr>
<tr>
<td>7.1.139</td>
<td>Werenskiold I</td>
<td>244</td>
</tr>
<tr>
<td>7.1.139</td>
<td>Parameters</td>
<td>244</td>
</tr>
<tr>
<td>7.1.140</td>
<td>Winkel I</td>
<td>245</td>
</tr>
<tr>
<td>7.1.140</td>
<td>Parameters</td>
<td>245</td>
</tr>
<tr>
<td>7.1.141</td>
<td>Winkel II</td>
<td>246</td>
</tr>
<tr>
<td>7.1.141</td>
<td>Parameters</td>
<td>246</td>
</tr>
<tr>
<td>7.1.142</td>
<td>Winkel Tripel</td>
<td>247</td>
</tr>
<tr>
<td>7.1.142</td>
<td>Parameters</td>
<td>247</td>
</tr>
<tr>
<td>7.2</td>
<td>Conversions</td>
<td>248</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Axis swap</td>
<td>248</td>
</tr>
<tr>
<td>7.2.1.1</td>
<td>Usage</td>
<td>248</td>
</tr>
<tr>
<td>7.2.1.2</td>
<td>Parameters</td>
<td>248</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Geodetic to cartesian conversion</td>
<td>249</td>
</tr>
<tr>
<td>7.2.2.1</td>
<td>Usage</td>
<td>249</td>
</tr>
<tr>
<td>7.2.2.2</td>
<td>Parameters</td>
<td>249</td>
</tr>
<tr>
<td>7.2.3</td>
<td>Geocentric Latitude</td>
<td>249</td>
</tr>
<tr>
<td>7.2.3.1</td>
<td>Mathematical definition</td>
<td>250</td>
</tr>
<tr>
<td>7.2.3.2</td>
<td>Usage</td>
<td>250</td>
</tr>
<tr>
<td>7.2.3.3</td>
<td>Parameters</td>
<td>251</td>
</tr>
<tr>
<td>7.2.4</td>
<td>Lat/long (Geodetic alias)</td>
<td>251</td>
</tr>
<tr>
<td>7.2.4.1</td>
<td>Parameters</td>
<td>251</td>
</tr>
<tr>
<td>7.2.5</td>
<td>No operation</td>
<td>251</td>
</tr>
<tr>
<td>7.2.6</td>
<td>Pop coordinate value to pipeline stack</td>
<td>252</td>
</tr>
</tbody>
</table>
7.2.6.1 Examples ........................................... 252
7.2.6.2 Parameters ........................................... 253
7.2.6.3 Further reading ........................................... 253
7.2.7 Push coordinate value to pipeline stack ........................................... 253
7.2.7.1 Examples ........................................... 253
7.2.7.2 Parameters ........................................... 254
7.2.7.3 Further reading ........................................... 254
7.2.8 Unit conversion ........................................... 254
7.2.8.1 Parameters ........................................... 255
7.2.8.2 Distance units ........................................... 256
7.2.8.3 Angular units ........................................... 256
7.2.8.4 Time units ........................................... 256
7.3 Transformations ........................................... 257
7.3.1 Affine transformation ........................................... 257
7.3.1.1 Parameters ........................................... 257
7.3.2 Kinematic datum shifting utilizing a deformation model ........................................... 258
7.3.2.1 Example ........................................... 258
7.3.2.2 Parameters ........................................... 259
7.3.2.3 Mathematical description ........................................... 260
7.3.2.4 See also ........................................... 260
7.3.3 Geographic offsets ........................................... 260
7.3.3.1 Examples ........................................... 261
7.3.3.2 Parameters ........................................... 261
7.3.4 Helmert transform ........................................... 261
7.3.4.1 Examples ........................................... 262
7.3.4.2 Parameters ........................................... 262
7.3.4.3 Mathematical description ........................................... 264
7.3.5 Horner polynomial evaluation ........................................... 266
7.3.5.1 Examples ........................................... 266
7.3.5.2 Parameters ........................................... 267
7.3.5.3 Further reading ........................................... 269
7.3.6 Molodensky transform ........................................... 269
7.3.6.1 Examples ........................................... 269
7.3.6.2 Parameters ........................................... 270
7.3.7 Molodensky-Badekas transform ........................................... 270
7.3.7.1 Example ........................................... 271
7.3.7.2 Parameters ........................................... 271
7.3.7.3 Mathematical description ........................................... 272
7.3.8 Horizontal grid shift ........................................... 272
7.3.8.1 Temporal gridshifting ........................................... 272
7.3.8.2 Parameters ........................................... 273
7.3.9 Vertical grid shift ........................................... 274
7.3.9.1 Temporal gridshifting ........................................... 274
7.3.9.2 Parameters ........................................... 275
7.4 The pipeline operator ........................................... 276
7.4.1 Rules for pipelines ........................................... 276
7.4.2 Parameters ........................................... 277
7.4.2.1 Required ........................................... 277
7.4.2.2 Optional ........................................... 277
7.5 Computation of coordinate operations between two CRS ........................................... 278
7.5.1 Introduction ........................................... 278
7.5.2 Geographic CRS to Geographic CRS, with known identifiers ........................................... 279
7.5.3 Filtering and sorting of coordinate operations ........................................... 280
7.5.4 Geodetic/geographic CRS to Geodetic/geographic CRS, without known identifiers ........................................... 280
10.9.2 Code example ............................................. 509
10.9.3 Function mapping from old to new API .................... 511

11 Community .................................................. 513
11.1 Communication channels ...................................... 513
  11.1.1 Mailing list ............................................. 513
  11.1.2 GitHub .................................................. 513
  11.1.3 Gitter .................................................... 513
11.2 Contributing ................................................ 514
  11.2.1 Help a fellow PROJ user ................................ 514
  11.2.2 Adding bug reports .................................... 514
  11.2.3 Feature requests ........................................ 515
  11.2.4 Write documentation ................................... 515
  11.2.5 Code contributions ..................................... 515
    11.2.5.1 Legalese ............................................ 515
  11.2.6 Additional Resources ................................... 516
  11.2.7 Acknowledgements ...................................... 516
11.3 Guidelines for PROJ code contributors ...................... 516
  11.3.1 Code contributions ..................................... 516
    11.3.1.1 Making Changes ................................... 516
    11.3.1.2 Submitting Changes ................................. 517
    11.3.1.3 Coding conventions ................................. 517
  11.3.2 Tools ................................................... 517
    11.3.2.1 cppcheck static analyzer .......................... 517
    11.3.2.2 CLang Static Analyzer (CSA) ....................... 518
    11.3.2.3 Typo detection and fixes .......................... 518
    11.3.2.4 Include What You Use (IWYU) ....................... 518
11.4 Code of Conduct ........................................... 519
  11.4.1 Our Pledge ............................................. 519
  11.4.2 Our Standards ......................................... 519
  11.4.3 Our Responsibilities ................................. 519
  11.4.4 Scope .................................................. 520
  11.4.5 Enforcement ........................................... 520
  11.4.6 Attribution ............................................ 520
11.5 Request for Comments ...................................... 520
  11.5.1 PROJ RFC 1: Project Committee Guidelines ............. 520
    11.5.1.1 Summary ............................................ 520
    11.5.1.2 List of PSC Members ............................... 521
    11.5.1.3 Detailed Process ................................. 521
    11.5.1.4 When is Vote Required? ........................... 522
    11.5.1.5 Observations ...................................... 522
    11.5.1.6 Committee Membership ............................. 522
    11.5.1.7 Membership Responsibilities ..................... 523
    11.5.1.8 Updates ............................................ 523
  11.5.2 PROJ RFC 2: Initial integration of “GDAL SRS barn” work 523
    11.5.2.1 Summary ............................................ 523
    11.5.2.2 Related standards .................................. 524
    11.5.2.3 Details .............................................. 524
    11.5.2.4 Code repository .................................... 528
    11.5.2.5 Database .......................................... 528
    11.5.2.6 Utilities .......................................... 530
    11.5.2.7 Impacted files ..................................... 534
    11.5.2.8 C API .............................................. 536
    11.5.2.9 Documentation ..................................... 537

xiii
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:


A BibTeX entry for LaTeX users is

```bibtex
@Manual{,
  title = {{PROJ} coordinate transformation software library},
  author = {{PROJ contributors}},
  organization = {Open Source Geospatial Foundation},
  year = {2020},
  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:

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CHAPTER TWO

NEWS

2.1 6.3.1 Release Notes

February 11th 2020

2.1.1 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

2.1.2 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)
2.2 6.3.0 Release Notes

January 1st 2020

2.2.1 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)

2.2.2 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 Windo (#1688)
2.3 6.2.1 Release Notes

November 1st 2019

2.3.1 Updates

• Update the EPSG database to version 9.8.2

2.3.2 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 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)
2.4 6.2.0 Release Notes

September 1st 2019

2.4.1 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)

2.4.2 Bug Fixes

• Fixed build failure on Solaris systems (#1554)

2.5 6.1.1 Release Notes

July 1st 2019

2.5.1 Updates

• Update EPSG registry to version 9.6.3 (#1485)

2.5.2 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)
2.6 6.1.0 Release Notes

May 15th 2019

2.6.1 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)

2.6.2 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.
2.7 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.

2.7.1 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 behaviour of proj: Now only allow initialization of projections (#1162)
• Changed behaviour of tmerc: Now defaults to the Extended Transverse Mercator algorithm (etmerc). Old implementation available by adding +approx (#404)
• Changed behaviour: 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)

2.7.2 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)

2.8 PROJ 5.2.0

September 15th 2018
2.8.1 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)

2.8.2 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)

2.9 PROJ 5.1.0

June 1st 2018

2.9.1 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)

2.9.2 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 etmerr (#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)

2.10 PROJ 5.0.1

March 1st 2018

2.10.1 Bug fixes

• Handle ellipsoid change correctly in pipelines when +towgs84=0,0,0 is set (#881)
• Handle the case where nad_cetable2_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)

2.11 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.

2.11.1 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.

2.11.2 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)
  – 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.

2.11.3 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 \(-z\) flag when calling \texttt{proj} with \texttt{\(-V\)). (#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 \texttt{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 \texttt{pj\_transform}. (#726)
• Additional bug fixes courtesy of Google’s OSS-Fuzz program
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

- 2020-02-11 proj-6.3.1.tar.gz (md5)
- 2018-09-15 proj-datumgrid-1.8.zip
- 2019-09-01 proj-datumgrid-europe-1.5.zip
- 2019-03-01 proj-datumgrid-north-america-1.3.zip
- 2018-03-01 proj-datumgrid-oceania-1.1.zip
- 2019-03-01 proj-datumgrid-world-1.0.zip

### 3.2 Past Releases

- 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
- 2018-03-01 proj-datumgrid-1.7.zip
• 2016-09-11 proj-datumgrid-1.6.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-1.2.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-1.0.zip
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 grid packages. Here’s how to install the `proj-datumgrid-europe` package:

```
conda install -c conda-forge proj-datumgrid-europe
```

Available is also the `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 it is likely that PROJ is already installed.

1. Download either the 32 bit or 64 bit installer.
2. Run the OSGeo4W setup program.
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.

You will need that and at least the standard proj-datumgrid package for a successful installation.

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)
- GNU make for autotools build or CMake >= 3.5

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, man/man1 and man/man3. If this default path prefix is proper, then execute:
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.

Before proceeding with the installation we need to add the datum grids. Unzip the contents of the `proj-datumgrid` package into `data/`:

```
unzip proj-datumgrid-1.7.zip -d proj-5.0.1/data/
```

The installation will automatically move the grid files to the correct location. Alternatively the grids can be installed manually in the directory pointed to by the `PROJ_LIB` environment variable. The default location is `/usr/local/share/proj`.

With the grid 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
```

The test suite requires that the `proj-datumgrid` package is installed in `PROJ_LIB`.

### 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-5.0.1
```

Create a build directory and step into it:

```
mkdir build
cd build
```

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

```
cmake ..
cmake --build .
```

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:

```
cctest
```

The test suite requires that the proj-datumgrid package is installed in `PROJ_LIB`.
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-string 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`:
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*.

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

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 (ie. `us-ft`). Alternatively the translation to meters can be specified with the `+to_meter` keyword (ie. 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 behaviour, 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 (ie. `us-ft`). Alternatively the translation to meters can be specified with the `+vto_meter` keyword (ie. 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` do 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 \textit{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 \(+\text{lon_wrap}=180\) 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 \texttt{cs2cs} does honour prime meridians but the \texttt{proj} user utility ignores them.

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

<table>
<thead>
<tr>
<th>Meridian</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>greenwich</td>
<td>0dE</td>
</tr>
<tr>
<td>lisbon</td>
<td>9d07'54.862&quot;W</td>
</tr>
<tr>
<td>paris</td>
<td>2d20'14.025&quot;E</td>
</tr>
<tr>
<td>bogota</td>
<td>7d40'51.3&quot;E</td>
</tr>
<tr>
<td>madrid</td>
<td>3d41'16.48&quot;W</td>
</tr>
<tr>
<td>rome</td>
<td>12d27'8.4&quot;E</td>
</tr>
<tr>
<td>bern</td>
<td>7d26'22.5&quot;E</td>
</tr>
<tr>
<td>jakarta</td>
<td>10d648'27.79&quot;E</td>
</tr>
<tr>
<td>ferro</td>
<td>17d40°W</td>
</tr>
<tr>
<td>brussels</td>
<td>4d22'4.71&quot;E</td>
</tr>
<tr>
<td>stockholm</td>
<td>18d3'29.8&quot;E</td>
</tr>
<tr>
<td>athens</td>
<td>23d42'58.815&quot;E</td>
</tr>
<tr>
<td>oslo</td>
<td>10d43'22.5&quot;E</td>
</tr>
</tbody>
</table>

Example of use. The location \texttt{long=0, lat=0} in the greenwich based lat/long coordinates is translated to lat/long coordinates with Madrid as the prime meridian.
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
  rx=-0.48488 ry=-0.02436 rz=-0.41321 s=-0.540645
```

(continues on next page)
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 tem-
poral units in decimal years. 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+datum</td>
<td>Datum name (see <code>proj -ld</code>)</td>
</tr>
<tr>
<td>+geoidgrids</td>
<td>Filename of GTX grid file to use for vertical datum transforms</td>
</tr>
<tr>
<td>+nadgrids</td>
<td>Filename of NTv2 grid file to use for datum transforms</td>
</tr>
<tr>
<td>+towgs84</td>
<td>3 or 7 term datum transform parameters</td>
</tr>
<tr>
<td>+to_meter</td>
<td>Multiplier to convert map units to 1.0m</td>
</tr>
<tr>
<td>+vto_meter</td>
<td>Vertical conversion to meters</td>
</tr>
</tbody>
</table>

**Warning:** This section documents the behaviour 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 trans-
form, 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 cor-
rection 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.

```plaintext
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.

```plaintext
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.

```plaintext
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)

```plaintext
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 ctatable, 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 of 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,stlrcn,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 3.006 -50d0'0.103"W 45d0'0.103"N 0.000
EOF
```

```
cs2cs +proj=latlong +ellps=clrk66 +nadgrids=conus,null \
   +to +proj=latlong +ellps=GRS80 +datum=NAD83 << EOF
-111 44
-111 55
EOF
```

```
111dW 50d0'0.103"N 0.000
111d0'2.788"W 43d59'59.725"N 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.

### 5.5 Known differences between versions

Once in a while, a new version of PROJ causes changes in the existing behaviour. In this section we track deliberate changes to PROJ that break from previous behaviour. Most times that will be caused by a bug fix. Unfortunately, some bugs have existed for so long that their faulty behaviour 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 $\lambda = 290^\circ$ is a full rotation of the circle larger than $\lambda = -70^\circ$ and hence should return the same output for both.

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

### 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 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.

5.6 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.

5.6.1 Schema

A JSON schema of its grammar is available at https://proj.org/schemas/v0.2/projjson.schema.json

5.6.2 History

- v0.2: addition of geoid_model in VerticalCRS object.
- v0.1: initial version for PROJ 6.2

5.6.3 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

5.6.4 Examples

5.6.4.1 GeographicCRS

The following invocation

```
projinfo EPSG:4326 -o PROJJSON -q
```

will output:

```json
{
  "$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
    }
  },
  "coordinate_system": {
    "subtype": "ellipsoidal",
    "axis": {
      "name": "Geodetic latitude",
      "abbreviation": "Lat",
      "direction": "north",
      "unit": "degree"
    }
  }
}
```

(continues on next page)
5.6.4.2 ProjectedCRS

The following invocation

```
projinfo EPSG:32631 -o PROJJSON -q
```

will output:

```json
{
  "$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
      }
    }
  },
  "coordinate_system": {
    "subtype": "ellipsoidal",
    "axis": [
      {
        "name": "Geodetic latitude",
        "abbreviation": "Lat",
        "direction": "north",
        "unit": "degree"
      },
      {
        "name": "Geodetic longitude",
        "abbreviation": "Lon",
        "direction": "east",
        "unit": "degree"
      }
    ]
  }
}
```

(continues on next page)
"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
      }
    },
    {
      "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
  },
  "id": {
    "authority": "EPSG",
    "code": 32631
  }
}
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.

6.1 cct

6.1.1 Synopsis

    cct [-cIostvz [args]] +opt[=arg] ... file ...

6.1.2 Description

`cct` 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.

-\texttt{v}, \texttt{--verbose}
Write non-essential, but potentially useful, information to stderr. Repeat for additional information ($-vv$, $-vvv$, etc.)

\texttt{--version}
Print version number.

The +\textit{opt} arguments are associated with coordinate operation parameters. Usage varies with operation.

\texttt{cct} is an acronym meaning \textit{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 \textit{coordinate operations}:

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

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

\subsection*{6.1.3 Examples}

1. The operator specs describe the action to be performed by \texttt{cct}. So the following script

\begin{verbatim}
  echo 12 55 0 0 | cct +proj=utm +zone=32 +ellps=GRS80
\end{verbatim}

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

\begin{verbatim}
  echo 12 55 | cct -z0 -t0 +proj=utm +zone=32 +ellps=GRS80
\end{verbatim}

Should give results comparable to the classic \texttt{proj} command

\begin{verbatim}
  echo 12 55 | proj +proj=utm +zone=32 +ellps=GRS80
\end{verbatim}

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

\begin{verbatim}
  cct +proj=utm +ellps=GRS80 +zone=32
\end{verbatim}

3. Roundtrip accuracy check for the case above:

\begin{verbatim}
  cct +proj=pipeline +proj=utm +ellps=GRS80 +zone=32 +step +step +inv
\end{verbatim}

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

\begin{verbatim}
  cct -c 5,2,1,4 +proj=utm +ellps=GRS80 +zone=32
\end{verbatim}

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

\begin{verbatim}
  cct -t 0 -z 0 +proj=utm +ellps=GRS80 +zone=32
\end{verbatim}

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

\begin{verbatim}
$ echo 12 56 100 2018.0 auxiliary data | cct +proj=merc
1335833.8895 7522963.2411 100.0000 2018.0000 auxiliary data
\end{verbatim}
6.1.4 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] [+opt[=arg] ...] [+to +opt[=arg] ...] file ...

or

cs2cs [-eEfIlrstvwW] [args] [source_crs] +to [target_crs] file ...

where {source_crs} or {target_crs} is a PROJ string, a WKT string or a AUTHORITY:CODE (where AUTHORITY is the name of a CRS authority and CODE the code of a CRS found in the proj.db database), expressing a coordinate reference system.

New in version 6.0.0.

or

cs2cs [-eEfIlrstvwW] [args] [source_crs] [target_crs]

New in version 6.0.0.

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\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 -1.

-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.

-ld
List of datums that can be selected with the +datum 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.

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, \texttt{cs2cs} uses the \texttt{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 \texttt{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 \texttt{-f %.12f} for decimal degrees with 12 decimal places), while projected (cartesian) coordinates will be in linear (meter, feet) units.

### 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 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
```
6.3 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.

- f <format>
  Where format is a printf format string to control the output form of the geographic coordinate values. The default mode is DMS for geographic coordinates and "%.3f" for distance.

- F <format>
  Where format is a printf format string to control the output form of the distance value (−F). The default mode is DMS for geographic coordinates and "%.3f" for distance.

- 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 \- specifies 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.
3. A geodesic bibliography.

6.4 gie

6.4.1 Synopsis

gie [ -hvql [ 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 \texttt{<gie>} and ends when \texttt{</gie>} is reached. Anything before \texttt{<gie>} and after \texttt{</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 \texttt{<gie>/gie>} tags it is also possible to add test cases to custom made init files. The tests will be ignored by PROJ when reading the init file with \texttt{+init} and gie ignores anything not wrapped in \texttt{<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** \texttt{<+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** \texttt{<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** \texttt{<x y [z [t]]> | <error code>}

Define the expected coordinate that will be returned from accepted coordinate passed through 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
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.
6.4.5 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.

- **-ld**
  List of datums that can be selected with the +datum 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.
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.

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.

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.

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

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.

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

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 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
+45.2591944444 111d30'000w
EOF
```
PROJ coordinate transformation software library, Release 6.3.1

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 crsoperationellipsoid] [--summary] [-q]
[=[area name_or_code] | [bbox west_long,south_lat,east_long,north_lat]]
[=spatial-test containsintersects]
[=crs-extent-use none|both|intersection|smallest]
[=grid-check none|discard_missing|sort] [--crs-extent-use none|both|intersection|smallest]
[=pivot-crs always|if_no_direct_transformation|never{auth:code[.auth:code]}]
[=boundcrs-to-wgs84]
[=main-db-path path] [*]

where {object_definition} or {srs_def} is

- a proj-string,
- a WKT string,
- 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 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/v0.1/projjson.schema.json (added in 6.2)

{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|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.
---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 area 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
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: 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.

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.
---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 WKT or PROJJSON strings on a single line, instead of multiple intended lines by default.

### 6.6.3 Examples

1. Query the CRS object corresponding to EPSG:4326

```bash
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]],

(continues on next page)
```
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]],
  USAGE[SCOPE["unknown"],
    AREA["World"],
    BBOX[-90,-180,90,180]],
  ID["EPSG",4326])
```

(continues on next page)
3. Export an object as a PROJJSON string

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

Output:

```json
{
    "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",
                "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
    }
}
```
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 Albers Equal Area

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and elliptical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>aea</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.1.1 Options

**Required**

+lat_1=value
  First standard parallel.
  
  *Defaults to 0.0.*

+lat_2=value
  Second standard parallel.
  
  *Defaults to 0.0.*
Fig. 1: 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.
### 7.1.2 Azimuthal Equidistant

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and elliptical projection</td>
</tr>
<tr>
<td>Alias</td>
<td>aeqd</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 2: proj-string: +proj=aeqd
7.1.2.1 Options

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

+guam
Use Guam elliptical formulas. Only accurate near the Island of Guam ($\lambda \approx 144.5^\circ, \phi \approx 13.5^\circ$)

+k_0=<value>
Scale factor. Determines scale factor used in the projection.
Defaults to 1.0.

+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.

+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.

7.1.3 Airy

The Airy projection is an azimuthal minimum error projection for the region within the small or great circle defined by an angular distance, $\phi_b$, from the tangency point of the plane $(\lambda_0, \phi_0)$.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>airy</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 3: proj-string: +proj=airy
7.1.3.1 Options

+lat_b
Angular distance from tangency point of the plane \((\lambda_0, \phi_0)\) 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.

7.1.4 Aitoff

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>aitoff</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.4.1 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.
7.1.5 Modified Stereographics of Alaska

<table>
<thead>
<tr>
<th>Classification</th>
<th>Modified azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and elliptical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Alaska</td>
</tr>
<tr>
<td>Alsk</td>
<td>alsk</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.5.1 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.
Fig. 5: proj-string: +proj=alsk
Defaults to 0.0.

+ellps=<value>
See proj -le for a list of available ellipsoids.
Defaults to “GRS80”.

7.1.6 Apian Globular I

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>apian</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 6: proj-string: +proj=apian

7.1.6.1 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.

7.1.7 August Epicycloidal

Fig. 7: proj-string: +proj=august

7.1.7.1 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.

+x_0=<value>
    False easting.
    Defaults to 0.0.
+y_0=<value>
False northing.
Defaults to 0.0.

7.1.8 Bacon Globular

Fig. 8: proj-string: +proj=bacon

7.1.8.1 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.
7.1.9 Bertin 1953

New in version 6.0.0.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>bertin1953</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 9: 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.

7.1.9.1 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
```
7.1.9.2 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.)*

7.1.9.3 Further reading


7.1.10 Bipolar conic of western hemisphere

7.1.10.1 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.)*
Fig. 10: proj-string: +proj=bipc +ns
7.1.11 Boggs Eumorphic

Fig. 11: proj-string: +proj=boggs

7.1.11.1 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.*

+y_0=<value>
   False northing.
   *Defaults to 0.0.*
7.1.12 Bonne (Werner lat_1=90)

Fig. 12: proj-string: +proj=bonne +lat_1=10

7.1.12.1 Parameters

Required

+lat_1=<value>
First standard parallel.
 Defaults to 0.0.

Optional

+lon_0=<value>
Longitude of projection center.
 Defaults to 0.0.

+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.
7.1.13 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.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conformal cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and elliptical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Only valid for the west coast of USA and Mexico</td>
</tr>
<tr>
<td>Alias</td>
<td>calcofi</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

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.

7.1.13.1 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
```

7.1.13.2 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.
7.1.13.3 Mathematical definition

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

7.1.13.4 Further reading

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

7.1.14 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.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Transverse and oblique cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, Spherical and Elliptical</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but best used near the central meridian with long, narrow areas</td>
</tr>
<tr>
<td>Alias</td>
<td>cass</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.14.1 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):

```bash
$ 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 +no_defs
```

```
66644.94 82536.22
```

Example using EPSG 3068 (Soldner Berlin):

```bash
$ echo 13.5 52.4 | proj +proj=cass +lat_0=52.41864827777778 +lon_0=13.62720366666667 +x_0=40000 +y_0=10000 +ellps=bessel +datum=potsdam +units=m +no_defs
```

```
31343.05 7932.76
```
Fig. 13: proj-string: +proj=cass
7.1.14.2 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.

7.1.14.3 Mathematical definition

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

φ₀ 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

\[
\begin{align*}
x &= \arcsin(\cos(\phi) \sin(\lambda)) \\
y &= \arctan(2(\tan(\phi), \cos(\lambda)) - \phi_0)
\end{align*}
\]
Inverse projection

\[ \phi = \arcsin(\sin(y + \phi_0) \cos(x)) \]
\[ \lambda = \arctan(2(\tan(x), \cos(y + \phi_0))) \]

Elliptical form

Forward projection

\[ N = (1 - e^2 \sin^2(\phi))^{-1/2} \]
\[ T = \tan^2(\phi) \]
\[ A = \lambda \cos(\phi) \]
\[ C = \frac{e^2}{1 - e^2} \cos^2(\phi) \]
\[ x = N(A - T \frac{A^3}{6} - (8 - T + 8C)T \frac{A^5}{120}) \]
\[ y = M(\phi) - M(\phi_0) + N \tan(\phi)\left(\frac{A^2}{2} + (5 - T + 6C)\frac{A^4}{24}\right) \]

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 \(\phi'\) and

\[ R = (1 - e^2)(1 - e^2 \sin^2 \phi')^{-3/2} \]
\[ D = x/N \]
\[ \phi = \phi' - \tan \phi' \frac{N}{R} \left(\frac{D^2}{2} - (1 + 3T)\frac{D^4}{24}\right) \]
\[ \lambda = \frac{(D - T \frac{D^3}{3} + (1 + 3T)T \frac{D^5}{15})}{\cos \phi'} \]
7.1.14.4 Further reading

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

7.1.15 Central Cylindrical

Fig. 14: proj-string: +proj=cc
7.1.15.1 Parameters

Note: All parameters are optional for the Central Cylindricla 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.

7.1.16 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.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but best used near the standard parallel</td>
</tr>
<tr>
<td>Alias</td>
<td>ccon</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.16.1 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 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].
7.1.16.2 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.
7.1.16.3 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

\[ y = \cot \phi_0 - y \]
\[ \phi = \phi_0 - \tan^{-1}\left(\sqrt{x^2 + y^2} - \cot \phi_0\right) \]
\[ \lambda = \frac{\tan^{-1}\left(\sqrt{x^2 + y^2}\right)}{\sin \phi_0} \]

7.1.16.4 Reference values

For ATPOL to WGS84 test, run the following script:

```bash
#!/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 +datum=WGS84 +no_def
0 0
0 700000
700000 0
700000 700000
330000 350000
EOF
```

It should result with

```
1.384023E+01 5.503304E+01 0.000000E+00
1.451535E+01 4.773535E+01 0.000000E+00
2.478291E+01 4.500452E+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:

```bash
cat << EOF | src/cs2cs -v -f "%E" +proj=longlat +datum=WGS84 +no_def +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:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6.500315E+05</td>
<td>4.106162E+03</td>
<td>0.000000E+00</td>
</tr>
<tr>
<td>3.707419E+04</td>
<td>6.768262E+05</td>
<td>0.000000E+00</td>
</tr>
<tr>
<td>6.960534E+05</td>
<td>6.722946E+05</td>
<td>0.000000E+00</td>
</tr>
<tr>
<td>3.300000E+05</td>
<td>3.500000E+05</td>
<td>0.000000E+00</td>
</tr>
</tbody>
</table>

7.1.17 Equal Area Cylindrical

Fig. 16: proj-string: +proj=cea

7.1.17.1 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._

+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
\[
\frac{\cos \phi_{ts}}{\sqrt{1-e^2 \sin^2 \phi_{ts}}}
\]

7.1.18 Chamberlin Trimetric

Fig. 17: proj-string: +proj=chamb +lat_1=10 +lon_1=30 +lon_2=40
7.1.18.1 Parameters

**Required**

+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.*

7.1.19 Collignon

![Collignon Projection](image)

Fig. 18: proj-string: +proj=collg

7.1. Projections
7.1.19.1 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.*

7.1.20 Compact Miller

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

See [Jenny2015]

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>comill</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.20.1 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.*
Fig. 19: proj-string: +proj=comill

\[ +y_0=\langle\text{value}\rangle \]
False northing.

*Defaults to 0.0.*

7.1.21 Craster Parabolic (Putnins P4)

Fig. 20: proj-string: +proj=crast
7.1.21.1 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.*

7.1.22 Denoyer Semi-Elliptical

![Fig. 21: proj-string: +proj=denoy](image)

*Fig. 21: proj-string: +proj=denoy*
7.1.22.1 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.*

7.1.23 Eckert I

Fig. 22: proj-string: +proj=eck1

\[
x = 2\sqrt{2/3\pi}\lambda(1 - |\phi|/\pi) \\
y = 2\sqrt{2/3\pi}\phi
\]
7.1.23.1 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.

7.1.24 Eckert II

Fig. 23: proj-string: +proj=eck2
7.1.24.1 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.*

7.1.25 Eckert III

Fig. 24: proj-string: +proj=eck3
7.1.25.1 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.

7.1.26 Eckert IV

Fig. 25: proj-string: +proj=eck4

\[ x = \lambda(1 + \cos\phi)/\sqrt{2 + \pi} \]
\[ y = 2\phi/\sqrt{2 + \pi} \]
7.1.26.1 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.*

7.1.27 Eckert V

![World map with grid lines](image)

*Fig. 26: proj-string: +proj=eck5*
7.1.27.1 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.

7.1.28 Eckert VI

Fig. 27: proj-string: +proj=eck6
7.1.28.1 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.

7.1.29 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).

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conformal cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but best used near the equator</td>
</tr>
<tr>
<td>Alias</td>
<td>eqc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 28: proj-string: +proj=eqc
7.1.29.1 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.

<table>
<thead>
<tr>
<th>Projection Name</th>
<th>(lat ts=) φ₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain/Plane Chart</td>
<td>0°</td>
</tr>
<tr>
<td>Simple Cylindrical</td>
<td>0°</td>
</tr>
<tr>
<td>Plate Carrée</td>
<td>0°</td>
</tr>
<tr>
<td>Ronald Miller—minimum overall scale distortion</td>
<td>37°30′</td>
</tr>
<tr>
<td>E.Grafarend and A.Niermann</td>
<td>42°</td>
</tr>
<tr>
<td>Ronald Miller—minimum continental scale distortion</td>
<td>43°30′</td>
</tr>
<tr>
<td>Gall Isographic</td>
<td>45°</td>
</tr>
<tr>
<td>Ronald Miller Equirectangular</td>
<td>50°30′</td>
</tr>
<tr>
<td>E.Grafarend and A.Niermann minimum linear distortion</td>
<td>61°7′</td>
</tr>
</tbody>
</table>

Example using EPSG 32662 (WGS84 Plate Carrée):

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

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

```bash
$ echo -88 30 | proj +proj=eqc +lat_ts=30 +lon_0=90w
192811.01 3339584.72
```

7.1.29.2 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.

7.1.29.3 Mathematical definition

The formulas describing the Equidistant Cylindrical projection are all taken from [Snyder1987].

$\phi_{ts}$ 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.

$\phi_0$ 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

\[
\lambda = x / \cos \phi_{ts} \\
\phi = y + \phi_0
\]

7.1.29.4 Further reading

1. Wikipedia
2. Wolfram Mathworld

7.1.30 Equidistant Conic

7.1.30.1 Parameters

Required

+lat_1=<value>
   First standard parallel.
   Defaults to 0.0.

+lat_2=<value>
   Second standard parallel.
   Defaults to 0.0.
Fig. 29: proj-string: +proj=eqdc +lat_1=55 +lat_2=60
Optional

+lon_0=<value>
   Longitude of projection center.
   Default to 0.0.
+ellps=<value>
   See proj -le for a list of available ellipsoids.
   Default 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.
   Default to 0.0.
+y_0=<value>
   False northing.
   Default to 0.0.

7.1.31 Equal Earth

New in version 5.2.0.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudo cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>eqearth</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 30: proj-string: +proj=eqearth
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].

### 7.1.31.1 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
```

### 7.1.31.2 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.*

### 7.1.31.3 Further reading

### 7.1.32 Euler

**Fig. 31: proj-string:** `+proj=euler +lat_1=67 +lat_2=75`

#### 7.1.32.1 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.

7.1.33 Fahey

Fig. 32: proj-string: +proj=fahey
7.1.33.1 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.

7.1.34 Foucaut

Fig. 33: proj-string: +proj=fouc
7.1.34.1 Parameters

Note: All parameters are optional for the Foucaut 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.

7.1.35 Foucaut Sinusoidal

Fig. 34: 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 \( 0 \leq n \leq 1 \).

\[
x = \lambda \cos \phi / (n + (1 - n) \cos \phi) \\
y = n\phi + (1 - n) \sin \phi
\]

For the inverse, the Newton-Raphson method can be used to determine \( \phi \) from the equation for \( y \) above. As \( n \to 0 \) and \( \phi \to \pi/2 \), convergence is slow but for \( n = 0 \), \( \phi = \sin^{-1} y \)
7.1.35.1 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.

7.1.36 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.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Transverse and oblique cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, Spherical</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>gall</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.36.1 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 Stereographical

```bash
$ echo 9 51 | proj +proj=gall +lon_0=0 +x_0=0 +y_0=0 +ellps=WGS84 +datum=WGS84
  +units=m +no_defs
708432.90  5193386.36
```
Example using Gall Stereographical (Central meridian 90°W)

```
$ echo 9 51 | proj +proj=gall +lon_0=90w +x_0=0 +y_0=0 +ellps=WGS84 +datum=WGS84 +units=m +no_defs
7792761.91 5193386.36
```

7.1.36.2 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”.

7.1.36.3 Mathematical definition

The formulas describing the Gall Stereographical are all taken from [Snyder1993].

Spherical form

Forward projection

\[
x = \frac{\lambda}{\sqrt{2}}
\]

\[
y = \left(1 + \frac{\sqrt{2}}{2}\right) \tan\left(\frac{\phi}{2}\right)
\]

Inverse projection

\[
\phi = 2 \arctan\left(\frac{y}{1 + \frac{\sqrt{2}}{2}}\right)
\]

\[
\lambda = \sqrt{2}x
\]

7.1.36.4 Further reading

1. Wikipedia


7.1.37 Geostationary Satellite View

The geos projection pictures how a geostationary satellite scans the earth at regular scanning angle intervals.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and elliptical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>geos</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 36: proj-string: +proj=geos +h=35785831.0 +lon_0=-60 +sweep=y
7.1.37.1 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 \(x\).

The resulting position is different because rotation in three dimensions is not commutative.

7.1.37.2 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 “\(y\)”.
Default: “\(y\)”.

**+lon_0=<value>**
Longitude of projection center.
Default: 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.
Default: “GRS80”.

**+x_0=<value>**
False easting.
Default: 0.0.

**+y_0=<value>**
False northing.
Default: 0.0.

7.1.38 Ginsburg VIII (TsNIIGAiK)

7.1.38.1 Parameters

**Note:** All parameters are optional for the Ginsburg VIII projection.
Fig. 37: proj-string: \texttt{+proj=gins8}

+\texttt{lon}_0=<\texttt{value}>

Longitude of projection center.

\textit{Defaults to 0.0.}

+\texttt{R}=<\texttt{value}>

Radius of the sphere given in meters. If used in conjunction with \texttt{+ellps +R} takes precedence.

+\texttt{x}_0=<\texttt{value}>

False easting.

\textit{Defaults to 0.0.}

+\texttt{y}_0=<\texttt{value}>

False northing.

\textit{Defaults to 0.0.}
7.1.39 General Sinusoidal Series

![General Sinusoidal Series Diagram](image)

Fig. 38: proj-string: `+proj=gn_sinu +m=2 +n=3`

7.1.39.1 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.*

7.1.40 Gnomonic

7.1.40.1 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.
Fig. 39: proj-string: +proj=gnom +lat_0=90 +lon_0=-50
7.1.41 Goode Homolosine

7.1.41.1 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.
7.1.42 Mod. Stereographics of 48 U.S.

Fig. 41: proj-string: +proj=gs48

7.1.42.1 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.

7.1.43 Mod. Stereographics of 50 U.S.

7.1.43.1 Parameters

Note: All parameters are optional for the projection.

+ellps=<value>
   See proj -le for a list of available ellipsoids.
   Defaults to “GRS80”.
Fig. 42: proj-string: +proj=gs50

+x_0=<value>
False easting.
Defaults to 0.0.

+y_0=<value>
False northing.
Defaults to 0.0.

7.1.44 Hammer & Eckert-Greifendorff

Fig. 43: proj-string: +proj=hammer
7.1.44.1 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.

7.1.45 Hatano Asymmetrical Equal Area

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical Projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>hatano</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.45.1 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.
Fig. 44: proj-string: +proj=hatano

+x_0=<value>
False easting.
 Defaults to 0.0.
+y_0=<value>
False northing.
 Defaults to 0.0.

Mathematical Definition

Forward

\[
\begin{align*}
x &= 0.85\lambda \cos \theta \\
y &= C_y \sin \theta \\
P(\theta) &= 2\theta + \sin 2\theta - C_p \sin \phi \\
P'(\theta) &= 2(1 + \cos 2\theta) \\
\theta_0 &= 2\phi
\end{align*}
\]

<table>
<thead>
<tr>
<th>Condition</th>
<th>(C_y)</th>
<th>(C_p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>For (\phi &gt; 0)</td>
<td>1.75859</td>
<td>2.67595</td>
</tr>
<tr>
<td>For (\phi &lt; 0)</td>
<td>1.93052</td>
<td>2.43763</td>
</tr>
</tbody>
</table>

For \(\phi = 0\), \(y \leftarrow 0\), and \(x \leftarrow 0.85\lambda\).
Further reading

1. Compare Map Projections
2. Mathworks

7.1.46 HEALPix

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and elliptical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>healpix</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

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.
7.1.46.1 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

7.1.46.2 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.

7.1.46.3 Further reading

1. NASA
2. Wikipedia
7.1.47 rHEALPix

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and elliptical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>rhealpix</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

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).
7.1.47.1 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
```

7.1.47.2 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.

7.1.47.3 Further reading

1. NASA
2. Wikipedia
7.1.48 Interrupted Goode Homolosine

Fig. 45: proj-string: +proj=igh

7.1.48.1 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.

7.1.49 International Map of the World Polyconic

7.1.49.1 Parameters

Required

+lat_1=<value>
    First standard parallel.
    Defaults to 0.0.
Fig. 46: proj-string: +proj=imw_p +lat_1=30 +lat_2=-40

+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.
7.1.50 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].

<table>
<thead>
<tr>
<th>Classification</th>
<th>Polyhedral, equal area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward, spherical</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>isea</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 47: proj-string: +proj=isea

7.1.50.1 Parameters

Note: All parameters are optional for the projection.

+orient=<string>
  Can be set to either isea or pole.
+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.
+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.

7.1.51 Kavraisky V

Fig. 48: proj-string: +proj=kav5

7.1.51.1 Parameters

Note: All parameters are optional for the Kavraisky 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.
7.1.52 Kavraisky VII

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.
7.1.53 Krovak

Fig. 50: proj-string: +proj=krovak

7.1.53.1 Parameters

Note: All parameters are optional for the Krovak projection.

+czech
Reverse the sign of the output coordinates, as is tradition in the Czech Republic.

+lon_0=<value>
Longitude of projection center.
+lat_0=<value>
Latitude of projection center.
Defaults to 0.0.

+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.

7.1.54 Laborde

7.1.54.1 Parameters

Required

+lon_0=<value>
Longitude of projection center.
Defaults to 0.0.

+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.
Fig. 51: proj-string: +proj=labrd +lon_0=40 +lat_0=-10
7.1.55 Lambert Azimuthal Equal Area

Fig. 52: proj-string: +proj=laea

7.1.55.1 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.
+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.

7.1.56 Lagrange

Fig. 53: proj-string: +proj=lagrng
7.1.56.1 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”.

+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 Larrivee

7.1.57.1 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.
Fig. 54: proj-string: +proj=larr
+y_0=<value>
False northing.
 Defaults to 0.0.

7.1.58 Laskowski

Fig. 55: proj-string: +proj=lask

7.1.58.1 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.
7.1.59 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.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conformal conic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and elliptical projection. One or two standard parallels (1SP and 2SP). “LCC 2SP Michigan” form can be used by setting (+k_0) parameter to specify ellipsoid scale.</td>
</tr>
<tr>
<td>Defined area</td>
<td>Best for regions predominantly east–west in extent and located in the middle north or south latitudes.</td>
</tr>
<tr>
<td>Alias</td>
<td>lcc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

![Lambert Conformal Conic Projection](image)

Fig. 56: proj-string: \(+proj=lcc +lon_0=-90 +lat_1=33 +lat_2=45\)
7.1.59.1 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.*
7.1.59.2 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)

7.1.60 Lambert Conformal Conic Alternative

Fig. 57: proj-string: +proj=lcc +lat_0=35

7.1.60.1 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”.
PROJ coordinate transformation software library, Release 6.3.1

+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 Equal Area Conic

![Fig. 58: proj-string: +proj=leac](image)

#### 7.1.61.1 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”.

7.1. Projections 143
+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 Lee Oblated Stereographic

#### 7.1.62.1 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.

### 7.1.63 Loximuthal

#### 7.1.63.1 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.
Fig. 59: proj-string: +proj=lee_os
Fig. 60: proj-string: +proj=loxim

+x_0=<value>
   False easting.
   Defaults to 0.0.
+y_0=<value>
   False northing.
   Defaults to 0.0.

7.1.64 Space oblique for LANDSAT

7.1.64.1 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”.

Chapter 7. Coordinate operations
Fig. 61: proj-string: `+proj=lsat +ellps=GRS80 +lat_1=-60 +lat_2=60 +lsat=2 +path=2`

**+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.*

### 7.1.65 McBryde-Thomas Flat-Polar Sine (No. 1)

#### 7.1.65.1 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.
Fig. 62: proj-string: +proj=mbt_s

Defaults to 0.0.

+y_0=<value>
False northing.
Defaults to 0.0.

7.1.66 McBryde-Thomas Flat-Pole Sine (No. 2)

Fig. 63: proj-string: +proj=mbt_fps
7.1.66.1 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.*

7.1.67 McBride-Thomas Flat-Polar Parabolic

![World map image](image.png)

**Fig. 64:** proj-string: `+proj=mbtfpp`

7.1.67.1 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.

### 7.1.68 McBryde-Thomas Flat-Polar Quartic

Fig. 65: proj-string: `+proj=mbtfpq`

#### 7.1.68.1 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.
7.1.69 McBryde-Thomas Flat-Polar Sinusoidal

Fig. 66: proj-string: +proj=mbtfps

7.1.69.1 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.*
7.1.70 Mercator

The Mercator projection is a cylindrical map projection that origins from the 15th century. It is widely recognized as the first regularly used map projection. The projection is conformal which makes it suitable for navigational purposes.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conformal cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and elliptical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but best used near the equator</td>
</tr>
<tr>
<td>Alias</td>
<td>merc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 67: proj-string: +proj=merc
7.1.70.1 Usage

Applications should be limited to equatorial regions, but is frequently used for navigational charts with latitude of true scale (\( +\text{lat}_\text{ts} \)) specified within or near chart’s boundaries. Often inappropriately used for world maps since the regions near the poles cannot be shown [Evenden1995].

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:

```
echo 56.35 12.32 | proj +proj=merc +k_0=2
12545706.61   2746073.80
```

Note that \( +\text{lat}_\text{ts} \) and \( +\text{k}_0 \) are mutually exclusive. If used together, \( +\text{lat}_\text{ts} \) takes precedence over \( +\text{k}_0 \).

7.1.70.2 Parameters

Note: All parameters for the projection are optional.

\( +\text{lat}_\text{ts}=<\text{value}> \)
Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over \( +\text{k}_0 \) if both options are used together.

 Defaults to 0.0.

\( +\text{k}_0=<\text{value}> \)
Scale factor. Determines scale factor used in the projection.

 Defaults to 1.0.

\( +\text{lon}_\text{0}=<\text{value}> \)
Longitude of projection center.

 Defaults to 0.0.

\( +\text{x}_0=<\text{value}> \)
False easting.

 Defaults to 0.0.

\( +\text{y}_0=<\text{value}> \)
False northing.

 Defaults to 0.0.

\( +\text{ellps}=<\text{value}> \)
See `proj -le` for a list of available ellipsoids.

 Defaults to “GRS80”.

\( +\text{R}=<\text{value}> \)
Radius of the sphere given in meters. If used in conjunction with \( +\text{ellps} +\text{R} \) takes precedence.
7.1.70.3 Mathematical definition

The formulas describing the Mercator projection are all taken from G. Evenden’s libproj manuals [Evenden2005].

**Spherical form**

For the spherical form of the projection we introduce the scaling factor:

\[ k_0 = \cos \phi_{ts} \]

**Forward projection**

\[ x = k_0 \lambda \]
\[ y = k_0 \ln \left( \tan \left( \frac{\pi}{4} + \frac{\phi}{2} \right) \right) \]

**Inverse projection**

\[ \lambda = \frac{x}{k_0} \]
\[ \phi = \frac{\pi}{2} - 2 \arctan \left[ e^{-\frac{y}{2k_0}} \right] \]

**Elliptical form**

For the elliptical form of the projection we introduce the scaling factor:

\[ k_0 = m(\phi_{ts}) \]

where \( m(\phi) \) is the parallel radius at latitude \( \phi \).

We also use the Isometric Latitude kernel function \( t() \).

**Note:** \( m() \) and \( t() \) should be described properly on a separate page about the theory of projections on the ellipsoid.

**Forward projection**

\[ x = k_0 \lambda \]
\[ y = k_0 \ln t(\phi) \]
Inverse projection

\[ \lambda = \frac{x}{k_0} \]
\[ \phi = t^{-1} \left[ e^{-y/k_0} \right] \]

7.1.7.0.4 Further reading

1. Wikipedia
2. Wolfram Mathworld

7.1.7.1 Miller Oblated Stereographic

Fig. 68: proj-string: +proj=mill_os
7.1.71.1 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.

7.1.72 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.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Neither conformal nor equal area cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse spherical</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but best used near the equator</td>
</tr>
<tr>
<td>Alias</td>
<td>mill</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.72.1 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
```
7.1.72.2 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.*
7.1.72.3 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

\[
\lambda = x \\
\phi = 2.5 * (\arctan (e^{0.8y}) - \frac{\pi}{4})
\]

7.1.72.4 Further reading

1. Wikipedia

7.1.73 Space oblique for MISR

7.1.73.1 Parameters

Required

+\texttt{path}=<value>
    
    Selected path of satellite. Value between 1 and 233.

Optional

+\texttt{lon}_0=<value>

    Longitude of projection center.
    
    \textit{Defaults to 0.0}.

+\texttt{ellps}=<value>

    See \texttt{proj -le} for a list of available ellipsoids.
    
    \textit{Defaults to “GRS80”}.

+\texttt{R}=<value>

    Radius of the sphere given in meters. If used in conjunction with \texttt{ellps} +\texttt{R} takes precedence.

+\texttt{x}_0=<value>

    False easting.
    
    \textit{Defaults to 0.0}. 

Chapter 7. Coordinate operations
Fig. 70: proj-string: +proj=misrsom +path=1
+y_0=<value>
False northing.
Defaults to 0.0.

7.1.74 Mollweide

Fig. 71: proj-string: +proj=moll

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 Murdoch I

![Map of Murdoch I projection]

Fig. 72: proj-string: `+proj=murdl +lat_1=30 +lat_2=50`

7.1.75.1 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.

7.1.76 Murdoch II

Fig. 73: proj-string: $+proj=murd2 +lat_1=30 +lat_2=50$

7.1.76.1 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.*

7.1.77 Murdoch III

![Map of Murdoch III projection](image)

Fig. 74: proj-string: `+proj=murd3 +lat_1=30 +lat_2=50`
7.1.77.1 Parameters

Required

+\texttt{lat\_1}=<\texttt{value}>
First standard parallel.
Defaults to 0.0.

+\texttt{lat\_2}=<\texttt{value}>
Second standard parallel.
Defaults to 0.0.

Optional

+\texttt{lon\_0}=<\texttt{value}>
Longitude of projection center.
Defaults to 0.0.

+\texttt{R}=<\texttt{value}>
Radius of the sphere given in meters. If used in conjunction with \texttt{+ellps} \texttt{R} takes precedence.

+\texttt{x\_0}=<\texttt{value}>
False easting.
Defaults to 0.0.

+\texttt{y\_0}=<\texttt{value}>
False northing.
Defaults to 0.0.

7.1.78 Natural Earth

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudo cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>natearth</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

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.
7.1.78.1 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
```

7.1.78.2 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.

+x_0=<value>
  False easting.
  
  Defaults to 0.0.

+y_0=<value>
  False northing.
  
  Defaults to 0.0.
7.1.79 Natural Earth II

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudo cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>natearth2</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

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]

7.1.79.1 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.
```
PROJ coordinate transformation software library, Release 6.3.1

+x_0=<value>
    False easting.
    *Defaults to 0.0.*

+y_0=<value>
    False northing.
    *Defaults to 0.0.*

7.1.80 Nell

Fig. 77: proj-string: +proj=nell

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 Nell-Hammer

Fig. 78: proj-string: +proj=nell_h

7.1.81.1 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.

7.1.82 Nicolosi Globular

7.1.82.1 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.
7.1.83 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.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal. Neither conformal nor equal area.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, although for one hemisphere at a time.</td>
</tr>
<tr>
<td>Alias</td>
<td>nsper</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.83.1 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.
Fig. 80: proj-string: +proj=nsper +h=3000000 +lat_0=-20 +lon_0=145
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.

7.1.84 New Zealand Map Grid

7.1.84.1 Parameters

Note: All standard projection parameters are hard-coded for this projection

7.1.85 General Oblique Transformation

7.1.85.1 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, \( \alpha \) and \( \beta \) 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 \( \beta \) 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
Fig. 81: proj-string: +proj=nzmg
Fig. 82: proj-string: +proj=ob_tran +o_proj=mill +o_lon_p=40 +o_lat_p=50 +lon_0=60

7.1.85.2 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

+\texttt{o}_{\alpha}=\texttt{value} \\
\text{Angle to rotate the projection with.}

+\texttt{o}_{\textit{lon}_{c}}=\texttt{value} \\
\text{Longitude of the point the projection will be rotated about.}

+\texttt{o}_{\textit{lat}_{c}}=\texttt{value} \\
\text{Latitude of the point the projection will be rotated about.}

New “equator” points

+\texttt{lon}_{1}=\texttt{value} \\
\text{Longitude of first point.}

+\texttt{lat}_{1}=\texttt{value} \\
\text{Latitude of first point.}

+\texttt{lon}_{2}=\texttt{value} \\
\text{Longitude of second point.}

+\texttt{lat}_{2}=\texttt{value} \\
\text{Latitude of second point.}

Optional

+\texttt{lon}_{0}=\texttt{value} \\
\text{Longitude of projection center.} \\
\text{\textit{Defaults to 0.0}.}

+\texttt{R}=\texttt{value} \\
\text{Radius of the sphere given in meters. If used in conjunction with +ellps +R takes precedence.}

+\texttt{x}_{0}=\texttt{value} \\
\text{False easting.} \\
\text{\textit{Defaults to 0.0}.}

+\texttt{y}_{0}=\texttt{value} \\
\text{False northing.} \\
\text{\textit{Defaults to 0.0}.}

7.1.86 Oblique Cylindrical Equal Area

7.1.86.1 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.
Fig. 83: proj-string: +proj=ocea

**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.*
\[ +y_0 = \text{<value>} \]
False northing.
Defaults to 0.0.

### 7.1.87 Oblated Equal Area

Described in [Snyder1988].

#### 7.1.87.1 Parameters

**Required**

\[ +m = \text{<value>} \]
\[ +n = \text{<value>} \]

**Optional**

\[ +\theta = \text{<value>} \]
Longitude of projection center.
Defaults to 0.0.
\[ +R = \text{<value>} \]
Radius of the sphere given in meters. If used in conjunction with \(+\text{ellps} +R\) takes precedence.
\[ +x_0 = \text{<value>} \]
False easting.
Defaults to 0.0.
\[ +y_0 = \text{<value>} \]
False northing.
Defaults to 0.0.

### 7.1.88 Oblique Mercator

The Oblique Mercator projection is a cylindrical map projection that closes the gap between the Mercator and the Transverse Mercator projections.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conformal cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and elliptical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but reasonably accurate only within 15 degrees of the oblique central line</td>
</tr>
<tr>
<td>Alias</td>
<td>omerc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

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.
Fig. 84: proj-string: `+proj=cea +m=1 +n=2`
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.

7.1.88.1 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]

```bash
$ echo 10.536498003 56.229892362 | proj +proj=omerc +axis=wnu +lonc=9.46 +lat_0=56.1333333 +x_0=-266906.229 +y_0=189617.957 +k=0.9999537 +alpha=-0.76324 +gamma=0 +ellps=GRS80
```

The input coordinate represents the System 34 datum point “Agri Bavnehøj”, 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.

### 7.1.88.2 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.

7.1.89 Ortelius Oval

Fig. 86: proj-string: +proj=ortel

7.1.89.1 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.
7.1.90 Orthographic

The orthographic projection is a perspective azimuthal projection centered around a given latitude and longitude.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, although only one hemisphere can be seen at a time</td>
</tr>
<tr>
<td>Alias</td>
<td>ortho</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.90.1 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.

+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. 87: proj-string: +proj=ortho
7.1.91 Patterson

The Patterson projection is a cylindrical map projection designed for general-purpose mapmaking. See [Patterson2014]

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>patterson</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 88: proj-string: +proj=patterson

7.1.91.1 Parameters

**Note:** All parameters are optional for projection.

```bash
+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 Perspective Conic

![Perspective Conic Diagram](image)

Fig. 89: proj-string: +proj=pconic +lat_1=25 +lat_2=75

7.1.92.1 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.

7.1.93 Polyconic (American)

Fig. 90: proj-string: +proj=poly
7.1.93.1 Parameters

Note: All parameters are optional for projection.

+lon_0=<value>
Longitute 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.

7.1.94 Putnins P1

Fig. 91: proj-string: +proj=putp1
7.1.94.1 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.*

7.1.95 Putnins P2

![Putnins P2 Projection](image)

Fig. 92: proj-string: +proj=putp2
7.1.95.1 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.

7.1.96 Putnins P3

Fig. 93: proj-string: +proj=putp3
7.1.96.1 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.

7.1.97 Putnins P3’

Fig. 94: proj-string: +proj=putp3p
7.1.97.1 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.*

7.1.98 Putnins P4'

Fig. 95: proj-string: `+proj=putp4p`
7.1.98.1 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.*

7.1.99 Putnins P5

![World map](image)

Fig. 96: proj-string: +proj=putp5
7.1.99.1 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.

7.1.100 Putnins P5’

Fig. 97: proj-string: +proj=putp5p
7.1.100.1 Parameters

Note: All parameters are optional for the projection.

\[+\text{lon}_0=<\text{value}>\]
Longitude of projection center.

*Defaults to 0.0.*

\[+R=<\text{value}>\]
Radius of the sphere given in meters. If used in conjunction with \(+\text{ellps}+R\) takes precedence.

\[+x_0=<\text{value}>\]
False easting.

*Defaults to 0.0.*

\[+y_0=<\text{value}>\]
False northing.

*Defaults to 0.0.*

7.1.101 Putnins P6

Fig. 98: proj-string: \(+\text{proj=putp6}\)
7.1.101.1 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.

7.1.102 Putnins P6'

Fig. 99: proj-string: +proj=putp6p
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 Quartic Authalic

Fig. 100: proj-string: +proj=qua_aut

7.1.103.1 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.

7.1.104 Quadrilateralized Spherical Cube

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, elliptical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>qsc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

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.

### 7.1.104.1 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 +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.

\[ \text{7.1.104.2 Parameters} \]

**Note:** All parameters for the projection are optional.

+lon_0=<value>
  Longitude of projection center.
  \text{Defaults to 0.0.}

+lat_0=<value>
  Latitude of projection center.
  \text{Defaults to 0.0.}
+ellps=<value>
   See \texttt{proj -le} for a list of available ellipsoids.
   \textit{Defaults to “GRS80”}.

+x_0=<value>
   False easting.
   \textit{Defaults to 0.0}.

+y_0=<value>
   False northing.
   \textit{Defaults to 0.0}.

7.1.104.3 Further reading

1. Wikipedia
2. NASA

7.1.105 Robinson

Fig. 101: proj-string: \texttt{+proj=robin}

7.1.105.1 Parameters

\textbf{Note:} All parameters are optional for the projection.

+lon_0=<value>
   Longitude of projection center.
   \textit{Defaults to 0.0}.

+R=<value>
   Radius of the sphere given in meters. If used in conjunction with \texttt{+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 Roussilhe Stereographic

![Roussilhe Stereographic Projection](image)

Fig. 102: proj-string: +proj=rouss

#### 7.1.106.1 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.
7.1.107 Rectangular Polyconic

Fig. 103: proj-string: +proj=rpoly

7.1.107.1 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.
7.1.108 Spherical Cross-track Height

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse.</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>sch</td>
</tr>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>3D coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

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]

7.1.108.1 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”.

202 Chapter 7. Coordinate operations
+R=<value>
    Radius of the sphere given in meters. If used in conjunction with +ellps +R takes precedence.

7.1.109 Sinusoidal (Sanson-Flamsteed)

Fig. 104: proj-string: +proj=sinu

MacBryde and Thomas developed generalized formulas for several of the pseudocylindricals with sinusoidal meridi-
ans:

\[
\begin{align*}
    x &= C \lambda (m + \cos \theta)/(m + 1) \\
    y &= C \theta \\
    C &= \sqrt{(m + 1)/n}
\end{align*}
\]

7.1.109.1 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.
7.1.110 Swiss Oblique Mercator

Fig. 105: proj-string: +proj=somerc

7.1.110.1 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.

7.1.111 Stereographic

Fig. 106: proj-string: +proj=stere +lat_0=90 +lat_ts=75
7.1.111.1 Parameters

Note: All parameters are optional for the projection.

+lats=<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.

+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.

7.1.112 Oblique Stereographic Alternative

7.1.112.1 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.
Fig. 107: proj-string: +proj=sterea +lat_0=90
+x_0=<value>
  False easting.
  Defaults to 0.0.
+y_0=<value>
  False northing.
  Defaults to 0.0.

7.1.113 Gauss-Schreiber Transverse Mercator (aka Gauss-Laborde Reunion)

Fig. 108: proj-string: +proj=gstmerc

7.1.113.1 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.
\texttt{proj-string: +proj=tcc}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{tcc_map.png}
\caption{proj-string: \texttt{+proj=tcc}}
\end{figure}

\section*{7.1.114.1 Parameters}

\textbf{Note:} All parameters are optional for the projection.

\begin{itemize}
\item \texttt{+lon\_0=<value>}
  \begin{itemize}
  \item Longitude of projection center.
  \end{itemize}
  \textit{Defaults to 0.0.}
\item \texttt{+R=<value>}
  \begin{itemize}
  \item Radius of the sphere given in meters. If used in conjunction with \texttt{+ellps R} takes precedence.
  \end{itemize}
\item \texttt{+x\_0=<value>}
  \begin{itemize}
  \item False easting.
  \end{itemize}
  \textit{Defaults to 0.0.}
\item \texttt{+y\_0=<value>}
  \begin{itemize}
  \item False northing.
  \end{itemize}
  \textit{Defaults to 0.0.}
\end{itemize}
7.1.115 Transverse Cylindrical Equal Area

7.1.115.1 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.

7.1.116 Times

See [Snyder1993], p.213-214.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>times</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.116.1 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.
Fig. 110: proj-string: +proj=tcea

7.1. Projections
+x_0=<value>
    False easting.
    *Defaults to 0.0.*

+y_0=<value>
    False northing.
    *Defaults to 0.0.*

### 7.1.117 Tissot

#### 7.1.117.1 Parameters

**Required**

+lat_1=<value>
    First standard parallel.
    *Defaults to 0.0.*

+lat_2=<value>
    Second standard parallel.
    *Defaults to 0.0.*
Fig. 112: proj-string: +proj=tissot +lat_1=60 +lat_2=65
Optional

```plaintext
+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.
```

### 7.1.118 Transverse Mercator

The transverse Mercator projection in its various forms is the most widely used projected coordinate system for world topographical and offshore mapping.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Transverse and oblique cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, Spherical and Elliptical</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but reasonably accurate only within 15 degrees of the central meridian</td>
</tr>
<tr>
<td>Alias</td>
<td>tmerc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

![Fig. 113: proj-string: +proj=tmerc](image)
7.1.118.1 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.

<table>
<thead>
<tr>
<th>Projection Name</th>
<th>Areas</th>
<th>Central meridian</th>
<th>Zone width</th>
<th>Scale Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Mercator</td>
<td>World wide</td>
<td>Various</td>
<td>less than 6°</td>
<td>Various</td>
</tr>
<tr>
<td>Transverse Mercator south oriented</td>
<td>Southern Africa</td>
<td>2° intervals E of 11°E</td>
<td>2°</td>
<td>1.000</td>
</tr>
<tr>
<td>UTM North hemisphere</td>
<td>World wide equator to 84°N</td>
<td>6° intervals E &amp; W of 3° E &amp; W</td>
<td>Always 6°</td>
<td>0.9996</td>
</tr>
<tr>
<td>UTM South hemisphere</td>
<td>World wide north of 80°S to equator</td>
<td>6° intervals E &amp; W of 3° E &amp; W</td>
<td>Always 6°</td>
<td>0.9996</td>
</tr>
<tr>
<td>Gauss-Kruger</td>
<td>Former USSR, Yugoslavia, Germany, S. America, China</td>
<td>Various, according to area</td>
<td>Usually less than 6°, often less than 4°</td>
<td>1.0000</td>
</tr>
<tr>
<td>Gauss Boaga</td>
<td>Italy</td>
<td>Various, according to area</td>
<td>6°</td>
<td>0.9996</td>
</tr>
</tbody>
</table>

Example using Gauss-Kruger on Germany area (aka EPSG:31467)

```bash
$ echo 9 51 | proj +proj=tmerc +lat_0=0 +lon_0=9 +k_0=1 +x_0=3500000 +y_0=0, +ellps=bessel +datum=potsdam +units=m +no_defs
3500000.00 5651505.56
```

Example using Gauss Boaga on Italy area (EPSG:3004)

```bash
$ 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 +no_defs
2520000.00 4649858.60
```

7.1.118.2 Parameters

**Note:** All parameters for the projection are optional.

**+approx**

New in version 6.0.0.

Use the algorithm described in section “Elliptical Form” below. It is faster than the default algorithm, but also diverges faster as the distance from the central meridian increases.

**+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.

7.1.118.3 Mathematical definition

The formulas describing the Transverse Mercator below are quoted from [Evenden2005].

φ₀ is the latitude of origin that match the center of the map. It can be set with +lat_0.

k₀ is the scale factor at the natural origin (on the central meridian). It can be set with +k_0.

M(φ) is the meridional distance.

Spherical form

Forward projection

\[
B = \cos \phi \sin \lambda \\
x = k_0 2 \ln \left( \frac{1 + B}{1 - B} \right) \\
y = k_0 \arctan \left( \frac{\tan(\phi)}{\cos \lambda} \right) - \phi_0
\]
Inverse projection

\[
D = \frac{y}{k_0} + \phi_0 \\
x' = \frac{x}{k_0} \\
\phi = \arcsin\left(\frac{\sin D}{\cosh x'}\right) \\
\lambda = \arctan\left(\frac{\sinh x'}{\cos D}\right)
\]

Elliptical form

The formulas below describe the algorithm used when giving the \texttt{+approx} option. They are originally from [Snyder1987], but here quoted from [Evenden1995]. The default algorithm is given by Poder and Engsager in [Poder1998]

Forward projection

\[
N = \frac{k_0}{(1-e^2 \sin^2 \phi)^{1/2}} \\
R = \frac{k_0(1-e^2)}{(1-e^2 \sin^2 \phi)^{3/2}} \\
t = \tan(\phi) \\
\eta = \frac{e^2}{1-e^2 \cos^2 \phi} \\
x = k_0 \lambda \cos \phi + \frac{k_0 \lambda^3 \cos^3 \phi}{3!} (1 - t^2 + \eta^2) + \frac{k_0 \lambda^5 \cos^5 \phi}{5!} (5 - 18t^2 + t^4 + 14\eta^2 - 58t^2 \eta^2) + \frac{k_0 \lambda^7 \cos^7 \phi}{7!} (61 - 479t^2 + 179t^4 - t^6) \\
y = M(\phi) + \frac{k_0 \lambda^2 \sin(\phi) \cos \phi}{2!} + \frac{k_0 \lambda^4 \sin(\phi) \cos^3 \phi}{4!} (5 - t^2 + 9\eta^2 + 4\eta^4) + \frac{k_0 \lambda^6 \sin(\phi) \cos^5 \phi}{6!} (61 - 58t^2 + t^4 + 270\eta^2 - 330t^2 \eta^2) + \frac{k_0 \lambda^8 \sin(\phi) \cos^7 \phi}{8!} (1385 - 3111t^2 + 543t^4 - t^6)
\]
Inverse projection

\[
\begin{align*}
\phi_1 &= M^{-1}(y) \\
N_1 &= k_0 \frac{1}{1 - e^2 \sin^2 \phi_1}^{1/2} \\
R_1 &= \frac{k_0(1 - e^2)}{(1 - e^2 \sin^2 \phi_1)^{3/2}} \\
t_1 &= \tan(\phi_1) \\
\eta_1 &= \frac{e^2}{1 - e^2 \cos^2 \phi_1} \\
\phi &= \phi_1 - \frac{t_1 x^2}{2! R_1 N_1^2} + \frac{t_1 x^4}{4! R_1 N_1^4} (5 + 3t_1^2 + \eta_1^2 - 4\eta_1^4 - 9\eta_1^2 t_1^2) \\
&\quad - \frac{t_1 x^6}{6! R_1 N_1^6} (61 + 90t_1^2 + 46\eta_1^2 + 45t_1^4 - 252\eta_1^2 t_1^2) \\
&\quad + \frac{t_1 x^8}{8! R_1 N_1^8} (1385 + 3633t_1^2 + 4095t_1^4 + 1575t_1^6) \\
\lambda &= \frac{x}{\cos \phi N_1} - \frac{x^3}{3! \cos \phi N_1^3} (1 + 2t_1^2 + \eta_1^2) \\
&\quad + \frac{x^5}{5! \cos \phi N_1^5} (5 + 6\eta_1^2 + 28t_1^2 - 3\eta_1^2 + 8t_1^2 \eta_1^2) \\
&\quad - \frac{x^7}{7! \cos \phi N_1^7} (61 + 662t_1^2 + 1320t_1^4 + 720t_1^6)
\end{align*}
\]

7.1.118.4 Further reading

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

7.1.119 Tobler-Mercator

New in version 6.0.0.

Equal area cylindrical projection with the same latitudinal spacing as Mercator projection.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical equal area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical only</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, conventionally truncated at about 80 degrees north and south</td>
</tr>
<tr>
<td>Alias</td>
<td>tobmerc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.119.1 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 anamorphose 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.

7.1.119.2 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.

\[ +y_0 = \text{value} \]
False northing. Defaults to 0.0.

\[ +R = \text{value} \]
Radius of the sphere given in meters. If used in conjunction with +ellps +R takes precedence.

### 7.1.119.3 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**

\[ \lambda = \frac{x}{k_0} \]
\[ \phi = \frac{\pi}{2} - 2 \arctan \left[ e^{-y/k_0} \right] \]

### 7.1.120 Two Point Equidistant

#### 7.1.120.1 Parameters

**Note:** All parameters are optional for the projection.

\[ +\text{lon}_1 = \text{value} \]
Longitude of first point.

\[ +\text{lat}_1 = \text{value} \]
Latitude of first point.
Fig. 115: proj-string: +proj=tpeqd +lat_1=60 +lat_2=65
PROJ coordinate transformation software library, Release 6.3.1

+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.

+x_0=<value>
   False easting.
   Defaults to 0.0.

+y_0=<value>
   False northing.
   Defaults to 0.0.

7.1.121 Tilted perspective

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>tpers</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

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.

7.1.121.1 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.
Fig. 116: proj-string: +proj=tpers +h=5500000 +lat_0=40
PROJ coordinate transformation software library, Release 6.3.1

+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.

7.1.122 Universal Polar Stereographic

7.1.122.1 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.
Fig. 117: proj-string: +proj=ups
Fig. 118: proj-string: +proj=urm5 +n=0.9 +alpha=2 +q=4

7.1.123.1 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 \( \alpha \) 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.

7.1.124 Urmaev Flat-Polar Sinusoidal

Fig. 119: proj-string: `+proj=urmfps +n=0.5`
7.1.124.1 Parameters

**Note:** All parameters are optional for the projection.

+\( n = \text{value} \)
  Set the \( n \) constant. Value between 0 and 1.

+\( \text{lon}_0 = \text{value} \)
  Longitude of projection center.
  *Defaults to 0.0.*

+\( R = \text{value} \)
  Radius of the sphere given in meters. If used in conjunction with +ellps +R takes precedence.

+\( x_0 = \text{value} \)
  False easting.
  *Defaults to 0.0.*

+\( y_0 = \text{value} \)
  False northing.
  *Defaults to 0.0.*

### 7.1.125 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.

<table>
<thead>
<tr>
<th><strong>Classification</strong></th>
<th>Transverse cylindrical, conformal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Available forms</strong></td>
<td>Forward and inverse, Spherical and Elliptical</td>
</tr>
<tr>
<td><strong>Defined area</strong></td>
<td>Within the used zone, but transformations of coordinates in adjacent zones can be expected to be accurate as well</td>
</tr>
<tr>
<td><strong>Alias</strong></td>
<td>utm</td>
</tr>
<tr>
<td><strong>Domain</strong></td>
<td>2D</td>
</tr>
<tr>
<td><strong>Input type</strong></td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td><strong>Output type</strong></td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

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].
7.1.125.1 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
```

7.1.125.2 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.
+ellps=<value>

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

*Defaults to “GRS80”.*

### 7.1.125.3 Further reading

1. Wikipedia

### 7.1.126 van der Grinten (I)

Fig. 121: proj-string: `+proj=vandg`
7.1.126.1 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.

7.1.127 van der Grinten II

7.1.127.1 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. 122: proj-string: +proj=vandq2
7.1.128 van der Grinten III

Fig. 123: proj-string: \texttt{+proj=vandg3}

7.1.128.1 Parameters

\begin{verbatim}
\textbf{Note:} All parameters are optional for the projection.

\texttt{+lon_0=<value>}
\quad Longitude of projection center.
\quad \textit{Defaults to 0.0.}

\texttt{+R=<value>}
\quad Radius of the sphere given in meters. If used in conjunction with \texttt{+ellps+R} takes precedence.

\texttt{+x_0=<value>}
\quad False easting.
\quad \textit{Defaults to 0.0.}
\end{verbatim}

7.1. Projections
PROJ coordinate transformation software library, Release 6.3.1

+y_0=<value>
False northing.

Defaults to 0.0.

7.1.129 van der Grinten IV

Fig. 124: proj-string: +proj=vandg4

7.1.129.1 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.
7.1.130 Vitkovsky I

Fig. 125: proj-string: +proj= vitk1 +lat_1=45 +lat_2=55

7.1.130.1 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.

7.1.131 Wagner I (Kavraisky VI)

Fig. 126: proj-string: +proj=wag1

7.1.131.1 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.
PROJ coordinate transformation software library, Release 6.3.1

+\text{x}_0=\langle\text{value}\rangle
\quad \text{False easting.}
\quad \text{Defaults to 0.0.}

+\text{y}_0=\langle\text{value}\rangle
\quad \text{False northing.}
\quad \text{Defaults to 0.0.}

7.1.132 Wagner II

Fig. 127: proj-string: +proj=wag2

\[
\begin{align*}
    x &= 0.92483\lambda \cos \theta \\
    y &= 1.38725\theta \\
    \sin \theta &= 0.88022 \sin(0.8855\phi)
\end{align*}
\]

7.1.132.1 Parameters

\textbf{Note:} All parameters are optional for the projection.

+\text{lon}_0=\langle\text{value}\rangle
\quad \text{Longitude of projection center.}
\quad \text{Defaults to 0.0.}

+R=\langle\text{value}\rangle
\quad \text{Radius of the sphere given in meters. If used in conjunction with \text{ellps} +R takes precedence.}

+\text{x}_0=\langle\text{value}\rangle
\quad \text{False easting.}
\quad \text{Defaults to 0.0.}
+y_0=<value>
    False northing.
    Defaults to 0.0.

7.1.133 Wagner III

Fig. 128: proj-string: +proj=wag3

\[
x = \left[ \cos \phi_{ts} / \cos(2\phi_{ts}/3) \right] \lambda \cos(2\phi/3)
\]
\[
y = \phi
\]

7.1.133.1 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.
  \textit{Defaults to 0.0.}

7.1.134 Wagner IV

![Wagner IV projection](image)

Fig. 129: proj-string: +proj=wag4

7.1.134.1 Parameters

\textbf{Note:} All parameters are optional.

+lon_0=<value>
  Longitude of projection center.
  \textit{ 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.
  \textit{Defaults to 0.0.}

+y_0=<value>
  False northing.
  \textit{Defaults to 0.0.}
7.1.135 Wagner V

Fig. 130: proj-string: +proj=wag5

7.1.135.1 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.
7.1.136 Wagner VI

**Fig. 131: proj-string: +proj=wag6**

### 7.1.136.1 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.*
7.1.137 Wagner VII

![World map showing Wagner VII projection](image)

Fig. 132: proj-string: `+proj=wag7`

7.1.138 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.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical (non conformant if used with ellipsoid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>webmerc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.138.1 Usage

Example:

```
$ echo 2 49 | proj +proj=webmerc +datum=WGS84
222638.98  6274861.39
```

7.1.138.2 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`.
```

7.1.138.3 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

\begin{align*}
\lambda &= x \\
\phi &= \frac{\pi}{2} - 2\arctan(e^{-y})
\end{align*}

7.1.138.4 Further reading

1. Wikipedia

7.1.139 Werenskiold I

Fig. 133: proj-string: +proj=weren

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 Winkel I

![Map of the world showing projection](image)

Fig. 134: proj-string: +proj=wink1

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 Winkel II

Fig. 135: proj-string: +proj=wink2

7.1.141.1 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.
7.1.142 Winkel Tripel

Fig. 136: proj-string: +proj=wintri

7.1.142.1 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.

<table>
<thead>
<tr>
<th>Alias</th>
<th>axisswap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D, 3D or 4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Any</td>
</tr>
<tr>
<td>Output type</td>
<td>Any</td>
</tr>
</tbody>
</table>

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).

<table>
<thead>
<tr>
<th>Alias</th>
<th>cart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Geocentric cartesian coordinates</td>
</tr>
</tbody>
</table>

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.

    Default to “GRS80”.

7.2.3 Geocentric Latitude

New in version 5.0.0.

Convert from Geodetic Latitude to Geocentric Latitude (in the forward path).

<table>
<thead>
<tr>
<th>Alias</th>
<th>geoc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Geocentric angular coordinates</td>
</tr>
</tbody>
</table>

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 \( \phi' \) to be the geocentric latitude and \( \phi \) 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 -l 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.

<table>
<thead>
<tr>
<th>Alias</th>
<th>pop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Any</td>
</tr>
<tr>
<td>Output type</td>
<td>Any</td>
</tr>
</tbody>
</table>

This operation 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 are four stacks available: One for 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 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.

<table>
<thead>
<tr>
<th>Alias</th>
<th>push</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Any</td>
</tr>
<tr>
<td>Output type</td>
<td>Any</td>
</tr>
</tbody>
</table>

This operation 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 are four stacks available: One for 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 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.

```bash
$ 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
```
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 Unit conversion

New in version 5.0.0.

Convert between various distance, angular and time units.

<table>
<thead>
<tr>
<th>Alias</th>
<th>unitconvert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D, 3D or 4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Any</td>
</tr>
<tr>
<td>Output type</td>
<td>Any</td>
</tr>
</tbody>
</table>

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 coordinate transformation software library, Release 6.3.1

(continued from previous page)

| 12.0056753463 | 55.9866540552 | 12.3000 | 2000.0000 |

---
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=helmert +epoch=2000.0 +t_obs=2017.5 ...

### 7.2.8.1 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=**
  - 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.
7.2.8.2 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.

<table>
<thead>
<tr>
<th>Label</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>km</td>
<td>Kilometer</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
<tr>
<td>dm</td>
<td>Decimeter</td>
</tr>
<tr>
<td>cm</td>
<td>Centimeter</td>
</tr>
<tr>
<td>mm</td>
<td>Millimeter</td>
</tr>
<tr>
<td>kmi</td>
<td>International Nautical Mile</td>
</tr>
<tr>
<td>in</td>
<td>International Inch</td>
</tr>
<tr>
<td>ft</td>
<td>International Foot</td>
</tr>
<tr>
<td>yd</td>
<td>International Yard</td>
</tr>
<tr>
<td>mi</td>
<td>International Statute Mile</td>
</tr>
<tr>
<td>fath</td>
<td>International Fathom</td>
</tr>
<tr>
<td>ch</td>
<td>International Chain</td>
</tr>
<tr>
<td>link</td>
<td>International Link</td>
</tr>
<tr>
<td>us-in</td>
<td>U.S. Surveyor’s Inch</td>
</tr>
<tr>
<td>us-ft</td>
<td>U.S. Surveyor’s Foot</td>
</tr>
<tr>
<td>us-yd</td>
<td>U.S. Surveyor’s Yard</td>
</tr>
<tr>
<td>us-ch</td>
<td>U.S. Surveyor’s Chain</td>
</tr>
<tr>
<td>us-mi</td>
<td>U.S. Surveyor’s Statute Mile</td>
</tr>
<tr>
<td>ind-yd</td>
<td>Indian Yard</td>
</tr>
<tr>
<td>ind-ft</td>
<td>Indian Foot</td>
</tr>
<tr>
<td>ind-ch</td>
<td>Indian Chain</td>
</tr>
</tbody>
</table>

7.2.8.3 Angular units

New in version 5.2.0.

In the table below all angular units supported by PROJ `unitconvert` are listed.

<table>
<thead>
<tr>
<th>Label</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>deg</td>
<td>Degree</td>
</tr>
<tr>
<td>grad</td>
<td>Grad</td>
</tr>
<tr>
<td>rad</td>
<td>Radian</td>
</tr>
</tbody>
</table>

7.2.8.4 Time units

In the table below all time units supported by PROJ are listed.

<table>
<thead>
<tr>
<th>Label</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>mjd</td>
<td>Modified Julian date</td>
</tr>
<tr>
<td>decimalyear</td>
<td>Decimal year</td>
</tr>
<tr>
<td>gps_week</td>
<td>GPS Week</td>
</tr>
<tr>
<td>yyyyymmdd</td>
<td>Date in yyyyymmdd format</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Alias</th>
<th>affine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>4D</td>
</tr>
<tr>
<td>Input type</td>
<td>XYZT</td>
</tr>
<tr>
<td>Output type</td>
<td>XYZT</td>
</tr>
</tbody>
</table>

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

\[
\begin{bmatrix}
X \\
Y \\
Z \\
T
\end{bmatrix}_{\text{dest}} =
\begin{bmatrix}
x_{\text{off}} \\
y_{\text{off}} \\
z_{\text{off}} \\
t_{\text{off}}
\end{bmatrix} +
\begin{bmatrix}
s11 & s12 & s13 & 0 \\
s21 & s22 & s23 & 0 \\
s31 & s32 & s33 & 0 \\
0 & 0 & 0 & \text{tscale}
\end{bmatrix}
\begin{bmatrix}
X \\
Y \\
Z \\
T
\end{bmatrix}_{\text{source}}
\]  

(7.1)

7.3.2 Kinematic datum shifting utilizing a deformation model

New in version 5.0.0.

Perform datum shifts means of a deformation/velocity model.

<table>
<thead>
<tr>
<th>Input type</th>
<th>Cartesian coordinates (spatial), decimal years (temporal).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output type</td>
<td>Cartesian coordinates (spatial), decimal years (temporal).</td>
</tr>
<tr>
<td>Domain</td>
<td>4D</td>
</tr>
</tbody>
</table>

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.

7.3.2.1 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
```
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:

```plaintext
proj = deformation t_epoch = 2000.0
xy_grids = ./nkgrf03vel_realigned_xy.ct2
z_grids = ./nkgrf03vel_realigned_z.gtx
```

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.

### 7.3.2.2 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 not complain if the grid is not available.
- If a grid is specified with a path that contains spaces, the value should be quoted. e.g. `+xy_grids="/my path/has/spaces.ct2"`
- Grids for the horizontal component of a deformation model are expected to be in CTable2 format.

**+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 not complain if the grid is not available.
- If a grid is specified with a path that contains spaces, the value should be quoted. e.g. `+z_grids="/my path/has/spaces.gtx"`
- Grids for the vertical component of a deformation model are expected to be in GTX format.

**+t_epoch=<value>**
- Central epoch of transformation given in decimal years. 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`.

---

### 7.3. Transformations 259
+\texttt{dt}=<\texttt{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 decimal years.

\begin{center}
\textbf{Note:} \texttt{+dt} is mutually exclusive with \texttt{+t\_epoch}
\end{center}

7.3.2.3 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 \( t_{\text{obs}} \) and \( t_c \) determine the magnitude of the coordinate correcton as seen in eq. (7.1) below.

\[
\begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix}_B = \begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix}_A + (t_{\text{obs}} - t_c) \begin{pmatrix}
V_X \\
V_Y \\
V_Z
\end{pmatrix}
\] (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 \texttt{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:

\[
\begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix} = \begin{pmatrix}
-\sin \phi \cos \lambda N - \sin \lambda E + \cos \phi \cos \lambda U \\
-\sin \phi \sin \lambda N + \sin \lambda E + \cos \phi \sin \lambda U \\
\cos \phi N + \sin \phi U
\end{pmatrix}
\] (7.1)

 where \( \phi \) and \( \lambda \) 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.

7.3.2.4 See also

1. \textit{Behavioural changes from version 5 to 6}

7.3.3 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.

<table>
<thead>
<tr>
<th>Alias</th>
<th>geogoffset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
<tr>
<td>output type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
</tbody>
</table>

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 convenience wrapper for the more general *Affine transformation*.

### 7.3.3.1 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
```

### 7.3.3.2 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.

### 7.3.4 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.

<table>
<thead>
<tr>
<th>Alias</th>
<th>helmert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D, 3D and 4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Cartesian coordinates (spatial), decimalyears (temporal).</td>
</tr>
<tr>
<td>Output type</td>
<td>Cartesian coordinates (spatial), decimalyears (temporal).</td>
</tr>
</tbody>
</table>

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 behaviour 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 \( t_{\text{epoch}} \). The observation time is given as part of the coordinate when using PROJ’s 4D-functionality.

### 7.3.4.1 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 \( \text{ITRF2000} \) to \( \text{ITRF93} \) 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
```

### 7.3.4.2 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 \( rx, ry, rz, drx, dry, drz \)), \( \text{convention} \) is required.

The two conventions are equally popular and a frequent source of confusion. The coordinate frame convention is also described as a 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 decimal year. Only used spatiotemporal transformations.
+exact
Use exact transformation equations.
See (7.6)
+transpose
Depreciated since version 5.2.0: (removed)
```
Transpose rotation matrix and follow the Position Vector rotation convention. If \( +\text{transpose} \) is not added the Coordinate Frame rotation convention is used.

### 7.3.4.3 Mathematical description

In the notation used below, \( \dot{P} \) is the rate of change of a given transformation parameter \( P \). \( \dot{P} \) is the kinematically adjusted version of \( P \), described by

\[
\dot{P} = P + \ddot{P} (t - t_{\text{central}})
\]

where \( t \) is the observation time of the coordinate and \( t_{\text{central}} \) 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 scaled. 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:

\[
\begin{bmatrix}
X \\
Y
\end{bmatrix}^B =
\begin{bmatrix}
T_x \\
T_y
\end{bmatrix} + s
\begin{bmatrix}
\cos \theta & \sin \theta \\
-\sin \theta & \cos \theta
\end{bmatrix}
\begin{bmatrix}
X \\
Y
\end{bmatrix}^A
\]

(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:

\[
\begin{bmatrix}
X \\
Y
\end{bmatrix}^B =
\begin{bmatrix}
\dot{T}_x \\
\dot{T}_y
\end{bmatrix} + s(t)
\begin{bmatrix}
\cos \dot{\theta} & \sin \dot{\theta} \\
-\sin \dot{\theta} & \cos \dot{\theta}
\end{bmatrix}
\begin{bmatrix}
X \\
Y
\end{bmatrix}^A
\]

(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 \( t_{\text{central}} \).

#### 3D Helmert

The general form of the 3D Helmert is

\[
V^B = T + (1 + s \times 10^{-6}) RV^A
\]

(7.2)

Where \( T \) is a vector consisting of the three translation parameters, \( s \) is the scaling factor and \( R \) 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 \( R_x = \text{radians} (rx) \), \( R_z = \text{radians} (ry) \) and \( R_z = \text{radians} (rz) \)

In the Coordinate Frame convention, \( R_x = -\text{radians} (rx) \), \( R_z = -\text{radians} (ry) \) and \( R_z = -\text{radians} (rz) \)

The rotation matrix is composed of three rotation matrices, one for each axis.

\[
R_x =
\begin{bmatrix}
1 & 0 & 0 \\
0 & \cos R_x & -\sin R_x \\
0 & \sin R_x & \cos R_x
\end{bmatrix}
\]

(7.2)
\[
\begin{align*}
R_Y &= \begin{bmatrix} \cos R_y & 0 & \sin R_y \\ 0 & 1 & 0 \\ -\sin R_y & 0 & \cos R_y \end{bmatrix} \\
R_Z &= \begin{bmatrix} \cos R_z & -\sin R_z & 0 \\ \sin R_z & \cos R_z & 0 \\ 0 & 0 & 1 \end{bmatrix}
\end{align*}
\]

The three rotation matrices can be combined in one:

\[
R = R_X R_Y R_Y
\]

For \(R\), this yields:

\[
\begin{bmatrix} \cos R_y \cos R_z & -\cos R_x \sin R_z + \sin R_x \sin R_z & + \sin R_x \sin R_y \\ \sin R_x \sin R_y \cos R_z - \cos R_x \sin R_z & \cos R_x \sin R_y \cos R_z & \cos R_x \sin R_z + \sin R_x \cos R_y \\ -\sin R_y & \sin R_x \cos R_y & \cos R_x \cos R_y \end{bmatrix}
\]

Using the small angle approximation the rotation matrix can be simplified to

\[
R = \begin{bmatrix} 1 & -R_z & R_y & R_z \\ R_z & 1 & -R_x & -R_y \\ -R_y & R_x & 1 & R_x \end{bmatrix}
\]

Which allow us to express the most common version of the Helmert transform, using the approximated rotation matrix:

\[
\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + (1 + s \times 10^{-6}) \begin{bmatrix} 1 & -R_z & R_y & R_z \\ R_z & 1 & -R_x & -R_y \\ -R_y & R_x & 1 & R_x \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A
\]

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:

\[
\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + (1 + s \times 10^{-6}) \begin{bmatrix} 1 & -\dot{R}_z & \dot{R}_y & \dot{R}_z \\ \dot{R}_z & 1 & -\dot{R}_x & -\dot{R}_y \\ -\dot{R}_y & \dot{R}_x & 1 & \dot{R}_x \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A
\]

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:

\[
\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A
\]

That after application of (7.1) has the following kinematic counterpart:
7.3.5 Horner polynomial evaluation

New in version 5.0.0.

<table>
<thead>
<tr>
<th>Alias</th>
<th>horner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D and 3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic and projected coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic and projected coordinates</td>
</tr>
</tbody>
</table>

The Horner polynomial evaluation scheme is used for transformations between reference frames where one or both are inhomogenous 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:

\[
\Delta X = \sum_{i,j} u_{i,j} U^i V^j \\
\Delta Y = \sum_{i,j} v_{i,j} U^i V^j
\]  
(7.7)

where

\[
U = X_{in} - X_{origin} \\
V = Y_{in} - Y_{origin}
\]  
(7.8)

and \(u_{i,j}\) and \(v_{i,j}\) are coefficients that make up the polynomial.

The final coordinates are determined as

\[
X_{out} = X_{in} + \Delta X \\
Y_{out} = Y_{in} + \Delta Y
\]  
(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:

\[
\Delta X + i\Delta Y = \sum_{j=1}^{n} (c_{2j-1} + i c_{2j})(U + iV)^j
\]  
(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).

7.3.5.1 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+06,9.9999791567e-01,1.5372750011e-10,5.9300860915e-15,2.
-2609497673e-19,4.3188227445e-05,2.8225130416e-10,7.8740007114e-16,-1.7453997279e-19,
-2906832535e-19,3.9984284847e-05,2.8225130416e-10,7.8740007114e-16,-1.7453997279e-19,
+fwd_u=8.7760574982e+05,9.9999752475e-01,2.881756773e-10,5.5641310680e-15,-1.
-5547000949e-18,-4.1357045890e-05,4.2106213519e-11,2.852551629e-14,-1.9107771273e-
-18,3.361559093e-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-14,-5.9304261011e-15,-2.
-2612705361e-19,-4.3188331419e-05,-2.8225549995e-10,-7.8740007114e-16,1.747657673e-
-19,-1.6877467989e-10,1.1234649773e-14,1.7042318057e-18,7.9300735275e-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,-2.0241230315e-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=6.19480258923588e+05,6.13258568148837e+06
+inv_c=6.13258562111350e+06,6.19480105709997e+05,9.993789662675206e-01,-2.
-82153291753490e-02,-2.70899971040026e-10,-1.77019590714070e-09,1.08522286274070e-14,
-2.11430299751604e-15
+inv_c=6.13342118787027e+06,4.9469018170311e+05,9.9984464710368e-01,2.
-8227907814774e-02,7.6612354220864e-11,1.78425334628927e-09,-1.05584823306400e-14,-
-3.32554258683744e-15

7.3.5.2 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”.

7.3. Transformations
PROJ coordinate transformation software library, Release 6.3.1

+\text{deg}=\text{<value>}
  
  Degree of polynomial

+fwd\_origin=\text{<northing,easting>}
  
  Coordinate of origin for the forward mapping

+inv\_origin=\text{<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=\text{<u\_11,u\_12,\ldots,u\_ij,\ldots,u\_mn>}
  
  Coefficients for the forward transformation i.e. latitude to northing as described in (7.7).

+fwd\_v=\text{<v\_11,v\_12,\ldots,v\_ij,\ldots,v\_mn>}
  
  Coefficients for the forward transformation i.e. longitude to easting as described in (7.7).

+inv\_u=\text{<u\_11,u\_12,\ldots,u\_ij,\ldots,u\_mn>}
  
  Coefficients for the inverse transformation i.e. latitude to northing as described in (7.7).

+inv\_v=\text{<v\_11,v\_12,\ldots,v\_ij,\ldots,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=\text{<c\_1,c\_2,\ldots,c\_N>}
  
  Coefficients for the complex forward transformation as described in (7.10).

+inv\_c=\text{<c\_1,c\_2,\ldots,c\_N>}
  
  Coefficients for the complex inverse transformation as described in (7.10).

**Optional**

+range=\text{<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.
7.3.5.3 Further reading

1. Wikipedia

7.3.6 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 parameterize, 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].

<table>
<thead>
<tr>
<th>Alias</th>
<th>molodensky</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
</tbody>
</table>

The Molodensky transform can be used to perform a datum shift from coordinate \((\phi_1, \lambda_1, h_1)\) to \((\phi_2, \lambda_2, h_2)\) 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 \((\delta a)\) and flattening \((\delta f)\), 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].

7.3.6.1 Examples

The abridged Molodensky:

```
proj=molodensky a=6378160 rf=298.25 da=-23 df=-8.120449e-8 dx=-134 dy=-48 dz=149
```

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
```
7.3.6.2 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.

7.3.7 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 which operates directly in the geodetic coordinates. Molodensky-Badekas can rather be seen as a variation of Helmert transform.

<table>
<thead>
<tr>
<th>Alias</th>
<th>molobadekas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Cartesian coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Cartesian coordinates</td>
</tr>
</tbody>
</table>

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.
7.3.7.1 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
```

7.3.7.2 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 arc seconds.

- **+rz=<value>**
  Z-axis rotation given 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.
7.3.7.3 Mathematical description

In the **Position Vector** convention, we define \( R_x = \text{radians}(rx) \), \( R_y = \text{radians}(ry) \) and \( R_z = \text{radians}(rz) \)

In the **Coordinate Frame** convention, \( R_x = -\text{radians}(rx) \), \( R_y = -\text{radians}(ry) \) and \( R_z = -\text{radians}(rz) \)

\[
\begin{bmatrix}
X_{\text{output}} \\
Y \\
Z
\end{bmatrix} = \begin{bmatrix}
T_x + P_x \\
T_y + P_y \\
T_z + P_z
\end{bmatrix} + (1 + s \times 10^{-6}) \begin{bmatrix}
1 & -R_z & R_y \\
R_z & 1 & -R_x \\
-R_y & R_x & 1
\end{bmatrix} \begin{bmatrix}
X_{\text{input}} - P_x \\
Y_{\text{input}} - P_y \\
Z_{\text{input}} - P_z
\end{bmatrix}
\]

7.3.8 Horizontal grid shift

New in version 5.0.0.

Change of horizontal datum by grid shift.

<table>
<thead>
<tr>
<th>Domain</th>
<th>2D, 3D and 4D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input type</td>
<td>Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)</td>
</tr>
</tbody>
</table>

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.

7.3.8.1 Temporal gridshifting

New in version 5.1.0.

By initializing the horizontal gridshifting 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 \(+t_{\text{epoch}}\) and the final epoch of the coordinate is set with \(+t_{\text{final}}\). 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
```
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
```

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 be offset by the last step in the pipeline.

### 7.3.8.2 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 not complain if the grid is not available.

If a grid is specified with a path that contains spaces, the value should be quoted. e.g. `+grids="/my path/has/spaces.gsb"`

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.
7.3.9 Vertical grid shift

New in version 5.0.0.

Change Vertical datum change by grid shift

<table>
<thead>
<tr>
<th>Domain</th>
<th>3D and 4D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input type</td>
<td>Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)</td>
</tr>
</tbody>
</table>

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.

7.3.9.1 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
```

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:
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 be 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 not complain if the grid is not available.

If a grid is specified with a path that contains spaces, the value should be quoted. e.g. +grids="/my path/has/spaces.gtx"

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:

$$Z_{target} = Z_{source} + multiplier \times gridvalue$$  \hfill (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.
7.4 The pipeline operator

New in version 5.0.0.

Construct complex operations by daisy-chaining operations in a sequential pipeline.

<table>
<thead>
<tr>
<th>Alias</th>
<th>pipeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D, 3D and 4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Any</td>
</tr>
<tr>
<td>Output type</td>
<td>Any</td>
</tr>
</tbody>
</table>

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 *Uurmaev 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 an 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
   ```

(continues on next page)
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

### Author
Even Rouault

### Last Updated
2020-01-02

#### 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
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 6.3.0. 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++

```cpp
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'"
```

<table>
<thead>
<tr>
<th>EPSG</th>
<th>Source CRS</th>
<th>Target CRS</th>
<th>Method Name</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1241</td>
<td>NAD27 to NAD83 (1)</td>
<td>NADCON</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>1243</td>
<td>NAD27 to NAD83 (2)</td>
<td>NADCON</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>1312</td>
<td>NAD27 to NAD83 (3)</td>
<td>NTv1</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>1313</td>
<td>NAD27 to NAD83 (4)</td>
<td>NTv2</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>1462</td>
<td>NAD27 to NAD83 (5)</td>
<td>NTv1</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>1573</td>
<td>NAD27 to NAD83 (6)</td>
<td>NTv2</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>8549</td>
<td>NAD27 to NAD83 (8)</td>
<td>NADCON5 (2D)</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>8555</td>
<td>NAD27 to NAD83 (7)</td>
<td>NADCON5 (2D)</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>9111</td>
<td>NAD27 to NAD83 (9)</td>
<td>NTv2</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>108003</td>
<td>NAD_1927_To_NAD_1983_PR_VI</td>
<td>NTv2</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

As we have found direct transformations, we will not attempt any more complicated research. One can note in the above result set that an 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. This operation is a sort of dummy operation that only takes into account potential difference of axis orders (long-lat vs lat-long), units (degree vs grads) and prime meridian (Greewich vs Paris/Rome/other historic prime meridians). It does not attempt any datum shift, hence the “ballpark” qualifier in its name.
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 tranformation.
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
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 first in lexicographic order (obviously completely arbitrary, but a sorting algorithm must be able to compare all entries)

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 “computationnally” 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.

```plaintext
$ projinfo -s EPSG:7042 -t EPSG:4936
Candidate operations found: 1
-------------------------------------
Operation n°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[  
  GEOCRS["RGF93 (lon-lat)",  
    [...],  
    ID["EPSG",7042]]],
TARGETCRS[  
  GEOCRS["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,  
      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."],
    ID["EPSG",1591]]],
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
--including EEZ
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:

- \( \text{SOURCE}_{_CRS} = \text{op1}\.source\_crs \text{ AND op1}\.target\_crs = \text{op2}\.source\_crs \text{ AND op2}\.target\_crs = \text{TARGET}_{_CRS} \)
- \( \text{SOURCE}_{_CRS} = \text{op1}\.source\_crs \text{ AND op1}\.target\_crs = \text{op2}\.target\_crs \text{ AND op2}\.source\_crs = \text{TARGET}_{_CRS} \)
- \( \text{SOURCE}_{_CRS} = \text{op1}\.target\_crs \text{ AND op1}\.source\_crs = \text{op2}\.source\_crs \text{ AND op2}\.target\_crs = \text{TARGET}_{_CRS} \)
- \( \text{SOURCE}_{_CRS} = \text{op1}\.target\_crs \text{ AND op1}\.source\_crs = \text{op2}\.target\_crs \text{ AND op2}\.source\_crs = \text{TARGET}_{_CRS} \)

Depending on which case is selected, op1 and op2 should be reversed, before being concatenated.

This logic is implemented 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
```
(continues on next page)
Operation n°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 n°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 \\
    +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 n°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 n°4:

(continues on next page)
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=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

One can see that the selected intermediate CRS that has been used is GDA94. This is a completely novel behaviour 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:

```bash
$ projinfo -s AGD84 -t GDA2020 --spatial-test intersects --pivot-crs EPSG:4326 -o PROJ
Candidate operations found: 2
-------------------------------------
Operation n°1:
unknown id, AGD84 to WGS 84 (7) + 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=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 n°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
```

7.5. Computation of coordinate operations between two CRS
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): frmo EPSG 4. Conversion from WGS 84 (G1762) (geocentric) to WGS 84 (G1762) (geoc2D): 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 n°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 symetric 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 n°1:
INVERSE(DERIVED_FROM(EPSG)):9229, Inverse of NAD83(2011) to NAVD88 height (3), 0.015ᵦ→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 n°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 n°2:
unknown id, Inverse of NGVD29 height (ftUS) to NGVD29 depth (ftUS) + NGVD29 height (ftUS) to 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
```

(continues on next page)
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:

```bash
$ 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, west of 112°W - onshore

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, 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 (1) + WGS 84 to WGS 84 (G1762), 3.15 m,

→ USA - CONUS south 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 (3) + WGS 84 to WGS 84 (G1762), 3.15 m,

→ USA - CONUS south of 41°N, 95°W to 78°W

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

→ 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, Ballpark geographic offset from NAD83(NSRS2007) to NAD83(2011) + Inverse

→ of NAD83(2011) to NAVD88 height (3) + Conversion from NAD83(2011) (geog2D) to

→ 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 (G1762) to (G1762)

→ Alaska; PRVI, has ballpark transformation

7.5. Computation of coordinate operations between two CRS
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
```

(continues on next page)
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

(continues on next page)
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:

```bash
$ 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" -t ETRS89 -o PROJ
Candidate operations found: 1
-------------------------------------
Operation n°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
```

Chapter 7. Coordinate operations
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.
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 transformation grids that have an explicit relative or absolute path, the directory specified in the grid 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.
- Path(s) set by the environment variable `PROJ_LIB`. On Linux/MacOSX/Unix, use `:` to separate paths. On Windows, `;`
- On Windows, 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 are installed under `.\bin\`, 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. Note, however, that since this is a hard-wired path setting, it only works if the whole PROJ installation is not moved somewhere else.
- The current directory

### 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 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.

8.4 External resources and packaged grids

8.4.1 proj-datumgrid

For a functioning PROJ, 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.

8.4.2 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.

8.4.3 World package

The world package includes grids that have global extent, e.g. the global geoid model EGM08.
8.4.4 -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 packages. 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).

8.5 Other transformation grids

Below is a list of grid resources for various countries which are not included in the grid distributions mentioned above.

8.5.1 Free grids

The following is a list of grids distributed under a free and open license.

8.5.1.1 Hungary

Hungarian grid ETRS89 - HD72/EOV (epsg:23700), both horizontal and elevation grids

8.5.2 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.

8.5.2.1 Austria

Overview of Austrian grids and other resources related to the local geodetic reference.

8.5.2.2 Brazil

Brazilian grids for datums Corrego Alegre 1961, Corrego Alegre 1970-72, SAD69 and SAD69(96)

8.5.2.3 Netherlands

Dutch grid (Registration required before download)

8.5.2.4 Portugal

Portuguese grids for ED50, Lisbon 1890, Lisbon 1937 and Datum 73
8.5.2.5 South Africa

South African grid (Cape to Hartebeeshoek94 or WGS84)

8.5.2.6 Spain

Spanish grids for ED50.

8.5.3 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).

8.5.3.1 Getting and building HTDP

The HTDP modelling program is in written 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
```

8.5.3.2 Getting crs2crs2grid.py

The _crs2crs2grid.py_ script can be found at https://github.com/OSGeo/gdal/tree/trunk/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
```
8.5.3.3 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.

```
```

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 the "htdp" program 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 the `htdp` program will be 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:

<table>
<thead>
<tr>
<th>CRS Id</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NAD_83(2011) (North America tectonic plate fixed)</td>
</tr>
<tr>
<td>2</td>
<td>NAD_83(PA11) (Pacific tectonic plate fixed)</td>
</tr>
<tr>
<td>3</td>
<td>NAD_83(MA11) (Mariana tectonic plate fixed)</td>
</tr>
<tr>
<td>4</td>
<td>WGS_72</td>
</tr>
<tr>
<td>5</td>
<td>WGS_84(1984) = ITRF92</td>
</tr>
<tr>
<td>6</td>
<td>WGS_84(G1150) = ITRF2000</td>
</tr>
<tr>
<td>7</td>
<td>WGS_84(G1173) = ITRF96</td>
</tr>
<tr>
<td>8</td>
<td>WGS_84(G1150) = ITRF2000</td>
</tr>
<tr>
<td>9</td>
<td>PNEOS_90 = ITRF90</td>
</tr>
<tr>
<td>10</td>
<td>NEOS_90 = ITRF90</td>
</tr>
<tr>
<td>11</td>
<td>SIG/MIT_92 = ITRF91</td>
</tr>
<tr>
<td>12</td>
<td>ITRF88</td>
</tr>
<tr>
<td>13</td>
<td>ITRF89</td>
</tr>
<tr>
<td>14</td>
<td>ITRF90</td>
</tr>
<tr>
<td>15</td>
<td>ITRF91</td>
</tr>
<tr>
<td>16</td>
<td>ITRF92</td>
</tr>
<tr>
<td>17</td>
<td>ITRF93</td>
</tr>
<tr>
<td>18</td>
<td>ITRF94 = ITRF96</td>
</tr>
<tr>
<td>19</td>
<td>ITRF96</td>
</tr>
<tr>
<td>20</td>
<td>ITRF97</td>
</tr>
<tr>
<td>21</td>
<td>IGS97 = ITRF97</td>
</tr>
<tr>
<td>22</td>
<td>ITRF00</td>
</tr>
<tr>
<td>23</td>
<td>IGS00 = ITRF2000</td>
</tr>
<tr>
<td>24</td>
<td>ITRF00</td>
</tr>
<tr>
<td>25</td>
<td>ITRF2005</td>
</tr>
<tr>
<td>26</td>
<td>ITRF05 = ITRF2005</td>
</tr>
<tr>
<td>27</td>
<td>ITRF2008</td>
</tr>
<tr>
<td>28</td>
<td>IGS08 = ITRF2008</td>
</tr>
</tbody>
</table>

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:

```
```

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...
```
8.5.3.4 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.

8.6 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 +ellps=WGS84
# ---- 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
Below is a list of the init files that are packaged with PROJ.

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GL27</td>
<td>Great Lakes Grids</td>
</tr>
<tr>
<td>ITRF2000</td>
<td>Full set of transformation parameters between ITRF2000 and other ITRF's</td>
</tr>
<tr>
<td>ITRF2008</td>
<td>Full set of transformation parameters between ITRF2008 and other ITRF's</td>
</tr>
<tr>
<td>ITRF2014</td>
<td>Full set of transformation parameters between ITRF2014 and other ITRF's</td>
</tr>
<tr>
<td>nad27</td>
<td>State plane coordinate systems, North American Datum 1927</td>
</tr>
<tr>
<td>nad83</td>
<td>State plane coordinate systems, North American Datum 1983</td>
</tr>
</tbody>
</table>
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 $\phi$ and longitude $\lambda$. (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 $(\phi_1, \lambda_1)$ and $(\phi_2, \lambda_2)$ is called the geodesic. Its length is $s_{12}$ and the geodesic from point 1 to point 2 has forward azimuths $\alpha_1$ and $\alpha_2$ 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 $\phi_1$, $\lambda_1$, $\alpha_1$, $s_{12}$, determine $\phi_2$, $\lambda_2$, $\alpha_2$.
- the inverse problem — given $\phi_1$, $\lambda_1$, $\phi_2$, $\lambda_2$, determine $s_{12}$, $\alpha_1$, $\alpha_2$.

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 counterclockwise, of the quadrilateral with corners $(\phi_1, \lambda_1)$, $(0, \lambda_1)$, $(0, \lambda_2)$, and $(\phi_2, \lambda_2)$. 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 $M_{12} = M_{21} = 1$.
- $\sigma_{12}$ 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 $180^\circ$.

If points 1, 2, and 3 lie on a single geodesic, then the following addition rules hold:

- $s_{13} = s_{12} + s_{23}$
- $\sigma_{13} = \sigma_{12} + \sigma_{23}$
- $S_{13} = S_{12} + S_{23}$
- $m_{13} = m_{12}M_{23} + m_{23}M_{12}$
- $M_{13} = M_{12}M_{23} - (1 - M_{12}M_{21})m_{23}/m_{12}$
- $M_{31} = M_{32}M_{21} - (1 - M_{23}M_{32})m_{12}/m_{23}$.

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 $\pm 180^\circ$ for oblate ellipsoids.)
- $\lambda_2 = \lambda_1 \pm 180^\circ$ (with neither point at a pole). If $\alpha_1 = 0^\circ$ or $\pm 180^\circ$, the geodesic is unique. Otherwise there are two geodesics and the second one is obtained by setting $[\alpha_1, \alpha_2] \leftarrow [-\alpha_2, -\alpha_1]$, $S_{12} \leftarrow -S_{12}$. (This occurs when $\phi_2$ 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 $\delta$. (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 $\delta$. 

Chapter 9. Geodesic calculations
9.5 Background

The algorithms implemented by this package are given in [Karney2013] (addenda) and are based on [Besse1825] 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).
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:

```c
#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.

```c
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
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,]`) (continues on next page)
The use of PROJ strings to describe a CRS is considered as legacy (one of the main weaknesses 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.

```c
P = proj_create_crs_to_crs (C, "EPSG:4326", /* 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.

```c
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;
```
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.

```c
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.

```c
b = proj_trans (P, PJ_FWD, a);
pprintf ("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.

```c
b = proj_trans (P, PJ_INV, b);
pprintf ("longitude: %g, latitude: %g\n", b.lp.lam, b.lp.phi);
```

Before ending the program the allocated memory needs to be released again:

```c
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:

```c
#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 */
    /* 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;
    }
}
```

(continues on next page)
32 proj_destroy(P);
33 P = P_for_GIS;
34
35 /* a coordinate union representing Copenhagen: 55d N, 12d E */
36 /* Given that we have used proj_normalize_for_visualization(), the order of */
37 /* coordinates is longitude, latitude, and values are expressed in degrees. */
38 a = proj_coord (12, 55, 0, 0);
39
40 /* transform to UTM zone 32, then back to geographical */
41 b = proj_trans (P, PJ_FWD, a);
42 printf (“easting: %.3f, northing: %.3f
”, b.enu.e, b.enu.n);
43 b = proj_trans (P, PJ_INV, b);
44 printf (“longitude: %g, latitude: %g
”, b.lp.lam, b.lp.phi);
45
46 /* Clean up */
47 proj_destroy(P);
48 proj_context_destroy (C); /* may be omitted in the single threaded case */
49 return 0;
50 }

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_ctxt() and pj_init_plus_ctxt() which take a projections context.

The projections context can be created with pj_ctxt_alloc(), and there is a global default context used when one is not provided by the application. There is a pj_ctxt_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:
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 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.
10.5.1.1 Transformation objects

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()`.

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:

```c
typedef enum proj_direction {
    PJ_FWD = 1, /* Forward */
    PJ_IDENT = 0, /* Do nothing */
    PJ_INV = -1 /* Inverse */
} PJ_DIRECTION;
```

PJ_FWD
Perform transformation in the forward direction.

PJ_IDENT
Identity. Do nothing.

PJ_INV
Perform transformation in the inverse direction.

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()`.

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.

10.5.1.2 2 dimensional coordinates

Various 2-dimensional coordinate data types.

PJ_LP
Geodetic coordinate, latitude and longitude. Usually in radians.

```c
typedef struct { double lam, phi; } PJ_LP;
```

double PJ_LP.lam
Longitude. Lambda.

double PJ_LP.phi
Latitude. Phi.

PJ_XY
2-dimensional cartesian coordinate.
typedef struct ( double x, y; ) PJ_XY;

double PJ_XY.x
   Easting.

double PJ_XY.y
   Northing.

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.

10.5.1.3 3 dimensional coordinates

The following data types are the 3-dimensional equivalents to the data types above.

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.

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.

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.

10.5. Reference
double \texttt{PJ\_UVW\_v}  
Latitude or northing, depending on use.

double \texttt{PJ\_UVW\_w}  
Vertical component.

### 10.5.1.4 Spatiotemporal coordinate types

The following data types are extensions of the triplets above into the time domain.

#### \texttt{PJ\_LPZT}

Spatiotemporal version of \texttt{PJ\_LPZ}.

```c
typedef struct {
    double lam;
    double phi;
    double z;
    double t;
} PJ\_LPZT;
```

double \texttt{PJ\_LPZT\_lam}  
Longitude.

double \texttt{PJ\_LPZT\_phi}  
Latitude

double \texttt{PJ\_LPZT\_z}  
Vertical component.

double \texttt{PJ\_LPZT\_t}  
Time component.

#### \texttt{PJ\_XYZT}

Generic spatiotemporal coordinate. Useful for e.g. cartesian coordinates with an attached time-stamp.

```c
typedef struct {
    double x;
    double y;
    double z;
    double t;
} PJ\_XYZT;
```

double \texttt{PJ\_XYZT\_x}  
Easting or the X component of a 3D cartesian system.

double \texttt{PJ\_XYZT\_y}  
Northing or the Y component of a 3D cartesian system.

double \texttt{PJ\_XYZT\_z}  
Vertical or the Z component of a 3D cartesian system.

double \texttt{PJ\_XYZT\_t}  
Time component.

#### \texttt{PJ\_UVWT}

Spatiotemporal version of \texttt{PJ\_UVW}.

```c
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.

10.5.1.5 Ancillary types for geodetic computations

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.

10.5.1.6 Complex coordinate types

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_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_COORD.xyz**
3-dimensional cartesian coordinate.

**PJ_COORD.uvw**
3-dimensional generic coordinate.

**PJ_COORD.lpz**
Longitude, latitude and vertical component.

**PJ_COORD.xy**
2-dimensional cartesian coordinate.

** PJCoord.uv**
2-dimensional generic coordinate.

**PJ_COORD.lp**
Longitude and latitude.

### 10.5.1.7 Projection derivatives

**PJ_FACTORS**
Various cartographic properties, such as scale factors, angular distortion and meridian convergence. Calculated with `proj_factors()`.

```c
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 \((\lambda, \phi)\).

double **PJ_FACTORS.parallel_scale**
Parallel scale at coordinate \((\lambda, \phi)\).

double **PJ_FACTORS.areal_scale**
Areal scale factor at coordinate \((\lambda, \phi)\).

double **PJ_FACTORS.angular_distortion**
Angular distortion at coordinate \((\lambda, \phi)\).

double **PJ_FACTORS.meridian_parallel_angle**
Meridian/parallel angle, \(\theta'\), at coordinate \((\lambda, \phi)\).

double **PJ_FACTORS.meridian_convergence**
Meridian convergence at coordinate \((\lambda, \phi)\). 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 $(\lambda, \phi)$.

double PJ_FACTORS.dy_dlam
Partial derivative $\frac{\partial y}{\partial \lambda}$ of coordinate $(\lambda, \phi)$.

double PJ_FACTORS.dx_dphi
Partial derivative $\frac{\partial x}{\partial \phi}$ of coordinate $(\lambda, \phi)$.

double PJ_FACTORS.dy_dphi
Partial derivative $\frac{\partial y}{\partial \phi}$ of coordinate $(\lambda, \phi)$.

### 10.5.1.8 List structures

**PJ_OPERATIONS**
Description of a PROJ.4 operation

```c
struct PJ_OPERATIONS {
    const char *id; /* operation keyword */
    PJ *(*proj)(PJ *); /* operation entry point */
    char * const *descr; /* description text */
};
```

cost char *id
Operation keyword.

$PJ *(*op)(PJ *)$
Operation entry point.

char * const *
Description of operation.

**PJ_ELLPS**
Description of ellipsoids defined in PROJ.4

```c
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.
PJ_UNITS
Distance units defined in PROJ.

```c
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 */
};
```

c const char *id
Keyword for the unit.

c const char *to_meter
Text representation of the factor that converts a given unit to meters

c const char *name
Name of the unit.

double factor
Conversion factor that converts the unit to meters.

PJ_PRIME_MERIDIANS
Prime meridians defined in PROJ.

```c
struct PJ_PRIME_MERIDIANS {
    const char *id;
    const char *defn;
};
```

c const char *id
Keyword for the prime meridian

c const char *def
Offset from Greenwich in DMS format.

10.5.1.9 Info structures

PJ_INFO
Struct holding information about the current instance of PROJ. Struct is populated by proj_info().

```c
typedef struct {
    int major;
    int minor;
    int patch;
    const char *release;
    const char *version;
    const char *searchpath;
} PJ_INFO;
```

c const char *PJ_INFO.release
Release info. Version number and release date, e.g. “Rel. 4.9.3, 15 August 2016”.

c const char *PJ_INFO.version
Text representation of the full version number, e.g. “4.9.3”.

c 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. “\Users\doctorwho;C:\OSGeo4W64\share\proj”. Grids and init files are looked for in directories in the search path.

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;

cast 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”.

cast char *PJ_PROJ_INFO.description
  Long describes of the operation the PJ object is based on, e.g. “Mercator Cyl, Sph&Ell lat_ts=”.

cast 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.

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;
  LP upperright;
  int n_lon, n_lat;
  double cs_lon, cs_lat;
} PJ_GRID_INFO;

cast char PJ_GRID_INFO.gridname[32]
  Name of grid, e.g. “BETA2007.gsb”.

cast PJ_GRID_INFO
  Full path of grid file, e.g. “C:\OSGeo4W64\share\proj\BETA2007.gsb”
PROJ coordinate transformation software library, Release 6.3.1

char PJ_GRID_INFO.format[8]
File format of grid file, e.g. “nnt2”

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.

PJ_INIT_INFO
Struct holding information about a specific init file in the search path of PROJ. Populated with the function `proj_init_info()`.

```c
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:\OSGeo4W6\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.

10.5.1.10 Logging

PJ_LOG_LEVEL
Enum of logging levels in PROJ. Used to set the logging level in PROJ. Usually using `proj_log_level()`.

PJ_LOG_NONE
Don’t log anything.

PJ_LOG_ERROR
Log only errors.

PJ_LOG_DEBUG
Log errors and additional debug information.
PJ_LOG_TRACE
Highest logging level. Log everything including very detailed debug information.

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.

PJ_LOG_FUNC
Function prototype for the logging function used by PROJ. Defined as

```c
typedef void (**PJ_LOG_FUNCTION)(void *, int, const char *);
```

where the `void` pointer references a data structure used by the calling application, the `int` is used to set the logging level and the `const char` pointer is the string that will be logged by the function.

New in version 5.1.0.

### 10.5.1.11 C API for ISO-19111 functionality

**enum** `isol19111_types::PJ_GUESSED_WKT_DIALECT`

Guessed WKT “dialect”.

**Values:**

- `PJ_GUESSED_WKT2_2019`
  - `WKT2_2019`
- `PJ_GUESSED_WKT2_2018`
  - `PJ_GUESSED_WKT2_2019`
    - Deprecated alias for `PJ_GUESSED_WKT2_2019`
- `PJ_GUESSED_WKT2_2015`
  - `WKT2_2015`
- `PJ_GUESSED_WKT1_GDAL`
  - `WKT1`
- `PJ_GUESSED_WKT1_ESRI`
  - ESRI variant of `WKT1`
- `PJ_GUESSED_NOT_WKT`
  - Not WKT / unrecognized

**enum** `isol19111_types::PJ_CATEGORY`

Object category.

**Values:**

- `PJ_CATEGORY_ELLIPSOID`
- `PJ_CATEGORY_PRIME_MERIDIAN`
- `PJ_CATEGORY_DATUM`
- `PJ_CATEGORY_CRS`
- `PJ_CATEGORY_COORDINATE_OPERATION`

**enum** `isol19111_types::PJ_TYPE`

Object type.

**Values:**
PJ_TYPE_UNKNOWN
PJ_TYPE_ELLIPSOID
PJ_TYPE_PRIME_MERIDIAN
PJ_TYPE_GEODEティCREFERENCE FRAME
PJ_TYPE_DYNAMIC_GEODEティCREFERENCE FRAME
PJ_TYPE_VERTICALREFERENCE FRAME
PJ_TYPE_DYNAMIC_VERTICALREFERENCE FRAME
PJ_TYPE_DATUMENSEMBLE
PJ_TYPE_CRS
Abstract type, not returned by proj_get_type()

PJ_TYPE_GEODEティC_CRS
PJ_TYPE_GEOCENTRIC_CRS
PJ_TYPE_GEOGRAPHIC_CRS

proj_get_type() will never return that type, but PJ_TYPE_GEOGRAPHIC_2D_CRS or PJ_TYPE_GEOGRAPHIC_3D_CRS.

PJ_TYPE_GEOGRAPHIC_2D_CRS
PJ_TYPE_GEOGRAPHIC_3D_CRS

enum is019111_types::PJ_COMPARISON_CRITERION
Comparison criterion.

Values:

PJ_COMP_STRING
All properties are identical.

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.
PJ_COMP_EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS
Same as EQUIVALENT, relaxed with an exception that the axis order of the base CRS of a Derived-CRS/ProjectedCRS or the axis order of a GeographicCRS is ignored. Only to be used with Derived-CRS/ProjectedCRS/GeographicCRS

enum iso19111_types::PJ_WKT_TYPE
WK T version.
Values:

PJ_WKT2_2015
cf osgeo::proj::io::WKTFormatter::Convention::WKT2

PJ_WKT2_2015_SIMPLIFIED
cf osgeo::proj::io::WKTFormatter::Convention::WKT2_SIMPLIFIED

PJ_WKT2_2019
cf osgeo::proj::io::WKTFormatter::Convention::WKT2_2019

PJ_WKT2_2018 = PJ_WKT2_2019
Deprecated alias for PJ_WKT2_2019

PJ_WKT2_2019_SIMPLIFIED
cf osgeo::proj::io::WKTFormatter::Convention::WKT2_2019_SIMPLIFIED

PJ_WKT2_2018_SIMPLIFIED = PJ_WKT2_2019_SIMPLIFIED
Deprecated alias for PJ_WKT2_2019

PJ_WKT1_GDAL
cf osgeo::proj::io::WKTFormatter::Convention::WKT1_GDAL

PJ_WKT1_ESRI
cf osgeo::proj::io::WKTFormatter::Convention::WKT1_ESRI

enum iso19111_types::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:

PJ_CRS_EXTENT_NONE
Ignore CRS extent

PJ_CRS_EXTENT_BOTH
Test coordinate operation extent against both CRS extent.

PJ_CRS_EXTENT_INTERSECTION
Test coordinate operation extent against the intersection of both CRS extent.

PJ_CRS_EXTENT_SMALLEST
Test coordinate operation against the smallest of both CRS extent.

enum iso19111_types::PROJ_GRID_AVAILABILITY_USE
Describe how grid availability is used.
Values:

PROJ_GRID_AVAILABILITY_USED_FOR_SORTING
Grid availability is only used for sorting results. Operations where some grids are missing will be sorted last.

PROJ_GRID_AVAILABILITY_DISCARD_OPERATION_IF_MISSING_GRID
Completely discard an operation if a required grid is missing.
PROJ_GRID_AVAILABILITY_IGNORED
Ignore grid availability at all. Results will be presented as if all grids were available.

enum iso19111_types::PJ_PROJ_STRING_TYPE
PROJ string version.
Values:

PJ_PROJ_5
cf osgeo::proj::io::PROJStringFormatter::Convention::PROJ_5
PJ_PROJ_4
cf osgeo::proj::io::PROJStringFormatter::Convention::PROJ_4

enum iso19111_types::PROJ_SPATIAL_CRITERION
Spatial criterion to restrict candidate operations.
Values:

PROJ_SPATIAL_CRITERION_STRICT_CONTAINMENT
The area of validity of transforms should strictly contain the area of interest.
PROJ_SPATIAL_CRITERION_PARTIAL_INTERSECTION
The area of validity of transforms should at least intersect the area of interest.

enum iso19111_types::PROJ_INTERMEDIATE_CRS_USE
Describe if and how intermediate CRS should be used
Values:

PROJ_INTERMEDIATE_CRS_USE_ALWAYS
Always search for intermediate CRS.
PROJ_INTERMEDIATE_CRS_USE_IF_NO_DIRECT_TRANSFORMATION
Only attempt looking for intermediate CRS if there is no direct transformation available.
PROJ_INTERMEDIATE_CRS_USE_NEVER

enum iso19111_types::PJ_COORDINATE_SYSTEM_TYPE
Type of coordinate system.
Values:

PJ_CS_TYPE_UNKNOWN
PJ_CS_TYPE_CARTESIAN
PJ_CS_TYPE_ELLIPSOIDAL
PJ_CS_TYPE_VERTICAL
PJ_CS_TYPE_SPHERICAL
PJ_CS_TYPE_ORDINAL
PJ_CS_TYPE_PARAMETRIC
PJ_CS_TYPE_DATETIMETEMPORAL
PJ_CS_TYPE_TEMPORALCOUNT
PJ_CS_TYPE_TEMPORALMEASURE

typedef char **PROJ_STRING_LIST
Type representing a NULL terminated list of NULL-terminate strings.
10.5.2 Functions

10.5.2.1 Threading contexts

PJ_CONTEXT* proj_context_create (void)
Create a new threading-context.

Returns PJ_CONTEXT*

void proj_context_destroy (PJ_CONTEXT *ctx)
Deallocate a threading-context.

Parameters

• ctx (PJ_CONTEXT*) – Threading context.

10.5.2.2 Transformation setup

The objects returned by the functions defined in this section have minimal interaction with the 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”),
• 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”)

Example call:

```c
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 \texttt{PJ}-pointer should be deallocated with \texttt{proj_destroy()}. 

\textbf{Parameters} 

- \texttt{ctx (PJ\_CONTEXT*)} – Threading context.
- \texttt{definition (const char*)} – Proj-string of the desired transformation.

\texttt{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 \texttt{argv}.

Example call:

\begin{verbatim}
char *args[3] = {"proj=utm", "zone=32", "ellps=GRS80"};
PJ* P = proj_create_argv(0, 3, args);
\end{verbatim}

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 \texttt{proj_errno()} or \texttt{proj_context_errno()}. 

The returned \texttt{PJ}-pointer should be deallocated with \texttt{proj_destroy()}. 

\textbf{Parameters} 

- \texttt{ctx (PJ\_CONTEXT*)} – Threading context 
- \texttt{argc (int)} – Count of arguments in \texttt{argv} 
- \texttt{argv (char**)} – Vector of strings with proj-string parameters, e.g. \texttt{+proj=merc}

\textbf{Returns} \texttt{PJ*}

\texttt{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.

\texttt{source\_crs} and \texttt{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 \texttt{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 \\texttt{"+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 \texttt{proj\_create()} representing a CRS

An “area of use” can be specified in \texttt{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 \texttt{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 of the CRS variety.

Parameters

- **options** – should be set to NULL currently.

Returns PJ*

PJ* proj_normalize_for_visualization(PJ_CONTEXT *ctx, const PJ* obj)

New in version 6.1.0.

Returns a PJ* object whose axis order is the one expected for visualization purposes.

The input object must be 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.

The returned PJ-pointer should be deallocated with proj_destroy().

Parameters

- **ctx** (PJ_CONTEXT*) – Threading context.
- **obj** – Object of type CoordinateOperation

Returns PJ*

PJ* proj_destroy(PJ *P)

Deallocate a PJ transformation object.

Parameters

- **P** (PJ*) –

Returns PJ*
10.5.2.3 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.

10.5.2.4 Coordinate transformation

PJ_COORD proj_trans (PJ *P, PJ_DIRECTION direction, PJ_COORD coord)
Transform a single PJ_COORD coordinate.

Parameters
• P (PJ*) –
• 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 behaviour 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:

```c
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, sizeof(XYQS),
    &survey[0].x, stride, 345, /* We have 345 eastings */
    &survey[0].y, stride, 345, /* ...and 345 northings. */
    &height, 1, /* The height is the constant 23.45 m */
    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 (\(stride = \text{sizeof(double)}\)), or strided views into an array of application specific data structures (\(stride = \text{sizeof(...)}\)).

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**

- \(P (\text{PJ}*)\) – Transformation object
- `direction` – Transformation direction
- `x (double*)` – Array of x-coordinates
- `y (double*)` – Array of y-coordinates
- `z (double*)` – Array of z-coordinates
- `t (double*)` – Array of t-coordinates
- `sx (size_t)` – Step length, in bytes, between consecutive elements of the corresponding array
• \textbf{nx} (size_t) – Number of elements in the corresponding array
• \textbf{sy} (size_t) – Step length, in bytes, between consecutive elements of the corresponding array
• \textbf{nv} (size_t) – Number of elements in the corresponding array
• \textbf{sz} (size_t) – Step length, in bytes, between consecutive elements of the corresponding array
• \textbf{nz} (size_t) – Number of elements in the corresponding array
• \textbf{st} (size_t) – Step length, in bytes, between consecutive elements of the corresponding array
• \textbf{nt} (size_t) – Number of elements in the corresponding array

Returns: Number of transformations successfully completed

def proj_trans_array(PJ *P, PJ_DIRECTION direction, size_t n, PJCOORD *coord):
    Batch transform an array of PJCOORD.

Parameters:
• \textbf{P} (PJ*) –
• \textbf{direction} (PJ_DIRECTION) – Transformation direction
• \textbf{n} (size_t) – Number of coordinates in coord

Returns: size_t 0 if all observations are transformed without error, otherwise returns error number

10.5.2.5 Error reporting

int proj_errno(PJ *P)
Get a reading of the current error-state of \textit{P}. An non-zero error codes indicates an error either with the transformation setup or during a transformation. In cases \textit{P} is \textit{0} the error number of the default context is read. A text representation of the error number can be retrieved with \textit{proj_errno_string()}.  


Returns: int

int proj_context_errno(PJ_CONTEXT *ctx)
Get a reading of the current error-state of \textit{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 \textit{proj_errno_string()}.  

Param: PJ_CONTEXT* \textit{ctx}: threading context.

Returns: int

void proj_errno_set(PJ *P, int err)
Change the error-state of \textit{P} to \textit{err}.

param PJ* \textit{P}: Transformation object.

param int \textit{err}: Error number.

int proj_errno_reset(PJ *P)
Clears the error number in \textit{P}, and bubbles it up to the context.

Example:
```c
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;
}
```

**Param** PJ* P: 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 code.

const char* **proj_errno_string** (int err)

New in version 5.1.0.

Get a text representation of an error number.

**Parameters**

- err (int) – Error number.

**Returns** const char* String with description of error.

### 10.5.2.6 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.

10.5.2.7 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

10.5.2.8 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:

```c
PJ_OPERATIONS *ops;
for (ops = proj_list_operations(); ops->id; ++ops)
    printf("%s
", ops->id);
```

Returns 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 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.

Returns 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 PJ_PRIME_MERIDIANS*

10.5.2.9 Distances

double proj_lp_dist (const PJ *, 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.

Parameters
• P (PJ*) – Transformation 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 *, 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.

Parameters
• P (PJ*) – Transformation object
• a (PJ_COORD) – Coordinate of first point
• b (PJCOORD) – 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
PROJ coordinate transformation software library, Release 6.3.1

- \( \mathbf{b} (\text{PJ\_COORD}) \) – Second coordinate

**Returns** double Distance between \( \mathbf{a} \) and \( \mathbf{b} \) in meters.

### 10.5.2.10 Various

**PJ\_COORD** \( \text{proj\_coord} \) (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

\[
\text{PJ\_COORD } c = \{10.0, 20.0, 30.0, 40.0\};
\]

or

\[
\begin{align*}
\text{PJ\_COORD } c; \\
// \text{ Assign using the PJ\_XYZT struct in the union}
\text{c.xyzt.x} &= 10.0; \\
\text{c.xyzt.y} &= 20.0; \\
\text{c.xyzt.z} &= 30.0; \\
\text{c.xyzt.t} &= 40.0;
\end{align*}
\]

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** \( \text{proj\_roundtrip} \) (PJ\* \( P \), PJ\_DIRECTION \( \text{direction} \), int \( n \), PJ\_COORD \*\( \text{coord} \))

Measure internal consistency of a given transformation. The function performs \( n \) round trip transformations starting in either the forward or reverse \( \text{direction} \). Returns the euclidean distance of the starting point \( \text{coo} \) and the resulting coordinate after \( n \) iterations back and forth.

**Parameters**

- \( P \) (const PJ\*) –
- \( \text{direction} \) (PJ\_DIRECTION) – Starting direction of transformation
- \( n \) (int) – Number of roundtrip transformations
- \( \text{coord} \) (PJ\_COORD) – Input coordinate

**Returns** double Distance between original coordinate and the resulting coordinate after \( n \) transformation iterations.

**PJ\_FACTORS** \( \text{proj\_factors} \) (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**

- \( P \) (const PJ\*) – Transformation object
• \texttt{lp} (const \texttt{PJCOORD}) – Geodetic coordinate

Returns \texttt{PJ_FACTORS}

double \texttt{proj\_torad} (double \texttt{angle\_in\_degrees})
Converts degrees to radians.

Parameters

• \texttt{angle\_in\_degrees} (double) – Degrees

Returns double Radians

double \texttt{proj\_to\_deg} (double \texttt{angle\_in\_radians})
Converts radians to degrees

Parameters

• \texttt{angle\_in\_radians} (double) – Radians

Returns double Degrees

double \texttt{proj\_dm\_to\_rad} (const char *is, char **rs)
Converts string of degrees, minutes and seconds to radians. Works similarly to the C standard library function \texttt{strtod()}.

Parameters

• \texttt{is} (const char*) – Value to be converted to radians

• \texttt{rs} – Reference to an already allocated char*, whose value is set by the function to the next character in \texttt{is} after the numerical value.

char *\texttt{proj\_rt\_dms} (char *s, double r, int pos, int neg)
Converts radians to string representation of degrees, minutes and seconds.

Parameters

• \texttt{s} (char*) – Buffer that holds the output string

• \texttt{r} (double) – Value to convert to dms-representation

• \texttt{pos} (int) – Character denoting positive direction, typically ‘N’ or ‘E’.

• \texttt{neg} (int) – Character denoting negative direction, typically ‘S’ or ‘W’.

Returns char* Pointer to output buffer (same as \texttt{s})

int \texttt{proj\_angular\_input} (\texttt{PJ *}P, enum \texttt{PJ\_DIRECTION} dir)
Checks if an operation expects input in radians or not.

Parameters

• \texttt{P} (const \texttt{PJ*}) – Transformation object

• \texttt{direction} (\texttt{PJ\_DIRECTION}) – Starting direction of transformation

Returns int 1 if input units is expected in radians, otherwise 0

int \texttt{proj\_angular\_output} (\texttt{PJ *}P, enum \texttt{PJ\_DIRECTION} dir)
Checks if an operation returns output in radians or not.

Parameters

• \texttt{P} (const \texttt{PJ*}) – Transformation object

• \texttt{direction} (\texttt{PJ\_DIRECTION}) – Starting direction of transformation

Returns int 1 if output units is expected in radians, otherwise 0
10.5.2.11 Cleanup

```c
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.

10.5.2.12 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/non-sensical 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.

```c
void proj_string_list_destroy(PROJ_STRING_LIST list)
```

Free a list of NULL terminated strings.

```c
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 openeded, and automatically re-openeded 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

```c
int proj_context_set_database_path(PJ_CONTEXT *ctx, const char *dbPath, const char *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.

Return TRUE in case of success

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

```c
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.

Return path, or nullptr
Parameters

- **ctx**: PROJ context, or NULL for default context

```c
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.

Return value, or nullptr

Parameters

- **ctx**: PROJ context, or NULL for default context
- **key**: Metadata key. Must not be NULL

```c
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)

```c
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.

Return Object that must be unreferenced with `proj_destroy()`, or NULL in case of error.

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:
  - STRIC_\text{}T=\text{}YES/\text{}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()`.

```c
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.

**Return** Object that must be unreferenced with proj_destroy(), or NULL in case of error.

**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

```c
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.

**Return** TRUE in case of success.

**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”, “angular”, “scale”, “time” or “parametric”;

```c
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.

**Return** TRUE in case of success.

**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

PJ *proj_clone (PJ_CONTEXT *ctx, const PJ *obj)
“Clone” an object.
Technically this just increases the reference counter on the object, since PJ objects are immutable.
The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Return Object that must be unreferenced with proj_destroy(), or NULL in case of error.
Parameters
• ctx: PROJ context, or NULL for default context
• obj: Object to clone. Must not be NULL.

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.

Return a result set that must be unreferenced with proj_list_destroy(), or NULL in case of error.
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

PJ_TYPE proj_get_type (const PJ *obj)
Return the type of an object.

Return its type.
Parameters
• obj: Object (must not be NULL)
int proj_is_deprecated (const PJ *obj)
Return whether an object is deprecated.

   Return  TRUE if it is deprecated, FALSE otherwise
   Parameters
   •  obj: Object (must not be NULL)

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.

   Return  a result set that must be unreferenced with proj_list_destroy(), or NULL in case of error.
   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.

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.

   Return  TRUE if they are equivalent
   Parameters
   •  obj: Object (must not be NULL)
   •  other: Other object (must not be NULL)
   •  criterion: Comparison criterion

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.

   Return  TRUE if they are equivalent
   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

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.

**Return** a string, or NULL in case of error or missing name.

**Parameters**
- **obj**: Object (must not be NULL)

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.

**Return** a string, or NULL in case of error or missing name.

**Parameters**
- **obj**: Object (must not be NULL)
- **index**: Index of the identifier. 0 = first identifier

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.

**Return** a string, or NULL in case of error or missing name.

**Parameters**
- **obj**: Object (must not be NULL)
- **index**: Index of the identifier. 0 = first identifier

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.

**Return** a string, or NULL in case of error.

**Parameters**
- **obj**: Object (must not be NULL)

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.

**Return** a string, or NULL in case of error or missing scope.

**Parameters**
- **obj**: Object (must not be NULL)
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.

Return TRUE in case of success, FALSE in case of error or if the area of use is unknown.

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.

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.

Return a string, or NULL in case of error.

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.
**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.

**Return** a string, or NULL in case of error.

**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. The currently recognized option is `USE_APPROX_TMERC=YES` to add the +approx flag to +proj=tmerc or +proj=utm

**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.

**Return** a string, or NULL in case of error.

**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.

**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.

**Return** Object that must be unreferenced with `proj_destroy()`, or NULL in case of error, or missing source CRS.

**Parameters**
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.

Return Object that must be unreferenced with proj_destroy(), or NULL in case of error, or missing target CRS.

Parameters
• ctx: PROJ context, or NULL for default context
• obj: Object of type BoundCRS or CoordinateOperation (must not be NULL)

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.
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 GeodeticCRS 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.

Return a list of matching reference CRS, or nullptr in case of error.

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().
Free an array of integer.

Return a NULL terminated list of NUL-terminated strings that must be freed with `proj_string_list_destroy()`, or NULL in case of error.

Parameters

- **ctx**: PROJ context, or NULL for default context

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()`.

Return a NULL terminated list of NUL-terminated strings that must be freed with `proj_string_list_destroy()`, or NULL in case of error.

See `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.
- **allowDeprecated**: whether we should return deprecated objects as well.

Instantiate a default set of parameters to be used by `proj_get_crs_list()`.

Return a new object to free with `proj_get_crs_list_parameters_destroy()`

Destroy an object returned by `proj_get_crs_list_parameters_create()`

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 functionally equivalent to `proj_get_crs_info_list_from_database()`, instantiating a PJ* object for each of the `proj_create_from_database()` and retrieving information with the various getters. However this function will be much faster.

Return an array of PROJ_CRS_INFO* pointers to be freed with `proj_crs_info_list_destroy()`, or NULL in case of error.

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.

```c
void proj_crs_info_list_destroy (PROJ_CRS_INFO **list)
```

Destroy the result returned by `proj_get_crs_info_list_from_database()`.

```c
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.

**Return** Object that must be unreferenced with `proj_operation_factory_context_destroy()`, or NULL in case of error.

**Parameters**
- ctx: Context, or NULL for default context.
- authority: Name of authority to which to restrict the search of candidate operations.

```c
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.

```c
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).
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).

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.

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: Spatial 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 use_PROJ_Names)

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 stratgey, all potential C candidates will be used if there is no direct tranformation.

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.

```c
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 }

```c
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

```c
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.

**Return** a result set that must be unreferenced with `proj_list_destroy()`, or NULL in case of error.

**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.
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.

Return  a new object that must be unreferenced with proj_destroy(), or nullptr in case of error.

Parameters
   • ctx: PROJ context, or NULL for default context
   • result: Object of type PJ_OBJ_LIST (must not be NULL)
   • index: Index

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.

PJ *proj_crs_get_geodetic_crs (PJ_CONTEXT *ctx, const PJ *crs)
Get the geodetic CRS / geographic CRS 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.

Return  Object that must be unreferenced with proj_destroy(), or NULL in case of error.

Parameters
   • ctx: PROJ context, or NULL for default context
   • crs: Object of type CRS (must not be NULL)

PJ *proj_crs_get_horizontal_datum (PJ_CONTEXT *ctx, const PJ *crs)
Get the horizontal datum 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.

Return  Object that must be unreferenced with proj_destroy(), or NULL in case of error.

Parameters
   • ctx: PROJ context, or NULL for default context
   • crs: Object of type CRS (must not be NULL)
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.

Return Object that must be unreferenced with proj_destroy(), or NULL in case of error.

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)

PJ *proj_crs_get_datum (PJ_CONTEXT *ctx, const PJ *crs)
Returns the datum 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.

Return Object that must be unreferenced with proj_destroy(), or NULL in case of error (or if there is no datum)

Parameters
- ctx: PROJ context, or NULL for default context
- crs: Object of type SingleCRS (must not be NULL)

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.

Return Object that must be unreferenced with proj_destroy(), or NULL in case of error.

Parameters
- ctx: PROJ context, or NULL for default context
- crs: Object of type SingleCRS (must not be NULL)

PJ_COORDINATE_SYSTEM_TYPE proj_cs_get_type (PJ_CONTEXT *ctx, const PJ *cs)
Returns the type of the coordinate system.

Return type, or PJ_CS_TYPE_UNKNOWN in case of error.

Parameters
- ctx: PROJ context, or NULL for default context
- cs: Object of type CoordinateSystem (must not be NULL)

int proj_cs_get_axis_count (PJ_CONTEXT *ctx, const PJ *cs)
Returns the number of axis of the coordinate system.

Return number of axis, or -1 in case of error.

Parameters
- ctx: PROJ context, or NULL for default context
• cs: Object of type CoordinateSystem (must not be NULL)

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.

Return TRUE in case of success

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

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.

Return Object that must be unreferenced with proj_destroy(), or NULL in case of error.

Parameters

• ctx: PROJ context, or NULL for default context
• obj: Object of type CRS or GeodeticReferenceFrame (must not be NULL)

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.

Return TRUE in case of success.

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

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.

**Return** Object that must be unreferenced with proj_destroy(), or NULL in case of error.

**Parameters**

• `ctx`: PROJ context, or NULL for default context

• `obj`: Object of type CRS or GeodeticReferenceFrame (must not be NULL)

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.

**Return** TRUE in case of success.

**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

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.

**Return** Object of type SingleOperation that must be unreferenced with proj_destroy(), or NULL in case of error.

**Parameters**

• `ctx`: PROJ context, or NULL for default context

• `crs`: Object of type DerivedCRS or BoundCRSs (must not be NULL)

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.
Return TRUE in case of success.

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

```c
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.

Return TRUE or FALSE.

Parameters
- `ctx`: PROJ context, or NULL for default context
- `coordoperation`: Object of type CoordinateOperation or derived classes (must not be NULL)

```c
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.

Return TRUE or FALSE.

Parameters
- `ctx`: PROJ context, or NULL for default context
- `coordoperation`: Object of type CoordinateOperation or derived classes (must not be NULL)

```c
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)

```c
int proj_coordoperation_get_param_index (PJ_CONTEXT *ctx, const PJ *coordoperation, const char *name)
```

Return the index of a parameter of a SingleOperation.

Return index (>=0), or -1 in case of error.

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

```c
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.

Return TRUE in case of success.

**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”, “angular”, “scale”, “time” or “parametric”;

```c
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)

```c
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.
Return TRUE in case of success.

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

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.

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.
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.

Return a new PJ* object to free with proj_destroy() in case of success, or nullptr in case of error.

Since 6.3

Parameters
• ctx: PROJ context, or NULL for default context
• obj: Object of type CoordinateOperation (must not be NULL)

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.

Return the number of steps, or 0 in case of error.

Parameters
• ctx: PROJ context, or NULL for default context
• concatoperation: Concatenated operation (must not be NULL)

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.

Return Object that must be unreferenced with proj_destroy(), or NULL in case of error.

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

10.5.3 C++ API

10.5.3.1 General documentation

namespace general_api_design
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
namespace general_properties
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 as a string.
- `osgeo::proj::metadata::Identifier::CODE_KEY` (“code”): a numeric or alphanumeric code, provided as an 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 as a string. For example “EPSG”.
- `osgeo::proj::metadata::Identifier::VERSION_KEY` (“version”): the version identifier for the namespace, provided as 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 an `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 an `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 an `osgeo::proj::util::ArrayOfBaseObjectNNPtr` of `osgeo::proj::common::ObjectDomainNNPtr`.

namespace standards
Applicable standards.

namespace ISO_19111

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.


namespace ISO_19111_2019

This is the revision mostly used for PROJ C++ modelling.
OGC 18-005r4, 2019-02-08, ISO 19111:2019

namespace ISO_19111_2007

The precedent version of the specification was: OGC 08-015r2, 2010-04-27, ISO 19111:2007

namespace WKT2
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

PROJ implements the two following revisions of the standard:

namespace WKT2_2019
OGC 18-010r7, 2019-06-24, WKT2-2019

namespace WKT2_2015
WKT2:2015.

namespace WKT1
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 v2.3 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

namespace ISO_19115
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.

namespace GeoAPI
GeoAPI.

A set of Java and Python language programming interfaces for geospatial applications.

GeoAPI main page
GeoAPI Javadoc

10.5. Reference
10.5.3.2 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 Angle : public osgeo::proj::common::Measure
#include <common.hpp> Numeric value, with a angular unit of measure.

Public Functions

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 DataEpoch
#include <common.hpp> Data epoch.
Public Functions

```cpp
const Measure &coordinateEpoch() const
```
Return the coordinate epoch, as a measure in decimal year.

```cpp
class DateTime
#include <common.hpp> Date-time value, as an ISO:8601 encoded string, or other string encoding.
```

Public Functions

```cpp
bool isISO_8601() const
```
Return whether the `DateTime` is ISO:8601 compliant.

Remark The current implementation is really simplistic, and aimed at detecting dates-times that are not ISO:8601 compliant.

```cpp
std::string toString() const
```
Return the `DateTime` as a string.

Public Static Functions

```cpp
DateTime create(const std::string &str)
```
Instantiate a `DateTime`.

class IdentifiedObject : public osgeo::proj::util::BaseObject, public osgeo::proj::util::IComparable, public osgeo::proj::io::IWKTExportable
#include <common.hpp> Abstract class representing 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::DatumEnsemble, osgeo::proj::datum::Ellipsoid, osgeo::proj::datum::PrimeMeridian, osgeo::proj::operation::GeneralOperationParameter, osgeo::proj::operation::OperationMethod

Public Functions

```cpp
const IdentifierNNPtr &name() const
```
Return the name of the object.

Generally, the only interesting field of the name will be `name()->description()`.

```cpp
const std::string &nameStr() const
```
Return the name of the object.

Return `*(name()->description())`

```cpp
const std::vector<IdentifierNNPtr> &identifiers() const
```
Return the identifier(s) of the object.

Generally, those will have Identifier::code() and Identifier::codeSpace() filled.

```cpp
const std::vector<GenericNameNNPtr> &aliases() const
```
Return the alias(es) of the object.
const std::string &remarks ()
   Return the remarks.

bool isDeprecated ()
   Return whether the object is deprecated.

   \textbf{Remark}  Extension of \textit{ISO\_19111\_2019}

std::string alias ()
   Return the (first) alias of the object as a string.
   Shortcut for \texttt{aliases()[0]->toFullyQualifiedName()->toString()}

int getEPSGCode ()
   Return the EPSG code.
   \textbf{Return} code, or 0 if not found

\section*{Public Static Attributes}

const std::string NAME_KEY
   Key to set the name of a \texttt{common::IdentifiedObject}.
   The value is to be provided as a string or \texttt{metadata::IdentifierNNPtr}.

const std::string IDENTIFIERS_KEY
   Key to set the identifier(s) of a \texttt{common::IdentifiedObject}.
   The value is to be provided as a \texttt{common::IdentifierNNPtr} or a \texttt{util::ArrayOfBaseObjectNNPtr} of \texttt{common::IdentifierNNPtr}.

const std::string ALIAS_KEY
   Key to set the alias(es) of a \texttt{common::IdentifiedObject}.
   The value is to be provided as string, a \texttt{util::GenericNameNNPtr} or a \texttt{util::ArrayOfBaseObjectNNPtr} of \texttt{util::GenericNameNNPtr}.

const std::string REMARKS_KEY
   Key to set the remarks of a \texttt{common::IdentifiedObject}.
   The value is to be provided as a string.

const std::string DEPRECATED_KEY
   Key to set the deprecation flag of a \texttt{common::IdentifiedObject}.
   The value is to be provided as a boolean.

\begin{verbatim}
class Length : public osgeo::proj::common::Measure
#include <common.hpp> Numeric value, with a linear unit of measure.
\end{verbatim}
Public Functions

**Length** (double `valueIn = 0.0`)
Instatiate a `Length`.

- **Parameters**
  - `valueIn`: value

**Length** (double `valueIn`, const `UnitOfMeasure &unitIn`)
Instatiate a `Length`.

- **Parameters**
  - `valueIn`: value
  - `unitIn`: unit. Constraint: `unit.type() == UnitOfMeasure::Type::LINEAR`

```cpp
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()`)  
Instatiate 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.

**Return** true if objects are equivalent.

- **Parameters**
  - `other`: other object to compare to
  - `criterion`: comparaison criterion.
  - `maxRelativeError`: Maximum relative error allowed.
**Public Static Attributes**

```
constexpr double DEFAULT_MAX_REL_ERROR = 1e-10
```

Default maximum resulative error.

**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 optional<std::string> & scope ()
Return the scope.
  Return the scope, or empty.
```

```
const ExtentPtr & domainOfValidity ()
Return the domain of validity.
  Return the domain of validity, or nullptr.
```

**Public Static Functions**

```
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::operation::CoordinateOperation

**Public Functions**

```
const std::vector<ObjectDomainNNPtr> & domains ()
Return the domains of the object.
```

**Public Static Attributes**

```
const std::string SCOPE_KEY
Key to set the scope of a common::ObjectUsage.
  The value is to be provided as a string.
```

```
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.
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.

class Scale : public osgeo::proj::common::Measure
    #include <common.hpp> Numeric value, without a physical unit of measure.

Public Functions

Scale (double valueIn = 0.0)
    Instantiate a Scale.

Parameters
    • valueIn: value

Scale (double valueIn, const UnitOfMeasure &unitIn)
    Instantiate a Scale.

Parameters
    • valueIn: value
    • unitIn: unit. Constraint: unit.type() == UnitOfMeasure::Type::SCALE

class UnitOfMeasure : public osgeo::proj::util::BaseObject
    #include <common.hpp> Unit of measure.
    This is a mutable object.

Public Types

denum Type
    Type of unit of measure.
    Values:
    UNKNOWN
        Unknown unit of measure
    NONE
        No unit of measure
    ANGULAR
        Angular unit of measure
    LINEAR
        Linear unit of measure
    SCALE
        Scale unit of measure
    TIME
        Time unit of measure
    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)

`Return` the conversion factor, or 0 if no conversion exists.

`UnitOfMeasure::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”

`Return` the code space, or empty string.

`const std::string &code ()`  
Return the code of the unit of measure.

`Return` 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**

`const UnitOfMeasure NONE`  
“Empty”/”None”, unit of measure of type NONE.

`const UnitOfMeasure SCALE_UNITY`  
Scale unity, unit of measure of type SCALE.

`const UnitOfMeasure PARTS_PER_MILLION`  
Parts-per-million, unit of measure of type SCALE.

`const UnitOfMeasure PPM_PER_YEAR`  
Part-per-million per year, unit of measure of type SCALE.

`const UnitOfMeasure METRE`  
Metre, unit of measure of type LINEAR (SI unit).

`const UnitOfMeasure METRE_PER_YEAR`  
Metre per year, unit of measure of type LINEAR.
const UnitOfMeasure RADIAN
Radian, unit of measure of type ANGULAR (SI unit).

const UnitOfMeasure MICRORADIAN
Microradian, unit of measure of type ANGULAR.

const UnitOfMeasure DEGREE
Degree, unit of measure of type ANGULAR.

const UnitOfMeasure ARC_SECOND
Arc-second, unit of measure of type ANGULAR.

const UnitOfMeasure GRAD
Grad, unit of measure of type ANGULAR.

const UnitOfMeasure ARC_SECOND_PER_YEAR
Arc-second per year, unit of measure of type ANGULAR.

const UnitOfMeasure SECOND
Second, unit of measure of type TIME (SI unit).

const UnitOfMeasure YEAR
Year, unit of measure of type TIME.

10.5.3.3 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.

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

ArrayOfBaseObjectNNPtr create ()
    Instantiate a ArrayOfBaseObject.

    Return a new ArrayOfBaseObject.

class BaseObject
    #include <util.hpp> Class that can be derived from, to emulate Java’s Object behaviour.

Subclassed by osgeo::proj::common::IdentifiedObject, osgeo::proj::common::Measure, osgeo::proj::common::ObjectDomain, 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

struct BaseObjectNNPtr: public util::nn<BaseObjectPtr>
    #include <util.hpp> Non-null shared pointer of BaseObject.

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 CodeList
   #include <util.hpp> Abstract class to define an enumeration of values.
   Subclassed by osgeo::proj::cs::AxisDirection, osgeo::proj::datum::RealizationMethod

Public Functions

const std::string &toString ()
   Return the CodeList item as a string.

operator std::string ()
   Return the CodeList item as a string.

class Exception : public exception
   #include <util.hpp> Root exception class.
   Subclassed by 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

const char *what () const
   Return the exception text.

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 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 Criterion
    Comparison criterion.
    Values:
    STRICT
        All properties are identical.
    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, pro-
        vided that the value is (with some tolerance) the same once expressed in a common unit.
    EQUIVALENT_EXCEPT_AXIS_ORDER_GEOCRS
        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: comparaision criterion.
    • dbContext: Database context, or nullptr.

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 Proper-
    tyMap.

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

c = const NameSpacePtr scope () const
    Return the scope of the object, possibly a global one.

std::string toString () const
    Return the LocalName as a string.

GenericNameNNPtr toFullyQualified() const
    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

NameSpaceNNPtr createNameSpace(const GenericNameNNPtr &name, const PropertyMap &properties)
Instantiate a NameSpace.
Return a new NameFactory.
Parameters
• name: name of the namespace.
• properties: Properties. Allowed keys are “separator” and “separator.head”.

LocalNameNNPtr createLocalName(const NameSpacePtr &scope, const std::string &name)
Instantiate a LocalName.
Return a new LocalName.
Parameters
• scope: scope.
• name: string of the local name.

GenericNameNNPtr createGenericName(const NameSpacePtr &scope, const std::vector<std::string> &parsedNames)
Instantiate a GenericName.
Return a new GenericName.
Parameters
• scope: scope.
• parsedNames: the components of the name.

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.

template<class T>
class optional
#include <util.hpp> Loose transposition of std::optional available from C++17.
Public Functions

```cpp
const T *operator->() const
Returns a pointer to the contained value.

const T &operator*() const
Returns a reference to the contained value.

operator bool() const
Return whether the optional has a value

bool has_value() const
Return whether the optional has a value
```

class PropertyMap
#include <util.hpp> Wrapper of a std::map<std::string, BaseObjectNNPtr>

Public Functions

```cpp
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 an 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 UnsupportedOperationException : public osgeo::proj::util::Exception
#include <util.hpp> Exception Thrown to indicate that the requested operation is not supported.

10.5.3.4 metadata namespace

namespace metadata
Common classes from ISO_19115 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**

**Citation (const std::string &titleIn)**
Constructs a citation by its title.

**const optional<std::string> &title ()**
Returns the name by which the cited resource is known.

**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 optional<std::string> &description ()**
Return a textual description of the extent.

**Return** the description, or empty.

**const std::vector<GeographicExtentNNPtr> &geographicElements ()**
Return the geographic element(s) of the extent

**Return** the geographic element(s), or empty.

**const std::vector<TemporalExtentNNPtr> &temporalElements ()**
Return the temporal element(s) of the extent

**Return** the temporal element(s), or empty.

**const std::vector<VerticalExtentNNPtr> &verticalElements ()**
Return the vertical element(s) of the extent

**Return** the vertical element(s), or empty.

**bool contains (const ExtentNNPtr &other) const**
Returns whether this extent contains the other one.

**Behaviour 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.

**Behaviour 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.

**Behaviour only well specified if there is one single GeographicExtent in each object. Returns nullptr otherwise.**
Public Static Functions

```cpp
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`. Return a new `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.

```cpp
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. Return a new `Extent`.

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.

Public Static Attributes

```cpp
const ExtentNNPtr WORLD
```

World extent.

```cpp
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

```cpp
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.

```cpp
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.

bool contains (const GeographicExtentNNPtr &other) const
    Returns whether this extent contains the other one.

bool intersects (const GeographicExtentNNPtr &other) const
    Returns whether this extent intersects the other one.

GeographicExtentPtr intersection (const GeographicExtentNNPtr &other) const
    Returns the intersection of this extent with another one.

Public Static Functions

GeographicBoundingBoxNNPtr create (double west, double south, double east, double north)
    Instantiate a GeographicBoundingBox.
    If east < west, then the bounding box crosses the anti-meridian.
    Return a new GeographicBoundingBox.

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).

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 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
Public Functions

const optional<Citation> &authority()
Return a citation for the organization responsible for definition and maintenance of the code.

const std::string &code()
Return the alphanumeric value identifying an instance in the codespace.
e.g. “4326” (for EPSG:4326 WGS 84 GeographicCRS)
Return the code.

const optional<std::string> &codeSpace()
Return the organization responsible for definition and maintenance of the code.
e.g “EPSG”
Return the authority codespace, or empty.

const 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.
Return the version or empty.

const optional<std::string> &description()
Return the natural language description of the meaning of the code value.
Return the description or empty.

const optional<std::string> &uri()
Return the URI of the identifier.

Return the URI or empty.

Public Static Functions

IdentifierNNPtr create(const std::string &codeIn = std::string(), const util::PropertyMap &properties = util::PropertyMap())
Instantiate a Identifier.

Return a new Identifier.

Parameters
• codeIn: Alphanumeric value identifying an instance in the codespace
• properties: See general_properties. Generally, the Identifier::CODESPACE_KEY should be set.

bool isEquivalentName(const char *a, const char *b)
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

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.

const std::string CODE_KEY
Key to set the code of a metadata::Identifier.
The value is to be provided as an integer or a string.

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.

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.

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.

const std::string URI_KEY
Key to set the URI of a metadata::Identifier.
The value is to be provided as a string.

const std::string EPSG
EPSG codespace.

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

Public Functions

const std::string &value ()
Return the value of the positional accuracy.

Public Static Functions

PositionalAccuracyNNPtr create (const std::string &valueIn)
Instantiate a PositionalAccuracy.
Parameters
• valueIn: positional accuracy value.

class TemporalExtent : public osgeo::proj::util::Comparable
#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

TemporalExtentNNPtr create (const std::string & start, const std::string & stop)
    Instantiate a TemporalExtent.
    Parameters
        • start: start.
        • stop: stop.

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 minValue ()
    Returns the minimum of the vertical extent.

double maxValue ()
    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

VerticalExtentNNPtr create(double minimumValue, double maximumValue, const common::UnitOfMeasureNNPtr &unitIn)

Instantiate a VerticalExtent.

Return a new VerticalExtent.

Parameters

- minimumIn: minimum.
- maximumIn: maximum.
- unitIn: unit.

10.5.3.5 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

cost 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.

cost AxisDirection NORTH_NORTH_EAST
    Axis positive direction is approximately north-north-east.

cost AxisDirection NORTH_EAST
    Axis positive direction is approximately north-east.

cost AxisDirection EAST_NORTH_EAST
    Axis positive direction is approximately east-north-east.
const AxisDirection EAST
Axis positive direction is 90deg clockwise from north.

const AxisDirection EAST_SOUTH_EAST
Axis positive direction is approximately east-south-east.

const AxisDirection SOUTH_EAST
Axis positive direction is approximately south-east.

const AxisDirection SOUTH_SOUTH_EAST
Axis positive direction is approximately south-south-east.

const AxisDirection SOUTH
Axis positive direction is 180deg clockwise from north.

const AxisDirection SOUTH_SOUTH_WEST
Axis positive direction is approximately south-south-west.

const AxisDirection SOUTH_WEST
Axis positive direction is approximately south-west.

const AxisDirection WEST_SOUTH_WEST
Axis positive direction is approximately west-south-west.

const AxisDirection WEST
Axis positive direction is 270deg clockwise from north.

const AxisDirection WEST_NORTH_WEST
Axis positive direction is approximately west-north-west.

const AxisDirection NORTH_WEST
Axis positive direction is approximately north-west.

const AxisDirection NORTH_NORTH_WEST
Axis positive direction is approximately north-north-west.

const AxisDirection UP
Axis positive direction is up relative to gravity.

const AxisDirection DOWN
Axis positive direction is down relative to gravity.

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.

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.

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.

const AxisDirection COLUMN_POSITIVE
Axis positive direction is towards higher pixel column.

const AxisDirection COLUMN_NEGATIVE
Axis positive direction is towards lower pixel column.

const AxisDirection ROW_POSITIVE
Axis positive direction is towards higher pixel row.
const AxisDirection ROW_NEGATIVE
    Axis positive direction is towards lower pixel row.

const AxisDirection DISPLAY_RIGHT
    Axis positive direction is right in display.

const AxisDirection DISPLAY_LEFT
    Axis positive direction is left in display.

const AxisDirection DISPLAY_UP
    Axis positive direction is towards top of approximately vertical display surface.

const AxisDirection DISPLAY_DOWN
    Axis positive direction is towards bottom of approximately vertical display surface.

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.

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.

const AxisDirection PORT
    Axis positive direction is port; for an observer at the centre of the object this will be towards its left.

const AxisDirection STARBOARD
    Axis positive direction is starboard; for an observer at the centre of the object this will be towards its right.

const AxisDirection CLOCKWISE
    Axis positive direction is clockwise from a specified direction.

const AxisDirection COUNTER_CLOCKWISE
    Axis positive direction is counter clockwise from a specified direction.

const AxisDirection TOWARDS
    Axis positive direction is towards the object.

const AxisDirection AWAY_FROM
    Axis positive direction is away from the object.

const AxisDirection FUTURE
    Temporal axis positive direction is towards the future.

const AxisDirection PAST
    Temporal axis positive direction is towards the past.

const AxisDirection UNSPECIFIED
    Axis positive direction is unspecified.

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

CartesianCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2)

Instantiate a CartesianCS.
Return a new CartesianCS.
Parameters
- properties: See general_properties.
- axis1: The first axis.
- axis2: The second axis.

CartesianCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2, const CoordinateSystemAxisNNPtr &axis3)

Instantiate a CartesianCS.
Return a new CartesianCS.
Parameters
- properties: See general_properties.
- axis1: The first axis.
- axis2: The second axis.
- axis3: The third axis.

CartesianCSNNPtr createEastingNorthing(const common::UnitOfMeasure &unit)

Instantiate a CartesianCS with a Easting (first) and Northing (second) axis.
Return a new CartesianCS.
Parameters
- unit: Linear unit of the axes.

CartesianCSNNPtr createNorthingEasting(const common::UnitOfMeasure &unit)

Instantiate a CartesianCS with a Northing (first) and Easting (second) axis.
Return a new CartesianCS.
Parameters
- unit: Linear unit of the axes.

CartesianCSNNPtr createNorthPoleEastingSouthNorthingSouth(const common::UnitOfMeasure &unit)

Instantiate a CartesianCS, north-pole centered, with a Easting (first) South-Oriented and Northing (second) South-Oriented axis.
Return a new CartesianCS.
Parameters
- unit: Linear unit of the axes.

CartesianCSNNPtr createSouthPoleEastingNorthNorthingNorth(const common::UnitOfMeasure &unit)

Instantiate a CartesianCS, south-pole centered, with a Easting (first) North-Oriented and Northing (second) North-Oriented axis.
Return a new CartesianCS.
Parameters
- unit: Linear unit of the axes.
CartesianCSNNPtr createWestingSouthing(const common::UnitOfMeasure &unit)

Instantiate a CartesianCS with a Westing (first) and Southing (second) axis.

Return a new CartesianCS.

Parameters
• unit: Linear unit of the axes.

CartesianCSNNPtr createGeocentric(const common::UnitOfMeasure &unit)

Instantiate a CartesianCS with the three geocentric axes.

Return a new CartesianCS.

Parameters
• unit: Linear unit of the axes.

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.

Return the axes.

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.

Return 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.

Return the direction.

\textbf{const \texttt{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.

Return the axis unit.

\textbf{const \texttt{util::optional<double> \&minimumValue()}}

Return the minimum value normally allowed for this axis, in the unit for the axis.

Return the minimum value, or empty.

\textbf{const \texttt{util::optional<double> \&maximumValue()}}

Return the maximum value normally allowed for this axis, in the unit for the axis.

Return the maximum value, or empty.

\textbf{const MeridianPtr \&meridian()} 

Return the meridian that the axis follows from the pole, for a coordinate reference system centered on
a pole.

Return the meridian, or null.

\section*{Public Static Functions}

\texttt{CoordinateSystemAxisNNPtr \texttt{create(const util::PropertyMap \&properties, const std::string \&abbreviationIn, const \texttt{AxisDirection \&directionIn, const \texttt{common::UnitOfMeasure \&unitIn, const MeridianPtr \&meridianIn = nullptr)}})

Instantiate a \texttt{CoordinateSystemAxis}.

Return a new \texttt{CoordinateSystemAxis}.

Parameters

\begin{itemize}
\item \texttt{properties}: See \texttt{general_properties}. The name should generally be defined.
\item \texttt{abbreviationIn}: Axis abbreviation (might be empty)
\item \texttt{directionIn}: Axis direction
\item \texttt{unitIn}: Axis unit
\item \texttt{meridianIn}: The meridian that the axis follows from the pole, for a coordinate reference
system centered on a pole, or nullptr
\end{itemize}

\textbf{class \texttt{DateTimeTemporalCS}}: \texttt{public osgeo::proj::cs::TemporalCS} 
\include <coordinateaxis.hpp> A one-dimensional coordinate system used to record time in dateTime
representation as defined in ISO 8601.

A \texttt{DateTimeTemporalCS} shall have one axis association. It does not use axisUnitID; the temporal quantities
are defined through the ISO 8601 representation.

\textbf{Remark} Implements \texttt{DateTimeTemporalCS} from \textit{ISO 19111_2019}
Public Static Functions

DateTimeTemporalCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis)
Instantiate a DateTimeTemporalCS.
Return a new DateTimeTemporalCS.
Parameters
- properties: See general_properties.
- axisIn: The axis.

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

EllipsoidalCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2)
Instantiate a EllipsoidalCS.
Return a new EllipsoidalCS.
Parameters
- properties: See general_properties.
- axis1: The first axis.
- axis2: The second axis.

EllipsoidalCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2, const CoordinateSystemAxisNNPtr &axis3)
Instantiate a EllipsoidalCS.
Return a new EllipsoidalCS.
Parameters
- properties: See general_properties.
- axis1: The first axis.
- axis2: The second axis.
- axis3: The third axis.

EllipsoidalCSNNPtr createLatitudeLongitude(const common::UnitOfMeasure &unit)
Instantiate a EllipsoidalCS with a Latitude (first) and Longitude (second) axis.
Return a new EllipsoidalCS.
Parameters
- unit: Angular unit of the axes.

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.

**Return** a new `EllipsoidalCS`.

**Parameters**
- `angularUnit`: Angular unit of the latitude and longitude axes.
- `linearUnit`: Linear unit of the ellipsoidal height axis.

`EllipsoidalCSNNPtr createLongitudeLatitude (const common::UnitOfMeasure &unit)`

Instantiate a `EllipsoidalCS` with a Longitude (first) and Latitude (second) axis.

**Return** a new `EllipsoidalCS`.

**Parameters**
- `unit`: Angular unit of the axes.

`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.

**Return** a new `EllipsoidalCS`.

Since 7.0

**Parameters**
- `angularUnit`: Angular unit of the latitude and longitude axes.
- `linearUnit`: Linear unit of the ellipsoidal height axis.

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.

**Note** There is no modelling for this concept in ISO_19111_2019

**Remark** Implements MERIDIAN from WKT2

**Public Functions**

```cpp
const common::Angle &longitude ()

Return the longitude of the meridian that the axis follows from the pole.
```

**Public Static Functions**

```cpp
MeridianNNPtr create (const common::Angle &longitudeIn)

Instantiate a Meridian.

**Return** new Meridian.

**Parameters**
- `longitudeIn`: longitude of the meridian that the axis follows from the pole.
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

OrdinalCSNNPtr create(const util::PropertyMap &properties, const std::vector<CoordinateSystemAxisNNPtr> &axisIn)
Instantiate a OrdinalCS.

Return a new OrdinalCS.

Parameters
- properties: See general_properties.
- axisIn: List of axis.

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

ParametricCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axisIn)
Instantiate a ParametricCS.

Return a new ParametricCS.

Parameters
- properties: See general_properties.
- axisIn: Axis.

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

SphericalCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2, const CoordinateSystemAxisNNPtr &axis3)
Instantiate a SphericalCS.

Return a new SphericalCS.

Parameters
- properties: See general_properties.
- axis1: The first axis.
• axis2: The second axis.
• axis3: The third axis.

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

TemporalCountCS::NNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis)
Instantiate a TemporalCountCS.

Returns a new TemporalCountCS.

Parameters
• properties: See general_properties.
• axisIn: The axis.

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 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

TemporalMeasureCS::NNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis)
Instantiate a TemporalMeasureCS.

Returns a new TemporalMeasureCS.

Parameters
• properties: See general_properties.
• axisIn: The axis.

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 \textit{VerticalCS} shall have one axis association.

**Remark** Implements \textit{VerticalCS} from \textit{ISO\_19111\_2019}

**Public Static Functions**

\texttt{VerticalCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis)}

Instantiate a \textit{VerticalCS}.

\textbf{Return} a new \textit{VerticalCS}.

\textbf{Parameters}

- \textit{properties}: See \textit{general\_properties}.
- \textit{axis}: The axis.

\texttt{VerticalCSNNPtr createGravityRelatedHeight(const common::UnitOfMeasure &unit)}

Instantiate a \texttt{VerticalCS} with a Gravity-related height axis.

\textbf{Return} a new \textit{VerticalCS}.

\textbf{Parameters}

- \textit{unit}: linear unit.

10.5.3.6 datum namespace

\texttt{namespace datum}

\texttt{Datum} (the relationship of a coordinate system to the body).

\texttt{osgeo.proj.datum} namespace

**Typedefs**

\texttt{typedef std::shared\_ptr\<Datum\> DatumPtr}  
Shared pointer of \textit{Datum}

\texttt{typedef util::nn\<DatumPtr\> DatumNNPtr}  
Non-null shared pointer of \textit{Datum}

\texttt{using DatumEnsemblePtr = std::shared\_ptr\<DatumEnsemble\>}  
Shared pointer of \textit{DatumEnsemble}

\texttt{using DatumEnsembleNNPtr = util::nn\<DatumEnsemblePtr\>}  
Non-null shared pointer of \textit{DatumEnsemble}

\texttt{typedef std::shared\_ptr\<PrimeMeridian\> PrimeMeridianPtr}  
Shared pointer of \textit{PrimeMeridian}

\texttt{typedef util::nn\<PrimeMeridianPtr\> PrimeMeridianNNPtr}  
Non-null shared pointer of \textit{PrimeMeridian}

\texttt{typedef std::shared\_ptr\<Ellipsoid\> EllipsoidPtr}  
Shared pointer of \textit{Ellipsoid}

\texttt{typedef util::nn\<EllipsoidPtr\> EllipsoidNNPtr}  
Non-null shared pointer of \textit{Ellipsoid}

\texttt{typedef std::shared\_ptr\<GeodeticReferenceFrame\> GeodeticReferenceFramePtr}  
Shared pointer of \textit{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.

Return 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.
Return 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

Return the conventional reference system, or nullptr.

class DatumEnsemble: public osgeo::proj::common::IdentifiedObject, 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.

Return 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.

Return the accuracy.
Public Static Functions

DatumEnsembleNNPtr create(const util::PropertyMap &properties, const std::vector<DatumNNPtr> &datumsIn, const meta::PositionalAccuracyNNPtr &accuracy)

Instantiate a DatumEnsemble.

Return new 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

Exceptions

• util::Exception:

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.

Return 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.

Return the name of the deformation model.

Public Static Functions

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.

Return new 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

```cpp
#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

```cpp
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.
    Return the frame reference epoch.
```

```cpp
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.
    Return the name of the deformation model.
```

Public Static Functions

```cpp
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.
    Return new 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
```

```cpp
#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.

Return 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 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.

Return 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 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.

Return 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.

Return 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.

Return 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.

Return the inverse flattening value of the ellipsoid, or 0 for a sphere.

double squaredEccentricity ()
Return the squared eccentricity of the ellipsoid.

Return 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.

Return 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.

Return a new Ellipsoid.

Public Static Functions

EllipsoidNNPtr createSphere(const util::PropertyMap &properties, const common::Length &radius, const std::string &celestialBody = EARTH)
Instantiate a Ellipsoid as a sphere.

Return new Ellipsoid.
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.

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.

Return new Ellipsoid.
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.

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.

Return new Ellipsoid.
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.

Public Static Attributes

const std::string EARTH
Earth celestial body.

const EllipsoidNNPtr CLARKE_1866
The EPSG:7008 / “Clarke 1866” Ellipsoid.

const EllipsoidNNPtr WGS84
The EPSG:7030 / “WGS 84” Ellipsoid.

const EllipsoidNNPtr GRS1980
**class EngineeringDatum**: public osgeo::proj::Datum
#include <datum.hpp>

The definition of the origin and orientation of an engineering coordinate reference system.

**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.

**Remark** Implements EngineeringDatum from ISO_19111_2019

**Public Static Functions**

```
EngineeringDatumNNPtr create(const util::PropertyMap &properties,
                          const util::optional<std::string> &anchor =
                          util::optional<std::string>())
```

Instantiates an EngineeringDatum.

**Return** new EngineeringDatum.

**Parameters**

- **properties**: See general_properties. At minimum the name should be defined.
- **anchor**: the anchor definition, or empty.

**class GeodeticReferenceFrame**: public osgeo::proj::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.

**Note** The terminology “Datum” is often used to mean a GeodeticReferenceFrame.

**Note** In ISO_19111_2007, this class was called GeodeticDatum.

**Remark** Implements GeodeticReferenceFrame from ISO_19111_2019

Subclassed by osgeo::proj::datum::DynamicGeodeticReferenceFrame

**Public Functions**

```
const PrimeMeridianNNPtr &primeMeridian()

    Return the PrimeMeridian associated with a GeodeticReferenceFrame.

    Return 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.

    Return the Ellipsoid.
```
**Public Static Functions**

```cpp
GeodeticReferenceFrameNNPtr create(const util::PropertyMap &properties, const EllipsoidNNPtr &ellipsoid, const util::optional<std::string> &anchor, const PrimeMeridianNNPtr &primeMeridian)
```

Instantiate a `GeodeticReferenceFrame`.

**Return** new `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`.

**Public Static Attributes**

```cpp
const GeodeticReferenceFrameNNPtr EPSG_6267
The EPSG:6267 / “North_American_Datum_1927” GeodeticReferenceFrame.
```

```cpp
const GeodeticReferenceFrameNNPtr EPSG_6269
```

```cpp
const GeodeticReferenceFrameNNPtr EPSG_6326
```

**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**

```cpp
ParametricDatumNNPtr create(const util::PropertyMap &properties, const util::optional<std::string> &anchor = util::optional<std::string>())
```

Instantiate a `ParametricDatum`.

**Return** new `ParametricDatum`.

**Parameters**
- `properties`: See `general_properties`. At minimum the name should be defined.
- `anchor`: the anchor definition, or empty.

**class PrimeMeridian : public osgeo::proj::common::IdentifiedObject, public osgeo::proj::io::IPROJStringExportable**

```
#include <datum.hpp>
```

The origin meridian from which longitude values are determined.

**Note** The default value for prime meridian name is “Greenwich”. When the default applies, the value for the longitude shall be 0 (degrees).

**Remark** Implements `PrimeMeridian` from `ISO_19111_2019`
Public Functions

```cpp
const common::Angle &longitude()
  Return the longitude of the prime meridian.
  It is measured from the internationally-recognised reference meridian (‘Greenwich meridian’), posi-
tive eastward. The default value is 0 degrees.
  Return the longitude of the prime meridian.
```

Public Static Functions

```cpp
PrimeMeridianNNPtr create(const util::PropertyMap &properties, const common::Angle &longitudeIn)
  Instantiate a PrimeMeridian.
  Return new PrimeMeridian.
  Parameters
  • properties: See general_properties. At minimum the name should be defined.
  • longitudeIn: the longitude of the prime meridian.
```

Public Static Attributes

```cpp
const PrimeMeridianNNPtr GREENWICH
  The Greenwich PrimeMeridian.
const PrimeMeridianNNPtr REFERENCE_MERIDIAN
  The “Reference Meridian” PrimeMeridian.
  This is a meridian of longitude 0 to be used with non-Earth bodies.
const PrimeMeridianNNPtr PARIS
  The Paris PrimeMeridian.
```

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

```cpp
const RealizationMethod LEVELLING
  The realization is by adjustment of a levelling network fixed to one or more tide gauges.
const RealizationMethod GEOID
  The realization is through a geoid height model or a height correction model. This is applied to a
  specified geodetic CRS.
const RealizationMethod TIDAL
  The realization is through a tidal model or by tidal predictions.
```

class TemporalDatum : public osgeo::proj::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**

```cpp
const common::DateTime &temporalOrigin() const
```

Return the date and time to which temporal coordinates are referenced, expressed in conformance with ISO 8601.

**Return** the temporal origin.

```cpp
const std::string &calendar() const
```

Return the calendar to which the temporal origin is referenced.

**Default value:** `TemporalDatum::CALENDAR_PROLEPTIC_GREGORIAN`.

**Return** the calendar.

**Public Static Functions**

```cpp
TemporalDatumNNPtr create(const util::PropertyMap &properties, const common::DateTime &temporalOriginIn, const std::string &calendarIn)
```

Instantiate a `TemporalDatum`.

**Return** new `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`)

**Public Static Attributes**

```cpp
const std::string CALENDAR_PROLEPTIC_GREGORIAN
```

The proleptic Gregorian calendar.

**class VerticalReferenceFrame : public osgeo::proj::Datum**

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.

**Note** In `ISO_19111_2007`, this class was called VerticalDatum.

**Remark** Implements `VerticalReferenceFrame` from `ISO_19111_2019`

Subclassed by `osgeo::proj::datum::DynamicVerticalReferenceFrame`

**Public Functions**

```cpp
const util::optional<RealizationMethod> &realizationMethod() const
```

Return the method through which this vertical reference frame is realized.

**Return** the realization method.
Public Static Functions

```cpp
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`.

Return new `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.

10.5.3.7 crs namespace

```cpp
namespace crs
```

`CRS` (coordinate reference system = coordinate system with a datum).

`osgeo.proj.crs` namespace

**Typedefs**

```cpp
typedef std::shared_ptr<CRS> CRSPtr
```

Shared pointer of `CRS`

```cpp
typedef util::nn<CRSPtr> CRSSNPtr
```

Non-null shared pointer of `CRS`

```cpp
typedef std::shared_ptr<GeographicCRS> GeographicCRSPtr
```

Shared pointer of `GeographicCRS`

```cpp
typedef util::nn<GeographicCRSPtr> GeographicCRSNPtr
```

Non-null shared pointer of `GeographicCRS`

```cpp
typedef std::shared_ptr<VerticalCRS> VerticalCRSPtr
```

Shared pointer of `VerticalCRS`

```cpp
typedef util::nn<VerticalCRSPtr> VerticalCRSNPtr
```

Non-null shared pointer of `VerticalCRS`

```cpp
using BoundCRSPtr = std::shared_ptr<BoundCRS>
```

Shared pointer of `BoundCRS`

```cpp
using BoundCRSNNPtr = util::nn<BoundCRSPtr>
```

Non-null shared pointer of `BoundCRS`

```cpp
using SingleCRSPtr = std::shared_ptr<SingleCRS>
```

Shared pointer of `SingleCRS`

```cpp
using SingleCRSNNPtr = util::nn<SingleCRSPtr>
```

Non-null shared pointer of `SingleCRS`

```cpp
typedef std::shared_ptr<GeodeticCRS> GeodeticCRSPtr
```

Shared pointer of `GeodeticCRS`

```cpp
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

typedef std::shared_ptr<CompoundCRS> CompoundCRSPtr
    Shared pointer of CompoundCRS

typedef util::nn<CompoundCRSPtr> CompoundCRSNNPtr
    Non-null shared pointer of CompoundCRS

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 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 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.

Note Contrary to other CRS classes of this package, there is no ISO_19111_2019 modelling of a BoundCRS.

Remark Implements BoundCRS from WKT2

Public Functions

const CRSNNPtr &baseCRS ()
    Return the base CRS.

    This is the CRS into which coordinates of the BoundCRS are expressed.

    Return 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.

    Return the base CRS.

const CRSNNPtr &hubCRS ()
    Return the target / hub CRS.

    Return the hub CRS.
const operation::TransformationNNPtr &transformation()  
    Return the transformation to the hub RS.
    
    Return transformation.

Public Static Functions

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.

    Return new BoundCRS.
    Parameters
        • baseCRSIn: base CRS.
        • hubCRSIn: hub CRS.
        • transformationIn: transformation from base CRS to hub CRS.

BoundCRSNNPtrcreateFromTOWGS84(const CRSNNPtr &baseCRSIn, std::vector<double> &TOWGS84Parameters)
Instantiate a BoundCRS from a base CRS and TOWGS84 parameters.

    Return new BoundCRS.
    Parameters
        • baseCRSIn: base CRS.
        • TOWGS84Parameters: a vector of 3 or 7 double values representing WKT1 TOWGS84 parameter.

BoundCRSNNPtrcreateFromNadgrids(const CRSNNPtr &baseCRSIn, const std::string &filename)
Instantiate a BoundCRS from a base CRS and nadgrids parameters.

    Return new BoundCRS.
    Parameters
        • baseCRSIn: base CRS.
        • filename: Horizontal grid filename.

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.

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.

Remark Implements CompoundCRS from ISO_19111_2019
**Public Functions**

```cpp
const std::vector<CRSNNPtr> &componentReferenceSystems() const
Return the components of a CompoundCRS.
```

```cpp
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.
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 do not match at all.
25% means that the CRS are not equivalent, but there is some similarity in the names.
Return a list of matching reference CRS, and the percentage (0-100) of confidence in the match.
```

**Parameters**
- `authorityFactory`: Authority factory (if null, will return an empty list)

**Public Static Functions**

```cpp
CompoundCRSNNPtr create(const util::PropertyMap &properties, const std::vector<CRSNNPtr> &components)
Instantiate a CompoundCRS from a vector of CRS.
Return new CompoundCRS.
```

**Parameters**
- `properties`: See `general_properties`. At minimum the name should be defined.
- `components`: the component CRS of the CompoundCRS.

```cpp
class CRS : public osgeo::proj::common::ObjectUsage, public osgeo::proj::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**

```cpp
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.

Return 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**.

Return 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**.

Return 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**.

Return a **CRS**.

**CRSNNPtr** `stripVerticalComponent () const`

Returns a **CRS** whose coordinate system does not contain a vertical component.

Return 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**

Return 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.

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 GE-OGCS[“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.

Return a list of matching reference CRS, and the percentage (0-100) of confidence in the match.

Parameters

• authorityFactory: Authority factory (or null, but degraded functionality)

std::list<CRSNNPtr> getNonDeprecated(const io::DatabaseContextNNPtr &dbContext)

Return CRSs that are non-deprecated substitutes for the current CRS.

CRSNNPtr promoteTo3D(const std::string &newName, const io::DatabaseContextPtr &dbContext)

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.

Return a new CRS promoted to 3D, or the current one if already 3D or not applicable.

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.

CRSNNPtr demoteTo2D(const std::string &newName, const io::DatabaseContextPtr &dbContext)

Return a variant of this CRS “demoted” to a 2D one, if not already the case.

Return a new CRS demoted to 2D, or the current one if already 2D or not applicable.

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.

class DerivedCRS: public virtual osgeo::proj::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<DerivedEngineeringCRSTraits>, osgeo::proj::crs::DerivedCRSTemplate<DerivedParametricCRSTraits>, osgeo::proj::crs::DerivedCRSTemplate<DerivedTemporalCRSTraits>, 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 () const
Return the base CRS of a DerivedCRS.

const operation::ConversionNNPtr derivingConversion () const
Return the deriving conversion from the base CRS to this CRS.

template<class DerivedCRSTraits>
class DerivedCRSTemplate : public 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 DerivedCRSTemplate< DerivedCRSTraits >::BaseNNPtr baseCRS () const
Return the base CRS of a DerivedCRSTemplate.

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.
Return new DerivedCRSTemplate.
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.

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 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 GeodeticCRSSNPtr baseCRS () const
    Return the base CRS (a GeodeticCRS) of a DerivedGeodeticCRS.

Public Static Functions

DerivedGeodeticCRSSNPtr create (const util::PropertyMap &properties, const GeodeticCRSSNPtr &baseCRSIn, const operation::ConversionNNPtr &derivingConversionIn, const cs::CartesianCSNPtr &csIn)
    Instantiate a DerivedGeodeticCRS from a base CRS, a deriving conversion and a cs::CartesianCS.

Return new DerivedGeodeticCRS.

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.

DerivedGeodeticCRSSNPtr create (const util::PropertyMap &properties, const GeodeticCRSSNPtr &baseCRSIn, const operation::ConversionNNPtr &derivingConversionIn, const cs::SphericalCSNPtr &csIn)
    Instantiate a DerivedGeodeticCRS from a base CRS, a deriving conversion and a cs::SphericalCS.

Return new DerivedGeodeticCRS.

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.

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.

Public Static Functions

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.

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 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.

Return the base CRS.
Public Static Functions

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.

Return new DerivedProjectedCRS.

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.

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

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.

Return the base CRS.

Public Static Functions

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.

Return new DerivedVerticalCRS.

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.

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*, it maps to a ENGINEERINGCRS / ENGCRS keyword. In *WKT1*, it maps to a LOCAL_CS keyword.

**Remark** Implements *EngineeringCRS* from *ISO_19111_2019*

**Public Functions**

```cpp
const datum::EngineeringDatumNNPtr datum() const
    Return the *datum::EngineeringDatum* associated with the *CRS*.
```

**Public Static Functions**

```cpp
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.

**class GeodeticCRS : public virtual osgeo::proj::crs::SingleCRS, public osgeo::proj::io::IPROJStringExportable**

*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**

```cpp
const datum::GeodeticReferenceFramePtr &datum() const
    Return the *datum::GeodeticReferenceFrame* associated with the *CRS*.
```

```cpp
const datum::PrimeMeridianNNPtr &primeMeridian() const
    Return the PrimeMeridian associated with the GeodeticReferenceFrame or with one of the GeodeticReferenceFrame of the *datumEnsemble()*.
```

```cpp
const datum::EllipsoidNNPtr &ellipsoid() const
    Return the ellipsoid associated with the GeodeticReferenceFrame or with one of the GeodeticReferenceFrame of the *datumEnsemble()*.
```
const std::vector<operation::PointMotionOperationNNPtr> &velocityModel()  
    Return the velocity model associated with the CRS.

Return 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.

Return 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.

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 
  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 do 
  not match at all.

• 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.

Return a list of matching reference CRS, and the percentage (0-100) of confidence in the match.

Parameters

• authorityFactory: Authority factory (or null, but degraded functionality)

Public Static Functions

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.

Return new GeodeticCRS.

Parameters

• properties: See general_properties. At minimum the name should be defined.

• datum: The datum of the CRS.

• cs: a SphericalCS.
**PROJ coordinate transformation software library, Release 6.3.1**

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.

**Return** new GeodeticCRS.

**Parameters**
- properties: See general_properties. At minimum the name should be defined.
- datum: The datum of the CRS.
- cs: a CartesianCS.

GeodeticCRSNNPtr create(const util::PropertyMap &properties, const datum::GeodeticReferenceFramePtr &datum, const 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.

**Return** new GeodeticCRS.

**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.

GeodeticCRSNNPtr create(const util::PropertyMap &properties, const datum::GeodeticReferenceFramePtr &datum, const 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.

**Return** new GeodeticCRS.

**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

**Public Static Attributes**

const GeodeticCRSNNPtr EPSG_4978

EPSG:4978 / “WGS 84” Geocentric.

class GeographicCRS:public osgeo::proj::crs::DerivedGeographicCRS

#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

\texttt{const cs::EllipsoidalCSNNPtr \&coordinateSystem()}  
Return the \texttt{cs::EllipsoidalCS} associated with the \texttt{CRS}.

Return a EllipsoidalCS.

\texttt{GeographicCRSNNPtr demoteTo2D(const std::string \&newName, const io::DatabaseContextPtr \&dbContext) const}  
Return a variant of this \texttt{CRS} “demoted” to a 2D one, if not already the case.

Return a new \texttt{CRS} demoted to 2D, or the current one if already 2D or not applicable.

Since 6.3

Parameters
- \texttt{newName}: Name of the new \texttt{CRS}. If empty, \texttt{nameStr()} will be used.
- \texttt{dbContext}: Database context to look for potentially already registered 2D \texttt{CRS}. May be \texttt{nullptr}.

Public Static Functions

\texttt{GeographicCRSNNPtr create(const util::PropertyMap \&properties, const datum::GeodeticReferenceFrameNNPtr \&datum, const cs::EllipsoidalCSNNPtr \&cs)}  
Instantiate a \texttt{GeographicCRS} from a \texttt{datum::GeodeticReferenceFrameNNPtr} and a \texttt{cs::EllipsoidalCS}.

Return new \texttt{GeographicCRS}.

Parameters
- \texttt{properties}: See \texttt{general_properties}. At minimum the name should be defined.
- \texttt{datum}: The datum of the \texttt{CRS}.
- \texttt{cs}: a EllipsoidalCS.

\texttt{GeographicCRSNNPtr create(const util::PropertyMap \&properties, const datum::GeodeticReferenceFramePtr \&datum, const DatumEnsemblePtr \&datumEnsemble, const cs::EllipsoidalCSNNPtr \&cs)}  
Instantiate a \texttt{GeographicCRS} from a \texttt{datum::GeodeticReferenceFramePtr} or \texttt{datum::DatumEnsemble} and a \texttt{cs::EllipsoidalCS}.

One and only one of datum or datumEnsemble should be set to a non-null value.

Return new \texttt{GeographicCRS}.

Parameters
- \texttt{properties}: See \texttt{general_properties}. At minimum the name should be defined.
- \texttt{datum}: The datum of the \texttt{CRS}, or \texttt{nullptr}
- \texttt{datumEnsemble}: The datum ensemble of the \texttt{CRS}, or \texttt{nullptr}.
- \texttt{cs}: a EllipsoidalCS.
Public Static Attributes

const GeographicCRSNNPtr EPSG_4267
EPSG:4267 / “NAD27” 2D GeographicCRS.

const GeographicCRSNNPtr EPSG_4269
EPSG:4269 / “NAD83” 2D GeographicCRS.

const GeographicCRSNNPtr EPSG_4326
EPSG:4326 / “WGS 84” 2D GeographicCRS.

const GeographicCRSNNPtr OGC_CRS84
OGC:CRS84 / “CRS 84” 2D GeographicCRS.

const GeographicCRSNNPtr EPSG_4807
EPSG:4807 / “NTF (Paris)” 2D GeographicCRS.

const GeographicCRSNNPtr EPSG_4979
EPSG:4979 / “WGS 84” 3D GeographicCRS.

class ParametricCRS: public virtual osgeo::proj::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, 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.

Return a ParametricDatum

const cs::ParametricCSNNPtr coordinateSystem() const
Return the cs::TemporalCS associated with the CRS.

Return a TemporalCS

Public Static Functions

ParametricCRSNNPtr create(const util::PropertyMap &properties, const datum::ParametricDatumNNPtr &datumIn, const cs::ParametricCSNNPtr &csIn)
Instantiate a ParametricCRS from a datum and a coordinate system.

Return new ParametricCRS.

Parameters
• properties: See general_properties. At minimum the name should be defined.
• datumIn: the datum.
• csIn: the coordinate system.

class ProjectedCRS: public osgeo::proj::DerivedCRS, public osgeo::proj::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.
  Return the base CRS.

const cs::CartesianCSNNPtr &coordinateSystem ()
  Return the cs::CartesianCS associated with the CRS.
  Return 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.
  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 do not match at all. 50% means that CRS have similarity (equivalent base CRS 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.
  Return a list of matching reference CRS, and the percentage (0-100) of confidence in the match.
  Parameters
  • authorityFactory: Authority factory (or null, but degraded functionality)

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.
  Return a new CRS demoted to 2D, or the current one if already 2D or not applicable.
  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.
Public Static Functions

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.

Return new ProjectedCRS.

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 coordinate system.

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.

Return 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.

Return a DatumEnsemble that might be null.

const cs::CoordinateSystemNNPtr &coordinateSystem()

Return the cs::CoordinateSystem associated with the CRS.

Return a CoordinateSystem.

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

```cpp
const datum::TemporalDatumNNPtr datum() const
    Return the datum::TemporalDatum associated with the CRS.
    Return a TemporalDatum

const cs::TemporalCSNNPtr coordinateSystem() const
    Return the cs::TemporalCS associated with the CRS.
    Return a TemporalCS
```

Public Static Functions

```cpp
TemporalCRSNNPtr create(const util::PropertyMap &properties, const datum::TemporalDatumNNPtr &datumIn, const cs::TemporalCSNNPtr &csIn)
    Instantiate a TemporalCRS from a datum and a coordinate system.
    Return new TemporalCRS.
```

Parameters

- `properties`: See general_properties. At minimum the name should be defined.
- `datumIn`: the datum.
- `csIn`: the coordinate system.

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.

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.

Remark Implements VerticalCRS from ISO_19111_2019

Subclassed by osgeo::proj::crs::DerivedVerticalCRS

Public Functions

```cpp
const datum::VerticalReferenceFramePtr datum() const
    Return the datum::VerticalReferenceFrame associated with the CRS.
    Return a VerticalReferenceFrame.

const cs::VerticalCSNNPtr coordinateSystem() const
    Return the cs::VerticalCS associated with the CRS.
    Return a VerticalCS.

const std::vector<operation::TransformationNNPtr> &geoidModel() const
    Return the geoid model associated with the CRS.
    Geoid height model or height correction model linked to a geoid-based vertical CRS.
    Return a geoid model. might be null
const std::vector<operation::PointMotionOperationNNPtr>& velocityModel()  
  
    Return 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 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 do not match at all. 25% means that the CRS are not equivalent, but there is some similarity in the names.

  Return a list of matching reference CRS, and the percentage (0-100) of confidence in the match.

Parameters  
  • authorityFactory: Authority factory (if null, will return an empty list)

Public Static Functions

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.

  Return new VerticalCRS.

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.

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.

  Return new VerticalCRS.

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.
10.5.3.8 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 util::PropertyMap createPropertiesForInverse(const CoordinateOperation *op, bool derivedFrom, bool approximateInversion)

static bool isTimeDependent(const std::string &methodName)

static double negate(double val)

static CoordinateOperationPtr createApproximateInverseIfPossible(const Transformation *op)

static void exportSourceCRSAndTargetCRSToWKT(const CoordinateOperation *co, io::WKTFormatter *formatter)

static crs::CRSNNPtr getResolvedCRS(const crs::CRSNNPtr &crs, const CoordinateOperationContextNNPtr &context, metadata::ExtentPtr &extentOut)

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

10.5. Reference
Public Functions

```cpp
const std::vector<CoordinateOperationNNPtr> &operations() const

Return the operation steps of the concatenated operation.
```

```cpp
CoordinateOperationNNPtr inverse() const

Return the inverse of the coordinate operation.
```

Exceptions

- `util::UnsupportedOperationException`:

```cpp
std::set<GridDescription> gridsNeeded(const io::DatabaseContextPtr &databaseContext) const

Return grids needed by an operation.
```

Public Static Functions

```cpp
ConcatenatedOperationNNPtr create(const util::PropertyMap &properties, const std::vector<CoordinateOperationNNPtr> &operationsIn, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a ConcatenatedOperation.

Return new Transformation.
```

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).

Exceptions

- `InvalidOperation`:

```cpp
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-emptyness of the intersection of the extents of the operations.

Exceptions

- `InvalidOperation`:

```cpp
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*

Public Functions

*CoordinateOperationNNPtr inverse() const*

Return the inverse of the coordinate operation.

Exceptions

- `util::UnsupportedOperationException`

*bool isUTM(int &zone, bool &north) const*

Return whether a conversion is a Universal Transverse Mercator conversion.

Return true if it is a UTM conversion.

Parameters

- `zone`: UTM zone number between 1 and 60.
- `north`: true for UTM northern hemisphere, false for UTM southern hemisphere.

*ConversionNNPtr identify() const*

Return a *Conversion* object where some parameters are better identified.

Return 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

Return new conversion, or nullptr.

Parameters

- `targetEPSGCode`: EPSG code of the target method.

Public Static Functions

*ConversionNNPtr create(const util::PropertyMap &properties, const OperationMethodNNPtr &methodIn, const std::vector<GeneralParameterValueNNPtr> &values)*

Instantiate a *Conversion* from a vector of *GeneralParameterValue*.

Return a new *Conversion*.

Parameters

- `properties`: See *general_properties*. At minimum the name should be defined.
- `methodIn`: the operation method.
- `values`: the values.

Exceptions

- `InvalidOperationException`
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.

Return a new Conversion.

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()

Exceptions

• InvalidOperation:

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.

Return a new Conversion.

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.

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.

Return a new Conversion.

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
\texttt{ConversionNNPtr createGaussSchreiberTransverseMercator(\textbf{const} util::PropertyMap &properties, \textbf{const} common::Angle &centerLat, \textbf{const} common::Angle &centerLong, \textbf{const} common::Scale &scale, \textbf{const} common::Length &falseEasting, \textbf{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.

\textbf{Return} a new Conversion.

\textbf{Parameters}

- \textbf{properties}: See \textit{general\_properties} of the conversion. If the name is not provided, it is automatically set.
- \textbf{centerLat}: See Latitude of natural origin/Center Latitude
- \textbf{centerLong}: See Longitude of natural origin/Central Meridian
- \textbf{scale}: See Scale Factor
- \textbf{falseEasting}: See False Easting
- \textbf{falseNorthing}: See False Northing

\texttt{ConversionNNPtr createTransverseMercatorSouthOriented(\textbf{const} util::PropertyMap &properties, \textbf{const} common::Angle &centerLat, \textbf{const} common::Angle &centerLong, \textbf{const} common::Scale &scale, \textbf{const} common::Length &falseEasting, \textbf{const} common::Length &falseNorthing)}

Instantiate a conversion based on the Transverse Mercator South Orientated projection method.

This method is defined as EPSG:9808.

\textbf{Return} a new Conversion.

\textbf{Parameters}

- \textbf{properties}: See \textit{general\_properties} of the conversion. If the name is not provided, it is automatically set.
- \textbf{centerLat}: See Latitude of natural origin/Center Latitude
- \textbf{centerLong}: See Longitude of natural origin/Central Meridian
- \textbf{scale}: See Scale Factor
- \textbf{falseEasting}: See False Easting
- \textbf{falseNorthing}: See False Northing
Instantiate a conversion based on the Two Point Equidistant projection method.

Return a new Conversion.

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.
- longitudeSecondPoint: Longitude of second point.
- falseEastings: See False Easting
- falseNorthing: See False Northing

This method is defined as EPSG:9816.

Note There is currently no implementation of the method formulas in PROJ.

Return a new Conversion.

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
- falseEastings: See False Easting
- falseNorthing: See False Northing

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

Return a new Conversion.

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

`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.

Return a new `Conversion`.

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

`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

Return a new `Conversion`.

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

```
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.

Return a new Conversion.

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.
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.

Warning The formulas used currently in PROJ are, incorrectly, the ones of the regular LCC_2SP method.

Note the order of arguments is conformant with the corresponding EPSG mode and different than OGRSpatialReference::setLCCB() of GDAL <= 2.3

Return a new Conversion.

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

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.

Return a new Conversion.

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

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.

Return a new Conversion.

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

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.

Return a new Conversion.

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

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.

Return a new Conversion.

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

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.

Return a new Conversion.

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

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.

Return a new Conversion.

Parameters
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 *

Return a new Conversion.

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

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.

Return a new Conversion.

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

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.

Return a new Conversion.

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

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.

Return a new Conversion.

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
• falseEastings: See False Easting
• falseNortings: See False Northing

ConversionNNPtr createEckertIV(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEastings, const common::Length &falseNortings)

Instantiate a conversion based on the Eckert IV projection method.

There is no equivalent in EPSG.

Return a new Conversion.

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
• falseEastings: See False Easting
• falseNortings: See False Northing

ConversionNNPtr createEckertV(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEastings, const common::Length &falseNortings)

Instantiate a conversion based on the Eckert V projection method.

There is no equivalent in EPSG.

Return a new Conversion.

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
• falseEastings: See False Easting
• falseNortings: See False Northing

ConversionNNPtr createEckertVI(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEastings, const common::Length &falseNortings)

Instantiate a conversion based on the Eckert VI projection method.

There is no equivalent in EPSG.

Return a new Conversion.

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
• falseEastings: See False Easting
• falseNortings: See False Northing
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.

Return a new Conversion.

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

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.

Return a new Conversion.

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
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.

**Return** a new `Conversion`.

**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

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.

**Return** a new `Conversion`.

**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

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.

**Return** a new `Conversion`.

**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

ConversionNNPtr `createGeostationarySatelliteSweepX` (const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &height, const common::Length &falseEasting, const common::Length &falseNorthing)

10.5. Reference
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.

**Return** a new *Conversion*.

**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.
- falseEastings: See False Easting
- falseNorthing: See False Northing

```cpp
ConversionNNPtr createGeostationarySatelliteSweepX(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &height, const common::Length &falseEastings, 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.

**Return** a new *Conversion*.

**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
- height: Height of the view point above the Earth.
- falseEastings: See False Easting
- falseNorthing: See False Northing

```cpp
ConversionNNPtr createGnomonic(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Length &falseEastings, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Gnomonic projection method.

There is no equivalent in EPSG.

**Return** a new *Conversion*.

**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
- falseEastings: See False Easting
- falseNorthing: See False Northing
**ConversionNNPtr createHotineObliqueMercatorVariantA** (const util::PropertyMap &properties, const common::Angle &latitudeProjectionCentre, const common::Angle &longitudeProjectionCentre, const common::Angle &azimuthInitialLine, const common::Angle &angleFromRectifiedToSkewGrid, 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 A 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 = angleFromRectifiedToSkewGrid = 90deg, this maps to the Swiss Oblique Mercator formulas.

**Return**  a new Conversion.

**Parameters**

- properties: See general_properties of the conversion. If the name is not provided, it is automatically set.
- latitudeProjectionCentre: See Latitude of projection centre
- longitudeProjectionCentre: See Longitude of projection centre
- azimuthInitialLine: See Azimuth of initial line
- angleFromRectifiedToSkewGrid: See Angle from Rectified to Skew Grid
- scale: See Scale factor on initial line
- falseEasting: See False Easting
- falseNorthing: See False Northing

**ConversionNNPtr createHotineObliqueMercatorVariantB** (const util::PropertyMap &properties, const common::Angle &latitudeProjectionCentre, const common::Angle &longitudeProjectionCentre, const common::Angle &azimuthInitialLine, const common::Angle &angleFromRectifiedToSkewGrid, 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 B variant without the no_uoff parameter, which corresponds to GDAL \( \geq 2.3 \) Hotine\_Oblique\_Mercator\_Azimuth\_Center projection. In this variant, the false grid coordinates are defined at the projection centre.

This method is defined as \texttt{EPSG:9815}.

\textbf{Note} In the case where \texttt{azimuthInitialLine = angleFromRectifiedToSkewGrid = 90deg}, this maps to the \texttt{Swiss Oblique Mercator} formulas.

\textbf{Return} a new \texttt{Conversion}.

\textbf{Parameters}

- \texttt{properties}: See \texttt{general\_properties} of the conversion. If the name is not provided, it is automatically set.
- \texttt{latitudeProjectionCentre}: See Latitude of projection centre
- \texttt{longitudeProjectionCentre}: See Longitude of projection centre
- \texttt{azimuthInitialLine}: See Azimuth of initial line
- \texttt{angleFromRectifiedToSkewGrid}: See Angle from Rectified to Skew Grid
- \texttt{scale}: See Scale factor on initial line
- \texttt{eastingProjectionCentre}: See Easting at projection centre
- \texttt{northingProjectionCentre}: See Northing at projection centre
ConversionNNPtr createHotineObliqueMercatorTwoPointNaturalOrigin(const util::PropertyMap &properties,
const common::Angle &latitudeProjectionCentre,
const common::Angle &latitudePoint1,
const common::Angle &longitudePoint1,
const common::Angle &latitudePoint2,
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.

**Return** a new Conversion.

**Parameters**

- **properties**: See general_properties of the conversion. If the name is not provided, it is automatically set.
- **latitudeProjectionCentre**: See Latitude 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

```cpp
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.

**Return** a new Conversion.

**Parameters**

- **properties**: See general_properties of the conversion. If the name is not provided, it is automatically set.
- **latitudeProjectionCentre**: See Latitude 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

```cpp
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

Return a new Conversion.

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

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.

Return a new Conversion.

Parameters

- properties: See general_properties of the conversion. If the name is not provided, it is automatically set.
- latitudeProjectionCentre: See Latitude 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

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.

Return a new Conversion.

Parameters
- `properties`: See `general_properties` of the conversion. If the name is not provided, it is automatically set.
- `latitudeProjectionCentre`: See Latitude 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

`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.

Return a new Conversion.

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

`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.

Return a new Conversion.

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
\texttt{ConversionNNPtr createMercatorVariantA} (const \texttt{util::PropertyMap} &\texttt{properties}, const \texttt{common::Angle} &\texttt{centerLat}, const \texttt{common::Angle} &\texttt{centerLong}, const \texttt{common::Scale} &\texttt{scale}, const \texttt{common::Length} &\texttt{falseEasting}, const \texttt{common::Length} &\texttt{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.

\textbf{Return} a new \textit{Conversion}.

\textbf{Parameters}

- \texttt{properties}: See \textit{general_properties} of the conversion. If the name is not provided, it is automatically set.
- \texttt{centerLat}: See Latitude of natural origin/Center Latitude. Should be 0.
- \texttt{centerLong}: See Longitude of natural origin/Central Meridian
- \texttt{scale}: See Scale Factor
- \texttt{falseEasting}: See False Easting
- \texttt{falseNorthing}: See False Northing

\texttt{ConversionNNPtr createMercatorVariantB} (const \texttt{util::PropertyMap} &\texttt{properties}, const \texttt{common::Angle} &\texttt{latitudeFirstParallel}, const \texttt{common::Angle} &\texttt{centerLong}, const \texttt{common::Length} &\texttt{falseEasting}, const \texttt{common::Length} &\texttt{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.

\textbf{Return} a new \textit{Conversion}.

\textbf{Parameters}

- \texttt{properties}: See \textit{general_properties} of the conversion. If the name is not provided, it is automatically set.
- \texttt{latitudeFirstParallel}: See Latitude of 1st standard parallel
- \texttt{centerLong}: See Longitude of natural origin/Central Meridian
- \texttt{falseEasting}: See False Easting
- \texttt{falseNorthing}: See False Northing

\texttt{ConversionNNPtr createPopularVisualisationPseudoMercator} (const \texttt{util::PropertyMap} &\texttt{properties}, const \texttt{common::Angle} &\texttt{centerLat}, const \texttt{common::Angle} &\texttt{centerLong}, const \texttt{common::Length} &\texttt{falseEasting}, const \texttt{common::Length} &\texttt{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.

Return a new Conversion.

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
- falseEastling: See False Easting. Usually 0
- falseNorthing: See False Northing. Usually 0

ConversionNNPtr createMollweide(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEastling, const common::Length &falseNorthing)

Instantiate a conversion based on the Mollweide projection method.

There is no equivalent in EPSG.

Return a new Conversion.

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
- falseEastling: See False Easting
- falseNorthing: See False Northing

ConversionNNPtr createNewZealandMappingGrid(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Length &falseEastling, const common::Length &falseNorthing)

Instantiate a conversion based on the New Zealand Map Grid projection method.

This method is defined as EPSG:9811.

Return a new Conversion.

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
- falseEastling: See False Easting
- falseNorthing: See False Northing

ConversionNNPtr createObliqueStereographic(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Scale &scale, const common::Length &falseEastling, const common::Length &falseNorthing)

Instantiate a conversion based on the Oblique Stereographic (alternative) projection method.

This method is defined as EPSG:9809.
Return a new Conversion.

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

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 At the time of writing, PROJ only implements the spherical formulation

Return a new Conversion.

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

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.

Return a new Conversion.

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

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 A variant of polar stereographic defined with a scale factor.

**Return** a new Conversion.

**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

```cpp
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 B variant of polar stereographic defined with a latitude of standard parallel.

**Return** a new Conversion.

**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

```cpp
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.

**Return** a new Conversion.

**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

```cpp
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.

**Return** a new Conversion.
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
• falseEastings: See False Easting
• falseNorthing: See False Northing

ConversionNNPtr createStereographic(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Scale &scale, const common::Length &falseEastings, 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().

Return a new Conversion.

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
• falseEastings: See False Easting
• falseNorthing: See False Northing

ConversionNNPtr createVanDerGrinten(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEastings, const common::Length &falseNorthing)

Instantiate a conversion based on the Van der Grinten projection method.

There is no equivalent in EPSG.

Return a new Conversion.

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
• falseEastings: See False Easting
• falseNorthing: See False Northing

ConversionNNPtr createWagnerI(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEastings, const common::Length &falseNorthing)

Instantiate a conversion based on the Wagner I projection method.

There is no equivalent in EPSG.

Return a new Conversion.

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
• falseEastings: See False Easting
• falseNorthing: See False Northing

ConversionNNPtr createWagnerII(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEastings, const common::Length &falseNortings)

Instantiate a conversion based on the Wagner II projection method.

There is no equivalent in EPSG.

Return a new Conversion.

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
• falseEastings: See False Easting
• falseNortings: See False Northing

ConversionNNPtr createWagnerIII(const util::PropertyMap &properties, const common::Angle &latitudeTrueScale, const common::Angle &centerLong, const common::Length &falseEastings, const common::Length &falseNortings)

Instantiate a conversion based on the Wagner III projection method.

There is no equivalent in EPSG.

Return a new Conversion.

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
• falseEastings: See False Easting
• falseNortings: See False Northing

ConversionNNPtr createWagnerIV(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEastings, const common::Length &falseNortings)

Instantiate a conversion based on the Wagner IV projection method.

There is no equivalent in EPSG.

Return a new Conversion.

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
• falseEastings: See False Easting
• falseNortings: See False Northing

ConversionNNPtr createWagnerV(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEastings, const common::Length &falseNortings)

Instantiate a conversion based on the Wagner V projection method.

There is no equivalent in EPSG.

Return a new Conversion.

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

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.
Return a new Conversion.
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

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.
Return a new Conversion.
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

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.
Return a new Conversion.
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
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.

Return a new Conversion.

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.

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.

Return a new Conversion.

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

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.

Return a new Conversion.

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)

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 exist. 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.

Return a new Conversion.

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.

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].

Return a new Conversion.

Parameters
• properties: See general_properties of the conversion. If the name is not provided, it is automatically set.
• factor: Conversion factor

ConversionNNPtr createHeightDepthReversal (const util::PropertyMap &properties)
Instantiate a conversion based on the Height Depth Reversal method.
This method is defined as EPSG:1068.
Return a new Conversion.
Since 6.3
Parameters
• properties: See general_properties of the conversion. If the name is not provided, it is automatically set.

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.
Return a new Conversion.
Parameters
• is3D: Whether this should apply on 3D geographicCRS

ConversionNNPtr createGeographicGeocentric (const util::PropertyMap &properties)
Instantiate a conversion based on the Geographic/Geocentric method.
This method is defined as EPSG:9602.
Return a new Conversion.
Parameters
• properties: See general_properties of the conversion. If the name is not provided, it is automatically set.

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.
Return 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.
Return 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.
Return 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.
Return target CRS, or null.

const crs::CRSPtr &interpolationCRS() const
Return the interpolation CRS of this coordinate operation.

const util::optional<common::DataEpoch> &sourceCoordinateEpoch() const
Return the source epoch of coordinates.
Return source epoch of coordinates, or empty.

const util::optional<common::DataEpoch> &targetCoordinateEpoch() const
Return the target epoch of coordinates.
Return target epoch of coordinates, or empty.

virtual CoordinateOperationNNPtr inverse() const = 0
Return the inverse of the coordinate operation.

Exceptions
• util::UnsupportedOperationException:

virtual std::set<GridDescription> gridsNeeded(const io::DatabaseContextPtr &databaseContext) const = 0
Return grids needed by an operation.
bool isPROJInstantiable(const io::DatabaseContextPtr &databaseContext) 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

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 CoordinateOperationContext

#include <coordinateoperation.hpp> Context in which a coordinate operation is to be used.


Public Types

enum 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:

NONE

Ignore CRS extent

BOTH

Test coordinate operation extent against both CRS extent.

INTERSECTION

Test coordinate operation extent against the intersection of both CRS extent.

SMALLEST

Test coordinate operation against the smallest of both CRS extent.

eenum SpatialCriterion

Spatial criterion to restrict candidate operations.

Values:

STRICT_CONTAINMENT

The area of validity of transforms should strictly contain the area of interest.

PARTIAL_INTERSECTION

The area of validity of transforms should at least intersect the area of interest.
enum GridAvailabilityUse
Describe how grid availability is used.
Values:

USE_FOR_SORTING
Grid availability is only used for sorting results. Operations where some grids are missing will be
sorted last.

DISCARD_OPERATION_IF_MISSING_GRID
Completely discard an operation if a required grid is missing.

IGNORE_GRID_AVAILABILITY
Ignore grid availability at all. Results will be presented as if all grids were available.

enum IntermediateCRSUse
Describe if and how intermediate CRS should be used
Values:

ALWAYS
Always search for intermediate CRS.

IF_NO_DIRECT_TRANSFORMATION
Only attempt looking for intermediate CRS if there is no direct transformation available.

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 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.

CoordinateOperationContext::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.

CoordinateOperationContext::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.

CoordinateOperationContext::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 AL-
   WAYS/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.
**CoordinateOperationContext::IntermediateCRSUse getAllowUseIntermediateCRS ()**

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**

**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 operation will be searched only in that authority namespace.

Return a new context.

**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.

**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.

Return a CoordinateOperation or nullptr.

Parameters
- sourceCRS: source CRS.
- targetCRS: source CRS.

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.

Return a list

Parameters
- sourceCRS: source CRS.
- targetCRS: target CRS.
- context: Search context.

Public Static Functions

CoordinateOperationFactoryNNPtr create()  
Instantiate a CoordinateOperationFactory.

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 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


```cpp
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 InvalidOperation: public osgeo::proj::util::Exception
#include <coordinateoperation.hpp> Exception that can be thrown when an invalid operation is attempted to be constructed.

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.

    Return 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.

    Return the formula citation, or empty.

const std::vector<GeneralOperationParameterNNPtr> &parameters ()
    Return the parameters of this operation method.
```
int getEPSGCode ()
    Return the EPSG code, either directly, or through the name.
    Return code, or 0 if not found

Public Static Functions

OperationMethodNNPtr create(const util::PropertyMap &properties, const
    std::vector<GeneralOperationParameterNNPtr> &parameters)
    Instantiate a operation method from a vector of GeneralOperationParameter.
    Return a new OperationMethod.
Parameters
    • properties: See general_properties. At minimum the name should be defined.
    • parameters: Vector of GeneralOperationParameterNNPtr.

OperationMethodNNPtr create(const util::PropertyMap &properties, const
    std::vector<OperationParameterNNPtr> &parameters)
    Instantiate a operation method from a vector of OperationParameter.
    Return a new OperationMethod.
Parameters
    • properties: See general_properties. At minimum the name should be defined.
    • parameters: Vector of OperationParameterNNPtr.

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.
    Return code, or 0 if not found

Public Static Functions

OperationParameterNNPtr create(const util::PropertyMap &properties)
    Instantiate a OperationParameter.
    Return a new OperationParameter.
Parameters
    • properties: See general_properties. At minimum the name should be defined.

const char *getNameForEPSGCode (int epsg_code)
    Return the name of a parameter designed by its EPSG code.
    Return name, or nullptr if not found
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**

```cpp
const OperationParameterNNPtr &parameter()
  Return the parameter (definition)
  Return the parameter (definition).
```

```cpp
const ParameterValueNNPtr &parameterValue()
  Return the parameter value.
  Return the parameter value.
```

**Public Static Functions**

```cpp
OperationParameterValueNNPtr create(const OperationParameterNNPtr &parameterIn,
const ParameterValueNNPtr &valueIn)
  Instantiate a OperationParameterValue.
  Return a new OperationParameterValue.
  Parameters
  • parameterIn: Parameter (definition).
  • valueIn: Parameter value.
```

**Public Types**

```cpp
enum Type
  Type of the value.
  Values:

  MEASURE
    Measure (i.e. value with a unit)

  STRING
    String

  INTEGER
    Integer

  BOOLEAN
    Boolean
```

```cpp
10.5. Reference 463
```
FILENAME
Filename

Public Functions

```cpp
const ParameterValue::Type &type ()
    Returns the type of a parameter value.
    Return the type.

const common::Measure &value ()
    Returns the value as a Measure (assumes type() == Type::MEASURE)
    Return the value as a Measure.

const std::string &stringValue ()
    Returns the value as a string (assumes type() == Type::STRING)
    Return the value as a string.

const std::string &valueFile ()
    Returns the value as a filename (assumes type() == Type::FILENAME)
    Return the value as a filename.

int integerValue ()
    Returns the value as an integer (assumes type() == Type::INTEGER)
    Return the value as an integer.

bool booleanValue ()
    Returns the value as a boolean (assumes type() == Type::BOOLEAN)
    Return the value as a boolean.
```

Public Static Functions

```cpp
ParameterValueNNPtr create (const common::Measure &measureIn)
    Instantiate a ParameterValue from a Measure (i.e. a value associated with a unit)
    Return a new ParameterValue.

ParameterValueNNPtr create (const char *stringValueIn)
    Instantiate a ParameterValue from a string value.
    Return a new ParameterValue.

ParameterValueNNPtr create (const std::string &stringValueIn)
    Instantiate a ParameterValue from a string value.
    Return a new ParameterValue.

ParameterValueNNPtr create (int integerValueIn)
    Instantiate a ParameterValue from a integer value.
    Return a new ParameterValue.

ParameterValueNNPtr create (bool booleanValueIn)
    Instantiate a ParameterValue from a boolean value.
```
Return a new ParameterValue.

ParameterValueNNPtr createFilename(const std::string &stringValueIn)
    Instantiate a ParameterValue from a filename.

Return a new ParameterValue.

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 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() const
    Return the parameter values.

Return the parameter values.

const OperationMethodNNPtr &method() const
    Return the operation method associated to the operation.

Return the operation method.

const ParameterValuePtr &parameterValue(const std::string &paramName, int epsg_code = 0) const
    Return the parameter value corresponding to a parameter name or EPSG code.

Return the value, or nullptr if not found.

Parameters
    • paramName: the parameter name (or empty, in which case epsg_code should be non zero)
    • epsg_code: the parameter EPSG code (possibly zero)

const ParameterValuePtr &parameterValue(int epsg_code) const
    Return the parameter value corresponding to a EPSG code.

Return the value, or nullptr if not found.

Parameters
    • epsg_code: the parameter EPSG code

const common::Measure &parameterValueMeasure(const std::string &paramName, int epsg_code = 0) const
    Return the parameter value, as a measure, corresponding to a parameter name or EPSG code.

Return the measure, or the empty Measure() object if not found.
PROJ coordinate transformation software library, Release 6.3.1

Parameters
- paramName: the parameter name (or empty, in which case epsg_code should be non zero)
- epsg_code: the parameter EPSG code (possibly zero)

```cpp
const common::Measure &parameterValueMeasure (int epsg_code) const
```

Return the parameter value, as a measure, corresponding to a EPSG code.

Parameters
- epsg_code: the parameter EPSG code

```cpp
std::set<GridDescription> gridsNeeded (const io::DatabaseContextPtr &databaseContext) const
```

Return grids needed by an operation.

```cpp
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

```cpp
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 Single-Operation modeling here is mostly to be able to get the PROJ string as a parameter.

Return the new instance

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).

class Transformation

```cpp
#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

```cpp
const crs::CRSNNPtr &sourceCRS ()
    Return the source crs::CRS of the transformation.
```

```cpp
const crs::CRSNNPtr &targetCRS ()
    Return the target crs::CRS of the transformation.
```

```cpp
CoordinateOperationNNPtr inverse () const
    Return the inverse of the coordinate operation.
```

Exceptions

• `util::UnsupportedOperationException`

```cpp
TransformationNNPtr substitutePROJAlternativeGridNames (io::DatabaseContextNNPtr databaseContext)
    Return an equivalent transformation to the current one, but using PROJ alternative grid names.
```

Public Static Functions

```cpp
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.
```

Return new Transformation.

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).

Exceptions

• `InvalidOperation`

```cpp
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 ands its OperationMethod.
```

Return new Transformation.

Parameters


10.5. Reference 467
• 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).

Exceptions
• InvalidOperation:

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.

Return new Transformation.

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).

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.

Return new Transformation.

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).

`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.

Return new `Transformation`.

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).
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.

Return new Transformation.

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).
- 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).
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::PositionalAccuracyNNPtr> &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.

Return new Transformation.

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).
- 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).

Exceptions

- InvalidOperation:

```
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

Return new Transformation.

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()

Exceptions

- InvalidOperation:

```
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.

Return new Transformation.

Parameters

- properties: See general_properties of the Transformation. At minimum the name should be defined.
- sourceCRSIn: Source CRS.
- targetCRSIn: Target CRS.
- filename: NTv2 filename.
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 createAbridgedMolodensky() for a related method.

Return new Transformation.

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).

Exceptions

• InvalidOperation:

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 createdMolodensky() for a related method.

Return new Transformation.

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).
• flatingDifference: The difference between the flattening values of the ellipsoids used in the target and source CRS.
• accuracies: Vector of positional accuracy (might be empty).

Exceptions
• InvalidOperation:

TransformationNNPtr createGravityRelatedHeightToGeographic3D(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, const crs::CRSPPtr &interpolationCRSIn, const std::string &filename, const std::vector< metadata::PositionalAccuracyNNPtr > &accuracies)

Instantiate a transformation from GravityRelatedHeight to Geographic3D.

Return new Transformation.

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).

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.

Return new Transformation.

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).

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.

Return new Transformation.

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.

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<memory::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with method Geographic 2D offsets.

This method is defined as EPSG:9619

Return new Transformation.

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).

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<memory::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with method Geographic 3D offsets.

This method is defined as EPSG:9660.

Return new Transformation.

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).
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.

Return new Transformation.

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).

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.

Return new Transformation.

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).

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].
Return a new Transformation.

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).

10.5.3.9 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**

```cpp
static crs::GeodeticCRSNNPtr cloneWithProps(const crs::GeodeticCRSNNPtr &geodCRS, const util::PropertyMap &props)
```

```cpp
util::BaseObjectNNPtr createUserInput(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 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.
- 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 interpreted the same way.

**Exceptions**

- `ParsingException`

```cpp
util::BaseObjectNNPtr createUserInput(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”
PROJ coordinate transformation software library, Release 6.3.1


• 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.

• PROJJSON string

Parameters

• text: One of the above mentioned text format

• ctx: PROJ context

Exceptions

• ParsingException:

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 ObjectType

Object type.

Values:

PRIME_MERIDIAN
Object of type datum::PrimeMeridian

ELLIPSOID
Object of type datum::Ellipsoid

DATUM
Object of type datum::Datum (and derived classes)

GEODETIC_REFERENCE_FRAME
Object of type datum::GeodeticReferenceFrame (and derived classes)

VERTICAL_REFERENCE_FRAME
Object of type datum::VerticalReferenceFrame (and derived classes)

CRS
Object of type crs::CRS (and derived classes)
GEOETIC_CRS
Object of type crs::GeodeticCRS (and derived classes)

GEOCENTRIC_CRS
GEOETIC_CRS of type geocentric

GEOGRAPHIC_CRS
Object of type crs::GeographicCRS (and derived classes)

GEOGRAPHIC_2D_CRS
GEOGRAPHIC_CRS of type Geographic 2D

GEOGRAPHIC_3D_CRS
GEOGRAPHIC_CRS of type Geographic 3D

PROJECTED_CRS
Object of type crs::ProjectedCRS (and derived classes)

VERTICAL_CRS
Object of type crs::VerticalCRS (and derived classes)

COMPOUND_CRS
Object of type crs::CompoundCRS (and derived classes)

COORDINATE_OPERATION
Object of type operation::CoordinateOperation (and derived classes)

CONVERSION
Object of type operation::Conversion (and derived classes)

TRANSFORMATION
Object of type operation::Transformation (and derived classes)

CONCATENATED_OPERATION
Object of type operation::ConcatenatedOperation (and derived classes)

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.

Return object.
Parameters
  • code: Object code allocated by authority. (e.g. “4326”)

Exceptions
  • NoSuchAuthorityCodeException:
  • FactoryException:

UnitOfMeasureNNPtr createUnitOfMeasure (const std::string &code) const
Returns a common::UnitOfMeasure from the specified code.

Return object.
Parameters
  • code: Object code allocated by authority.
Exceptions
- NoSuchAuthorityCodeException:
- FactoryException:

metadata::ExtentNNPtr createExtent (const std::string &code) const
Returns a metadata::Extent from the specified code.

Parameters
- code: Object code allocated by authority.

Exceptions
- NoSuchAuthorityCodeException:
- FactoryException:

datum::PrimeMeridianNNPtr createPrimeMeridian (const std::string &code) const
Returns a datum::PrimeMeridian from the specified code.

Parameters
- code: Object code allocated by authority.

Exceptions
- NoSuchAuthorityCodeException:
- FactoryException:

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.

Exceptions
- FactoryException:

datum::EllipsoidNNPtr createEllipsoid (const std::string &code) const
Returns a datum::Ellipsoid from the specified code.

Parameters
- code: Object code allocated by authority.

Exceptions
- NoSuchAuthorityCodeException:
- FactoryException:

datum::DatumNNPtr createDatum (const std::string &code) const
Returns a datum::Datum from the specified code.

Parameters
- code: Object code allocated by authority.

Exceptions
- NoSuchAuthorityCodeException:
- FactoryException:

datum::GeodeticReferenceFrameNNPtr createGeodeticDatum (const std::string &code) const
Returns a datum::GeodeticReferenceFrame from the specified code.

Parameters
- code: Object code allocated by authority.

Exceptions
- NoSuchAuthorityCodeException:
- FactoryException:
Parameters
• code: Object code allocated by authority.

Exceptions
• NoSuchAuthorityCodeException:
• FactoryException:

datum::VerticalReferenceFrameNNPtr createVerticalDatum(const std::string &code) const
Returns a datum::VerticalReferenceFrame from the specified code.

Return object.
Parameters
• code: Object code allocated by authority.

Exceptions
• NoSuchAuthorityCodeException:
• FactoryException:

cs::CoordinateSystemNNPtr createCoordinateSystem(const std::string &code) const
Returns a cs::CoordinateSystem from the specified code.

Return object.
Parameters
• code: Object code allocated by authority.

Exceptions
• NoSuchAuthorityCodeException:
• FactoryException:

crs::GeodeticCRSNNPtr createGeodeticCRS(const std::string &code) const
Returns a crs::GeodeticCRS from the specified code.

Return object.
Parameters
• code: Object code allocated by authority.

Exceptions
• NoSuchAuthorityCodeException:
• FactoryException:

crs::GeographicCRSNNPtr createGeographicCRS(const std::string &code) const
Returns a crs::GeographicCRS from the specified code.

Return object.
Parameters
• code: Object code allocated by authority.

Exceptions
• NoSuchAuthorityCodeException:
• FactoryException:

crs::VerticalCRSNNPtr createVerticalCRS(const std::string &code) const
Returns a crs::VerticalCRS from the specified code.

Return object.
Parameters
• code: Object code allocated by authority.

Exceptions
• NoSuchAuthorityCodeException:
• FactoryException:

operation::ConversionNNPtr createConversion(const std::string &code) const
Returns a operation::Conversion from the specified code.
Return object.

Parameters
- code: Object code allocated by authority.

Exceptions
- NoSuchAuthorityCodeException:
- FactoryException:

```cpp
const crs::ProjectedCRSNNPtr createProjectedCRS(const std::string &code) const
```

Returns a `crs::ProjectedCRS` from the specified code.

Return object.

Parameters
- code: Object code allocated by authority.

Exceptions
- NoSuchAuthorityCodeException:
- FactoryException:

```cpp
const crs::CompoundCRSNNPtr createCompoundCRS(const std::string &code) const
```

Returns a `crs::CompoundCRS` from the specified code.

Return object.

Parameters
- code: Object code allocated by authority.

Exceptions
- NoSuchAuthorityCodeException:
- FactoryException:

```cpp
const crs::CRSNNPtr createCoordinateReferenceSystem(const std::string &code) const
```

Returns a `crs::CRS` from the specified code.

Return object.

Parameters
- code: Object code allocated by authority.

Exceptions
- NoSuchAuthorityCodeException:
- FactoryException:

```cpp
const operation::CoordinateOperationNNPtr createCoordinateOperation(const std::string &code, bool usePROJAlternativeGridNames) const
```

Returns a `operation::CoordinateOperation` from the specified code.

Return object.

Parameters
- code: Object code allocated by authority.
- usePROJAlternativeGridNames: Whether PROJ alternative grid names should be substituted to the official grid names.

Exceptions
- NoSuchAuthorityCodeException:
- FactoryException:
PROJ coordinate transformation software library, Release 6.3.1

std::vector<operation::CoordinateOperationNNPtr> createFromCoordinateReferenceSystemCodes(const std::string &sourceCRSCode, const std::string &targetCRSCode)

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.

Return  list of coordinate operations

Parameters
  • sourceCRSCode: Source CRS code allocated by authority.
  • targetCRSCode: Source CRS code allocated by authority.

Exceptions
  • NoSuchAuthorityCodeException:
  • FactoryException:

const std::string &getAuthority() const

Returns the authority name associated to this factory.

Return  name.

std::set<std::string> getAuthorityCodes(const ObjectType &type, bool allowDeprecated = true) const

Returns the set of authority codes of the given object type.

Return  the set of authority codes for spatial reference objects of the given type

Parameters
  • type: Object type.
  • allowDeprecated: whether we should return deprecated objects as well.

Exceptions
  • FactoryException:

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.

Return  description.

Parameters
  • code: Object code allocated by authority. (e.g. “4326”)

Exceptions
  • NoSuchAuthorityCodeException:
  • FactoryException:

std::list<AuthorityFactory::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.

Exceptions
• `FactoryException`:

```cpp
class DatabaseContextNNPtr & databaseContext() const

Returns the database context.
```
std::vector<operation::CoordinateOperationNNPtr> createFromCoordinateReferenceSystemCodes(const std::string &source-CR-Auth-Name, const std::string &source-CRSCode, const std::string &targetCR-Auth-Name, const std::string &targetCRSCode, bool use-PRO-JA-n-Grid-Names, bool discardIfMissing-Grid, bool discard-Superseded, bool tryReverse-Order = false, bool report-Only-Intersecting-Transformations)
Returns a list of coordinate operations 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 (ie 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.

**Return** list of coordinate operations

**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.
- `discardSuperseded`: Whether coordinate 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.

**Exceptions**

- `NoSuchAuthorityCodeException`
- `FactoryException`
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 discardSuperceded, const std::vector<std::pair<std::string, std::string>> &intermediateCRSAuthCodes, ObjectType allowedIntermediateTypes = ObjectType::CRS, const std::vector<std::string> &allowedAuthorities = std::vector<std::string>(), const metadata::ExtentPtr &intersectingExtent1 = nullptr, const metadata::ExtentPtr &intersectingExtent2 = nullptr)
Returns a list \texttt{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 (ie contrary to \texttt{createFromCoordinateReferenceSystemCodes()}, you do not need to call it with source\texttt{CRS} and target\texttt{CRS} switched)

If \texttt{getAuthority()} returns empty, then coordinate operations from all authorities are considered.

**Return** list of coordinate operations

**Parameters**

- \texttt{sourceCRSAuthName}: Authority name of \texttt{sourceCRSCode}
- \texttt{sourceCRSCode}: Source CRS code allocated by authority \texttt{sourceCRSAuthName}.
- \texttt{targetCRSAuthName}: Authority name of \texttt{targetCRSCode}
- \texttt{targetCRSCode}: Source CRS code allocated by authority \texttt{targetCRSAuthName}.
- \texttt{usePROJAUTHERNAMEAlternativeGridNames}: Whether PROJ alternative grid names should be substituted to the official grid names.
- \texttt{discardIfMissingGrid}: Whether coordinate operations that reference missing grids should be removed from the result set.
- \texttt{discardSuperseded}: Whether coordinate operations that are superseded (but not deprecated) should be removed from the result set.
- \texttt{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.
- \texttt{allowedIntermediateObjectType}: Restrict the type of the intermediate object considered. Only \texttt{ObjectType::CRS} and \texttt{ObjectType::GEOGRAPHIC_CRS} supported currently
- \texttt{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.
- \texttt{intersectingExtent1}: Optional extent that the resulting operations must intersect.
- \texttt{intersectingExtent2}: Optional extent that the resulting operations must intersect.

**Exceptions**

- \texttt{NoSuchAuthorityCodeException}:
- \texttt{FactoryException}:

```cpp
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)
```

Gets the official name from a possibly alias name.

**Return** official name (or empty if not found).

**Parameters**

- \texttt{aliasedName}: Alias name.
- \texttt{tableName}: Table name/category. Can help in case of ambiguities. Or empty otherwise.
- \texttt{source}: Source of the alias. Can help in case of ambiguities. Or empty otherwise.
- \texttt{tryEquivalentNameSpelling}: whether the comparison of \texttt{aliasedName} with the alt\_name column of the alis\_name table should be done with using \texttt{meta\_data::Identifier::isEquivalentName()} rather than strict string comparison;
- \texttt{outTableName}: Table name in which the official name has been found.
- \texttt{outAuthName}: Authority name of the official name that has been found.
- \texttt{outCode}: Code of the official name that has been found.

**Exceptions**

- \texttt{FactoryException}:
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 by their name.

Return list of matched objects.

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.

Exceptions

• FactoryException:

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.

Return list of (auth_name, code) of matched objects.

Parameters

• name: Searched name.
• approximateMatch: Whether approximate name identification is allowed.

Exceptions

• FactoryException:

Public Static Functions

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 is called.

Return new AuthorityFactory.

Parameters

• context: Context.
• authorityName: Authority name.

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.

```cpp
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

\[\text{DatabaseContextNNPtr create}(\text{const std::string &databasePath} = \text{std::string()}, \text{const std::vector<std::string> &auxiliaryDatabasePaths} = \text{std::vector<std::string>()}, \text{PJ_CONTEXT *ctx} = \text{nullptr})\]

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.

Exceptions
• FactoryException:

\text{class FactoryException : public osgeo::proj::util::Exception}\n\text{#include <io.hpp> Exception thrown when a factory can’t create an instance of the requested object.}

Subclassed by \text{osgeo::proj::io::NoSuchAuthorityCodeException}

\text{class FormattingException : public osgeo::proj::util::Exception}\n\text{#include <io.hpp> Exception possibly thrown by IWKTExportable::exportToWKT() or IPROJStringExportable::exportToPROJString().}

\text{class IJSONExportable}\n\text{#include <io.hpp> Interface for an object that can be exported to JSON.}

Subclassed by \text{osgeo::proj::crs::CRS, osgeo::proj::cs::CoordinateSystem, osgeo::proj::cs::CoordinateSystemAxis}, \text{osgeo::proj::datum::Datum, osgeo::proj::datum::Datum Ensemble, 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

\text{std::string exportToJSON (JSONFormatter *formatter) const}\nBuilds a JSON representation. May throw a FormattingException

\text{class IPROJStringExportable}\n\text{#include <io.hpp> Interface for an object that can be exported to a PROJ string.}

Subclassed by \text{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.

Return a PROJ string.

Parameters

- formatter: PROJ string formatter.

Exceptions

- FormattingException:

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 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)*

Whether to use multi line output or not.

*JSONFormatter &setIndentationWidth (int width)*

Set number of spaces for each indentation level (defaults to 4).

*JSONFormatter &setSchema (const std::string &schema)*

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

*JSONFormatterNNPtr create (DatabaseContextPtr dbContext = nullptr)*

Constructs a new formatter.

A formatter can be used only once (its internal state is mutated)

Return new formatter.

*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.

*class ParsingException : public osgeo::proj::util::Exception*

#include <io.hpp> Exception possibly thrown by WKTNode::createFrom() or WKT-Parser::createFromWKT().

*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 Convention*

PROJ variant.

*Values:*

*PROJ_5*

PROJ v5 (or later versions) string.

*PROJ_4*

PROJ v4 string as output by GDAL exportToProj4()
Public Functions

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

PROJStringFormatterNNPtr create (Convection 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 behaviour can be adjusted with the different setters.
Return new formatter.
Parameters
• conventionIn: PROJ string flavor. Defaults to Convention::PROJ_5
• dbContext: Database context (can help to find alternative grid names). May be nullptr

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.

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 CoordinateOperation.

Exceptions
• 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

```plaintext
enum Convention_
    WKT variant.

Values:

 - WKT2
    Full WKT string, conforming to ISO 19162:2015(E) / OGC 12-063r5 (_WKT2_2015) with all possible nodes and new keyword names.

 - _WKT2_2015 = WKT2

 - 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.

 - _WKT2_2015_SIMPLIFIED = WKT2_SIMPLIFIED

 - WKT2_2019
    Full WKT 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.

 - _WKT2_2018 = _WKT2_2019
    Deprecated alias for _WKT2_2019

 - _WKT2_2019_SIMPLIFIED
    with the simplification rule of WKT2_SIMPLIFIED

 - _WKT2_2018_SIMPLIFIED = _WKT2_2019_SIMPLIFIED
    Deprecated alias for _WKT2_2019_SIMPLIFIED

 - _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.

 - _WKT1_ESRI
    WKT1 as traditionally output by ESRI software, deriving from OGC 99-049.

enum OutputAxisRule
    Rule for output AXIS nodes

Values:

 - YES
    Always include AXIS nodes

 - NO
    Never include AXIS nodes

 - _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)`

Whether to use multi line output or not.

`WKTFormatter &setIndentationWidth (int width)`

Set number of spaces for each indentation level (defaults to 4).

`WKTFormatter &setOutputAxis (OutputAxisRule outputAxis)`

Set whether AXIS nodes should be output.

`WKTFormatter &setStrict (bool strict)`

Set whether the formatter should operate on strict more or not.

The default is strict mode, in which case a `FormatException` can be thrown.

`bool isStrict () const`  

Returns whether the formatter is in strict mode.

`const std::string &toString () const`  

Returns the WKT string from the formatter.

**Public Static Functions**

`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 behaviour can be adjusted with the different setters.

**Return** new formatter.

**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.

`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 behaviour can be adjusted with the different setters.

**Return** new formatter.

**Parameters**

- `other`: source formatter.

**class WKTNode**  

#include <io.hpp>  

Node in the tree-splitted WKT representation.
Public Functions

`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)`
Return the (occurrence-1)th sub-node of name `childName`.

Return the child, or `nullptr`.

Parameters
- `childName`: name of the child.
- `occurrence`: occurrence index (starting at 0)

`int countChildrenOfName(const std::string &childName) const`
Return the count of children of given name.

Return count

Parameters
- `childName`: name of the children to look for.

`std::string toString () const`
Return a WKT representation of the tree structure.

Public Static Functions

`WKTNodeNNPtrcreateFrom(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.

Exceptions
- `ParsingException`:

`class WKTParser`
`#include <io.hpp>` Parse a WKT string into the appropriate subclass of `util::BaseObject`. 
Public Types

enum WKTGuessedDialect
    Guessed WKT “dialect”

    Values:
    WKT2_2019  
        WKT2_2019
    WKT2_2018 = WKT2_2019
        Deprecated alias for WKT2_2019
    WKT2_2015  
        WKT2_2015
    WKT1_GDAL  
        WKT1
    WKT1_ESRI  
        ESRI variant of WKT1
    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.

BaseObjectNNPtrcreateFromWKT (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.

Exceptions

    • ParsingException:

WKTParser::WKTGuessedDialect guessDialect (const std::string &wkt)
    Guess the “dialect” of the WKT string.
10.5.4 Deprecated API

Contents

- Deprecated API
  - Introduction
  - Example
  - API Functions
    * `pj_transform`
    * `pj_init_plus`
    * `pj_free`
    * `pj_is_latlong`
    * `pj_is_geocent`
    * `pj_get_def`
    * `pj_latlong_from_proj`
    * `pj_set_finder`
    * `pj_set_searchpath`
    * `pj_deallocate_grids`
    * `pj_strerror`
    * `pj_get_errno_ref`
    * `pj_get_release`

10.5.4.1 Introduction

Procedure `pj_init()` selects and initializes a cartographic projection with its argument control parameters. `argc` is the number of elements in the array of control strings `argv` that each contain individual cartographic control keyword assignments (+ proj arguments). The list must contain at least the `proj=projection` and Earth's radius or elliptical parameters. If the initialization of the projection is successful a valid address is returned otherwise a NULL value.

The `pj_init_plus()` function operates similarly to `pj_init()` but takes a single string containing the definition, with each parameter prefixed with a plus sign. For example `+proj=utm +zone=11 +ellps=WGS84`.

Once initialization is performed either forward or inverse projections can be performed with the returned value of `pj_init()` used as the argument `proj`. The argument structure `projUV values u and v contain respective longitude and latitude or x and y. Latitude and longitude are in radians. If a projection operation fails, both elements of `projUV` are set to `HUGE_VAL` (defined in `math.h`).

Note: all projections have a forward mode, but some do not have an inverse projection. If the projection does not have an inverse the `projPJ` structure element `inv` will be NULL.

The `pj_transform` function may be used to transform points between the two provided coordinate systems. In addition to converting between cartographic projection coordinates and geographic coordinates, this function also takes care of datum shifts if possible between the source and destination coordinate system. Unlike `pj_fwd()` and `pj_inv()` it is also allowable for the coordinate system definitions (`projPJ *`) to be geographic coordinate...
systems (defined as +proj=latlong). The x, y and z arrays contain the input values of the points, and are replaced with the output values. The function returns zero on success, or the error number (also in pj_errno) on failure. Memory associated with the projection may be freed with pj_free().

10.5.4.2 Example

The following program reads latitude and longitude values in decimal degrees, performs Mercator projection with a Clarke 1866 ellipsoid and a 33° latitude of true scale and prints the projected cartesian values in meters:

```c
#include <proj_api.h>

main(int argc, char **argv) {
    projPJ pj_merc, pj_latlong;
    double x, y;
    if (!(pj_merc = pj_init_plus("+proj=merc +ellps=clrk66 +lat_ts=33")) )
        exit(1);
    if (!(pj_latlong = pj_init_plus("+proj=latlong +ellps=clrk66")) )
        exit(1);
    while (scanf("%lf %lf", &x, &y) == 2) {
        x *= DEG_TO_RAD;
        y *= DEG_TO_RAD;
        p = pj_transform(pj_latlong, pj_merc, 1, 1, &x, &y, NULL);
        printf("%.2f \t%.2f\n", x, y);
    }
    exit(0);
}
```

For this program, an input of -16 20.25 would give a result of -1495284.21 1920596.79.

10.5.4.3 API Functions

**pj_transform**

```c
int pj_transform( projPJ srcdefn, projPJ dstdefn, long point_count, int point_offset, double *x, double *y, double *z );
```

Transform the x/y/z points from the source coordinate system to the destination coordinate system.

- **srcdefn**: source (input) coordinate system.
- **dstdefn**: destination (output) coordinate system.
- **point_count**: the number of points to be processed (the size of the x/y/z arrays).
- **point_offset**: the step size from value to value (measured in doubles) within the x/y/z arrays - normally 1 for a packed array. May be used to operate on xyz interleaved point arrays.
- **x/y/z**: The array of X, Y and Z coordinate values passed as input, and modified in place for output. The Z may optionally be NULL.
- **return**: The return is zero on success, or a PROJ4 error code.
The *pj_transform()* function transforms the passed in list of points from the source coordinate system to the destination coordinate system. Note that geographic locations need to be passed in radians, not decimal degrees, and will be returned similarly. The z array may be passed as NULL if Z values are not available.

If there is an overall failure, an error code will be returned from the function. If individual points fail to transform - for instance due to being over the horizon - then those x/y/z values will be set to `HUGE_VAL` on return. Input values that are `HUGE_VAL` will not be transformed.

**pj_init_plus**

```c
projPJ pj_init_plus(const char *definition);
```

This function converts a string representation of a coordinate system definition into a projPJ object suitable for use with other API functions. On failure the function will return NULL and set pj_errno. The definition should be of the general form `+proj=tmerc +lon_0 +datum=WGS84`. Refer to PROJ.4 documentation and the Geodetic transformation notes for additional detail.

Coordinate system objects allocated with *pj_init_plus()* should be deallocated with *pj_free()*.

**pj_free**

```c
void pj_free( projPJ pj );
```

Frees all resources associated with pj.

**pj_is_latlong**

```c
int pj_is_latlong( projPJ pj );
```

Returns TRUE if the passed coordinate system is geographic (`proj=latlong`).

**pj_is_geocent**

```c
int pj_is_geocent( projPJ pj );
```

Returns TRUE if the coordinate system is geocentric (`proj=geocent`).

**pj_get_def**

```c
char *pj_get_def( projPJ pj, int options);
```

Returns the PROJ.4 initialization string suitable for use with *pj_init_plus()* that would produce this coordinate system, but with the definition expanded as much as possible (for instance `+init=` and `+datum=` definitions).
pjlatlong_from_proj

```c
projPJ pj_latlong_from_proj( projPJ pj_in );```

Returns a new coordinate system definition which is the geographic coordinate (lat/long) system underlying `pj_in`.

pj_set_finder

```c
void pj_set_finder( const char *(*new_finder)(const char *) );```

Install a custom function for finding init and grid shift files.

pj_set_searchpath

```c
void pj_set_searchpath ( int count, const char **path );```

Set a list of directories to search for init and grid shift files.

pj_deallocate_grids

```c
void pj_deallocate_grids( void );```

Frees all resources associated with loaded and cached datum shift grids.

pj_strerrno

```c
char *pj_strerrno( int );```

Returns the error text associated with the passed in error code.

pj_get_errno_ref

```c
int *pj_get_errno_ref( void );```

Returns a pointer to the global pj_errno error variable.

pj_get_release

```c
const char *pj_get_release( void );```

Returns an internal string describing the release version.
**Obsolete Functions**

XY pj_fwd( LP lp, PJ *P );
LP pj_inv( XY xy, PJ *P );
projPJ pj_init(int argc, char **argv);

### 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 `${PROJ4_LIBRARIES}` provided by the CMake configuration which comes with the library. Typical usage is:

```cpp
find_package(PROJ4)
target_link_libraries(MyApp ${PROJ4_LIBRARIES})
```

By adding the imported library target `${PROJ4_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

```cpp
include_directories(${PROJ4_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 `PROJ4_DIR`.

### 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: Low-level bindings and a Julian API over 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;
```
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	%.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=clrk66",
        "+proj=merc +ellps=clrlk66 +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;
    }
    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

<table>
<thead>
<tr>
<th>Old API functions</th>
<th>New API functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>pj_fwd</td>
<td>proj_trans()</td>
</tr>
<tr>
<td>pj_inv</td>
<td>proj_trans()</td>
</tr>
<tr>
<td>pj_fwd3</td>
<td>proj_trans()</td>
</tr>
<tr>
<td>pj_inv3</td>
<td>proj_trans()</td>
</tr>
<tr>
<td>pj_transform</td>
<td>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()</td>
</tr>
<tr>
<td>pj_init</td>
<td>proj_create() / proj_create_crs_to_crs()</td>
</tr>
<tr>
<td>pj_init2</td>
<td>proj_create() / proj_create_crs_to_crs()</td>
</tr>
<tr>
<td>pj_free</td>
<td>proj_destroy()</td>
</tr>
<tr>
<td>pj_is_latlong</td>
<td>proj_get_type()</td>
</tr>
<tr>
<td>pj_is_geocent</td>
<td>proj_get_type()</td>
</tr>
<tr>
<td>pj_get_def</td>
<td>proj_pj_info()</td>
</tr>
<tr>
<td>pj_get_def2</td>
<td>No direct equivalent, but can be accomplished by chaining proj_create(), proj_crs_get_horizontal_datum() and proj_create_geographic_crs_from_datum()</td>
</tr>
<tr>
<td>pj_set_finder</td>
<td>proj_context_set_file_finder()</td>
</tr>
<tr>
<td>pj_set_search</td>
<td>proj_context_set_search_paths()</td>
</tr>
<tr>
<td>pj_deallocate</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_strerror</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_get_errno</td>
<td>proj_errno()</td>
</tr>
<tr>
<td>pj_get_release</td>
<td>proj_info()</td>
</tr>
</tbody>
</table>

10.8. Version 4 to 6 API Migration
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 use 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>

int 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 %.2f
", x, y);
    }

    pj_free(pj_longlat);
    pj_free(pj_merc);
    return 0;
}
```

The same program implemented using PROJ v. 5:

```c
#include <proj.h>
```

(continues on next page)
main(int argc, char **argv) {
  PJ *P;
  PJCOORD 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	%.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 PJCOORD, 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

<table>
<thead>
<tr>
<th>Old API functions</th>
<th>New API functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>pj_fwd</td>
<td>proj_trans()</td>
</tr>
<tr>
<td>pj_inv</td>
<td>proj_trans()</td>
</tr>
<tr>
<td>pj_fwd3</td>
<td>proj_trans()</td>
</tr>
<tr>
<td>pj_inv3</td>
<td>proj_trans()</td>
</tr>
<tr>
<td>pj_transform</td>
<td>proj_trans_array or proj_trans_generic</td>
</tr>
<tr>
<td>pj_init</td>
<td>proj_create()</td>
</tr>
<tr>
<td>pj_init_plus</td>
<td>proj_create()</td>
</tr>
<tr>
<td>pj_free</td>
<td>proj_destroy()</td>
</tr>
<tr>
<td>pj_is_latlong</td>
<td>proj_angular_output()</td>
</tr>
<tr>
<td>pj_is_geocent</td>
<td>proj_angular_output()</td>
</tr>
<tr>
<td>pj_get_def</td>
<td>proj_pj_info()</td>
</tr>
<tr>
<td>pj_latlong_from_proj</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_set_finder</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_set_searchpath</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_deallocate_grids</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_strerror</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_get_errno_ref</td>
<td>proj_errno()</td>
</tr>
<tr>
<td>pj_get_release</td>
<td>proj_info()</td>
</tr>
</tbody>
</table>

The source code for PROJ is maintained in a [git repository on GitHub](https://github.com/PROJ- Webster/PROJ). Additionally, a collection of PROJ-compatible transformation grids are maintained in a separate [git repository](https://github.com/PROJ-Webster/PROJ-data).

**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 will be removed from PROJ in version 7.0.0 scheduled for release March 1st 2020.

**Attention:** With the introduction of PROJ 5, behavioural changes has been made to existing functionality. Consult *Known differences between versions* for the details.
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.

11.1 Communication channels

11.1.1 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

11.1.2 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.

11.1.3 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
11.2 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.

11.2.1 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.

11.2.2 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.
11.2.3 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.

11.2.4 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.

11.2.5 Code contributions

See Code contributions

11.2.5.1 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.

11.2.6 Additional Resources

• General GitHub documentation
• GitHub pull request documentation

11.2.7 Acknowledgements

The code contribution section of this CONTRIBUTING file is inspired by PDAL’s and the legalese section is modified from GDAL committer guidelines

11.3 Guidelines for PROJ code contributors

This is a guide for PROJ, casual or regular, code contributors.

11.3.1 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.

11.3.1.1 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
11.3.1.2 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:

<table>
<thead>
<tr>
<th>Wiz the bang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixes #123.</td>
</tr>
</tbody>
</table>

- PROJ developers will look at your patch and take an appropriate action.

11.3.1.3 Coding conventions

Programming language

PROJ is developed strictly in ANSI C 89.

Coding style

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.

File names

Files in which projections are implemented are prefixed with an upper-case PJ_ and most other files are prefixed with lower-case pj_. Some file deviate from this pattern, most of them dates back to the very early releases of PROJ. New contributions should follow the pj-prefix pattern. Unless there are obvious reasons not to.

11.3.2 Tools

11.3.2.1 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

```c
/* cppcheck-suppress duplicateBreak */
```

in the preceding line. Replace duplicateBreak with the actual name of the violated rule emitted by cppcheck.
11.3.2.2 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:

```bash
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:

```bash
./clang+llvm-6/bin/scan-build ./configure
```

Build under scan-build:

```bash
./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

```bash
./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!

11.3.2.3 Typo detection and fixes

Run `scripts/fix_typos.sh`

11.3.2.4 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
11.4 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.

11.4.1 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.

11.4.2 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

11.4.3 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.
11.4.4 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.

11.4.5 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.

11.4.6 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

11.5 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.

11.5.1 PROJ RFC 1: Project Committee Guidelines

Author Frank Warmerdam, Howard Butler
Contact howard@hobu.co
Status Passed
Last Updated 2018-06-08

11.5.1.1 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.

11.5.1.2 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

11.5.1.3 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.

11.5. Request for Comments
• 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.

11.5.1.4 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.

11.5.1.5 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.

11.5.1.6 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.

11.5.1.7 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.

11.5.1.8 Updates

June 2018

RFC 1 was ratified by the following members

11.5.2 PROJ RFC 2: Initial integration of “GDAL SRS barn” work

<table>
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11.5.2.1 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

11.5. Request for Comments
• management and query of a SQLite3 database of CRS and Coordinate Operation definition
• a C API binding part of those capabilities

11.5.2.2 Related standards

Consult Applicable standards
(They will be linked from the PROJ documentation)

11.5.2.3 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, InvalidValueType-Exception, 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, IdentifedObject, ObjectDomain, ObjectUsage

• osgeo::proj::cs: Coordinate systems and their axis
  Classes AxisDirection, Meridian, CoordinateSystemAxis, CoordinateSystem, SphericalCS, EllipsoidalCS, VerticalCS, CartesianCS, OrdinalCS, ParametricCS, TemporalCS, DateTimeTemporalCS, TemporaiCountCS, TemporalMeasureCS

• osgeo::proj::datum: Datum (the relationship of a coordinate system to the body)

• 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

• osgeo::proj::operation: Coordinate operations (relationship between any two coordinate reference systems)

524 Chapter 11. Community
PROJ coordinate transformation software library, Release 6.3.1

• 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 artifact 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:

```cpp
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));
```

(continues on next page)
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
11.5.2.4 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-useful comparison with a fixed snapshot of master branch

11.5.2.5 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.

### 11.5.2.6 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

```bash
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:
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=165.732,216.720,180.505,-0.6434,-0.4512,-0.0791,7.420400
  +a=6378388.0000 +rf=297.0000000000000 +lat_0=0.0000000000000000 +lon_0=-141.8000000000000
  +k_0=0.9996000000000000 +x_0=500000.0000000000000 +y_0=10000000.0000000000000
  +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=165.732,216.720,180.505,-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]],
        ...]]]}

(continues on next page)
ID["EPSG",8901]],
CONVERSION["unknown",
  METHOD["Transverse Mercator",
    ID["EPSG",9807]],
  PARAMETER["Latitude of natural origin",0,
    ANGLEUNIT["degree",0.0174532925199433],
    ID["EPSG",8801]],
  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,
Find transformations between 2 CRS

Between “Poland zone I” (based on Pulkovo 42 datum) and “UTM WGS84 zone 34N”

Summary view:

```bash
$ 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:

```bash
$ PROJ_LIB=data src/projinfo -s EPSG:2171 -t EPSG:32634 -c PROJ
```

PROJ string:

```
+proj=pipeline +step +proj=axisswap +order=2,1 +step +inv +proj=sterea +lat_0=50.625 +lon_0=21.0 +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 +convention=position_vector +step +inv +proj=cart +ellps=WGS84 +step +proj=utm +zone=34 +ellps=WGS84
```
11.5.2.7 Impacted files

New files (excluding makefile.am, CMakeLists.txt and other build infrastructure artifacts):

- **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 WKTCustom.
  - 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/**:  

11.5. Request for Comments
-- 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

11.5.2.8 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.)
11.5.2.9 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 the Sphinx extension Breathe, producing:

- One section with the C++ API
- One section with the C API

11.5.2.10 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.

11.5.2.11 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.

11.5.2.12 Runtime requirements

- libc++/libstdc++/MSVC runtime consistent with the compiler used
- libsqlite3 >= 3.7
### 11.5.2.13 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.

### 11.5.2.14 Future work

The work described in this RFC will be pursued in a number of directions. Non-exhaustively:

- Support for ESRI WKTI 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.

### 11.5.2.15 Adoption status

The RFC has been adopted with support from PSC members Kurt Schwehr, Kristian Evers, Howard Butler and Even Rouault.

### 11.5.3 PROJ RFC 3: Dependency management

**Author** Kristian Evers  
**Contact** kreve@sdfe.dk  
**Status** Adopted  
**Last Updated** 2019-01-16

#### 11.5.3.1 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.

### 11.5.3.2 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. :ref:`RFC2 <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.

### 11.5.3.3 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 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 aknowledges 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.

### 11.5.3.4 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.

### 11.5. Request for Comments
At the time of writing the minimum version required for SQLite is 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.

11.5.3.5 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 acceptance 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)

11.5.3.6 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

11.5.4 PROJ RFC 4: Remote access to grids and GeoTIFF grids

Author Even Rouault, Howard Butler

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Status Adopted

Implementation target PROJ 7

Last Updated 2020-01-10

11.5.4.1 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 be 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 necessarily “cloud optimized” for incremental access across a network.

### 11.5.4.2 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 an 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 behaviour.

### 11.5.4.3 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 \( \text{proj_context_set_enable_network}() \) through the \text{PROJ\_NETWORK=ON} environment variable, or the \text{network = on} setting of \text{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 \( \geq 7.29.0 \) (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 \text{proj_context_set_url_endpoint}() or through the \text{PROJ\_NETWORK\_ENDPOINT} environment variable.

The rationale for putting \text{proj.ini} in that location is that it is a well-known place by PROJ users, with the existing \text{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:

```c
/** 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 null character). *
 * @return a non-NULL opaque handle in case of success. */
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: close callback */
typedef void (*proj_network_close_cbk_type)(PJ_CONTEXT* ctx, PROJ_NETWORK_HANDLE* handle, void* user_data);
```

(continues on next page)
/** 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.
* @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 behaviour of the GDAL /vsicurl/ I/O layer. The plan is to mostly copy GDAL’s vsicurl implementation inside PROJ, with needed adjustments and proper namespaces of it.

A retry strategy (typically a delay with an exponential back-off and some random jitter) will be added to account for

11.5. Request for Comments
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 base-name 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

```c
/** 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. */
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.

```c
/** 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. */
```

(continues on next page)
The planned database structure is:

```sql
CREATE TABLE properties(
    url TEXT PRIMARY KEY NOT NULL,
    lastChecked TIMESTAMP NOT NULL,
    fileSize INTEGER NOT NULL,
    lastModified TEXT,
    etag TEXT
);

CREATE TABLE chunk_data(
    id INTEGER PRIMARY KEY AUTOINCREMENT CHECK (id > 0),
    data BLOB NOT NULL
);

CREATE TABLE chunks(
    id INTEGER PRIMARY KEY AUTOINCREMENT CHECK (id > 0),
```

(continues on next page)
The chunks table will store 16 KB chunks (or less for terminating chunks). The linked_chunks and linked_chunks_head_tail table will 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/a54ea98feed0a7593475b94de3a359e9e1fe8fddb/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 advertised 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)

11.5.4.4 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 mentionned 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 mentionned 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.

Description of the PROJ GeoTIFF format

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 refered 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 file 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 = PixelsIsPoint convention. This is the convention used by most existing grid formats currently. Note that GDAL typically use a PixelsIsArea 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 PixelsIsArea convention is shifted by a half-pixel towards the upper-left direction). Unspecified behaviour 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.

In the future, different values of SamplesPerPixel may be used to accommodate for other needs. For example for deformation models, SamplesPerPixel = 3 to combine 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 fo 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 fo 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 fo 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 maximize 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 an 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: \( \text{offset} + \text{scale} \times \text{raw_value_from_geotiff_file} \)

For a offset value of 1 and scaling of 2, the following payload should be stored:

```xml
<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 hgridshift 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 vgridshift 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 vgridshift 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 xyzgridshift 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 deformation method.

For example:

```xml
<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.

For example:

```xml
<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>
```

- 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)
Example


$ 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
Tag 33550: 0.100000,0.100000,0.000000
Tag 33922: 0.000000,0.000000,0.000000,-5.500000,52.000000,0.000000
Tag 34735: 1,1,1,3,1024,0,1,2,1025,0,1,2,1024,0,1,4275
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>
<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:
(continues on next page)
PROJ coordinate transformation software library, Release 6.3.1

(continued from previous page)

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'
Lower Left
( 5d30'
Upper Right
( 10d 6'
Lower Right
( 10d 6'
Center
( 2d18'

0.00"W,
0.00"W,
0.00"E,
0.00"E,
0.00"E,

52d 0'
40d54'
52d 0'
40d54'
46d27'

0.00"N)
0.00"N)
0.00"N)
0.00"N)
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",
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)
(continues on next page)

11.5. Request for Comments

557


**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 *Description of the PROJ GeoTIFF format*. 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 envisioned 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-resoluted 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.

Examples of multi-grid dataset


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/rouault/sample_proj_gtiff_grids/blob/master/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.

**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.

### 11.5.4.5 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 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.

### 11.5.4.6 Backward compatibility issues

None anticipated, except the removal of the (presumably little used) grid catalog functionality.
11.5.4.7 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.

11.5.4.8 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.

11.5.4.9 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.

11.5.4.10 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)

11.5.4.11 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

11.6 Conference
FOSS4G 2020 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 be held in Calgary, Canada, August 24th - August 29th, 2020.
12.1 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.

12.2 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 n°1:
unknown id, Inverse of UTM zone 32N + DKTM1, 0 m, World
PROJ string:
+proj=pipeline +inv +proj=utm +zone=32 +ellps=GRS80
+step +proj=tmerc +lat_0=0 +lon_0=9 +k=0.99998 +x_0=2000000 +y_0=-5000000 +ellps=GRS80
```

See the projinfo documentation for more info on how to use it.
12.3 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.

12.4 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.

12.5 How do I contribute to PROJ?

Any contributions from the PROJ community is welcome. See Contributing for more details.

12.6 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.

12.7 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.
12.8 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:

```bash
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]]
```
12.9 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.

12.10 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 behaviour of the software, e.g. “PROJ.4 strings” as seen in *projinfo* output.
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.


Symbols

+M=<value> command line option, 121
+W=<value> command line option, 121, 137
+abridged command line option, 270
+alpha=<value> command line option, 175, 179, 227
+aperture=<value> command line option, 129
+approx command line option, 215, 229
+azi=<value> command line option, 129, 133, 222
+convention=coordinate_frame/position_vector command line option, 262, 271
+czech command line option, 132
+da=<value> command line option, 270
+datum=<value> command line option, 251
+deg=<value> command line option, 267
+df=<value> command line option, 270
+dh=<value> command line option, 261
+dlat=<value> command line option, 261
+dlon=<value> command line option, 261
+drx=<value> command line option, 263
+dry=<value>
  command line option, 263
+drz=<value>
  command line option, 263
+ds=<value>
  command line option, 263
+dt=<value>
  command line option, 259
+dx=<value>
  command line option, 263, 270
+dy=<value>
  command line option, 263, 270
+dz=<value>
  command line option, 263, 270
+ellps=<value>
  command line option, 62, 64, 69, 76, 78, 81, 87, 101, 103, 104, 111, 114, 119, 124, 126, 135, 137, 141–144, 146, 153, 156, 158, 186, 198, 200, 202, 204, 206, 208, 216, 224, 227, 229, 243, 249, 251, 267, 270
+exact
  command line option, 263
+fwd_c=<c_1, c_2, ..., c_N>
  command line option, 268
+fwd_origin=<northing, easting>
  command line option, 268
+fwd_u=<u_11, u_12, ..., u_ij, ..., u_mn>
  command line option, 268
+fwd_v=<v_11, v_12, ..., v_ij, ..., v_mn>
  command line option, 268
+gamma=<value>
  command line option, 179
+grids=<list>
  command line option, 273, 275
+guam
  command line option, 64
+h=<value>
  command line option, 114, 169, 222
+h_0=<value>
  command line option, 202
+inv
  command line option, 277
+inv_c=<c_1, c_2, ..., c_N>
  command line option, 268
+inv_origin=<northing, easting>
  command line option, 268
+inv_u=<u_11, u_12, ..., u_ij, ..., u_mn>
  command line option, 268
+inv_v=<v_11, v_12, ..., v_ij, ..., v_mn>
  command line option, 268
+k_0=<value>
  command line option, 64, 87, 133, 141, 153, 175, 179, 204, 208, 210, 216, 219
+lat_0=<value>
  command line option, 64, 66, 69, 81, 100, 130, 133, 135, 141, 142, 171, 179, 181, 198, 206, 208, 215, 224
+lat_1=<value>
command line option, 61, 76, 85, 89, 101, 105, 127, 137, 141, 143, 144, 161, 162, 164, 174, 175, 179, 184, 212, 220, 235, 247
+lat_2=<value>
   command line option, 61, 89, 105, 127, 141, 161, 162, 164, 174, 175, 179, 184, 212, 222, 235
+lat_3=<value>
   command line option, 89
+lat_b
   command line option, 66
+lat_ts=<value>
   command line option, 64, 87, 100, 153, 201, 206, 238, 245, 246
+lon_0=<value>
+lon_1=<value>
   command line option, 89, 174, 175, 179, 220
+lon_2=<value>
   command line option, 89, 174, 175, 179, 220
+lon_3=<value>
   command line option, 89
+lonc=<value>
   command line option, 175, 179
+lsat=<value>
   command line option, 146
+m=<value>
   command line option, 176
+mode=<string>
   command line option, 129
+multiplier=<value>
   command line option, 275
+n=<value>
   command line option, 109, 176, 226, 228
+no_cut
   command line option, 66
+no_off
   command line option, 179
+no_rot
   command line option, 179
+north_square
   command line option, 126
+ns
   command line option, 73
+o_alpha=<value>
   command line option, 174
+o_lat_c=<value>
   command line option, 174
+o_lat_p=<latitude>
   command line option, 174
+o_lon_c=<value>
   command line option, 173
+o_lon_p=<longitude>
   command line option, 174
+o_proj=<projection>
command line option, 173
+omit_fwd
command line option, 277
+omit_inv
command line option, 278
+order=<list>
command line option, 248
+orient=<string>
command line option, 129
+path=<value>
command line option, 146, 158
+phdg_0=<value>
command line option, 202
+plat_0=<value>
command line option, 202
+plon_0=<value>
command line option, 202
+px=<value>
command line option, 271
+py=<value>
command line option, 271
+pz=<value>
command line option, 271
+q=<value>
command line option, 227
+range=<value>
command line option, 268
+resolution=<value>
command line option, 129
+rot_xy
command line option, 124
+rx=<value>
command line option, 263, 271
+ry=<value>
command line option, 263, 271
+rz=<value>
command line option, 263, 271
+s11=<value>
command line option, 257
+s12=<value>
command line option, 257
+s13=<value>
command line option, 257
+s21=<value>
command line option, 257
+s22=<value>
command line option, 257
+s23=<value>
command line option, 257
+s31=<value>
command line option, 257
+s32=<value>
command line option, 257
+s33=<value>

576 Index
command line option, 258
+s=<value>
   command line option, 263, 271
+south
   command line option, 143, 224, 229
+south_square
   command line option, 126
+step
   command line option, 277
+sweep=<axis>
   command line option, 114
+t_epoch=<time>
   command line option, 273, 275
+t_epoch=<value>
   command line option, 259, 263
+t_final=<time>
   command line option, 273, 275
+t_in=<unit>
   command line option, 255
+t_out=<unit>
   command line option, 255
+theta=<value>
   command line option, 176, 263
+tilt=<value>
   command line option, 222
+toff=<value>
   command line option, 257
+towgs84=<list>
   command line option, 251
+transpose
   command line option, 263
+tscale=<value>
   command line option, 258
+uneg
   command line option, 268
+v_1
   command line option, 253, 254
+v_2
   command line option, 253, 254
+v_3
   command line option, 253, 254
+v_4
   command line option, 253, 254
+vneg
   command line option, 268
+x=<value>
   command line option, 263, 271
+x_0=<value>
+xoff=<value>
   command line option, 257
+xy_grids=<list>
  command line option, 259
+xy_in=<unit> or <conversion_factor>
  command line option, 255
+xy_out=<unit> or <conversion_factor>
  command line option, 255
+y=<value>
  command line option, 263, 271
+y_0=<value>
+yoff=<value>
  command line option, 257
+z=<value>
  command line option, 263, 271
+z_grids=<list>
  command line option, 259
+z_in=<unit> or <conversion_factor>
  command line option, 255
+z_out=<unit> or <conversion_factor>
  command line option, 255
+zoff=<value>
  command line option, 257
+zone=<value>
  command line option, 229
-E
  cs2cs command line option, 44
  proj command line option, 53
-F <format>
  geod command line option, 46
-I
  cct command line option, 41
  cs2cs command line option, 43
  geod command line option, 46
  proj command line option, 53
-S
  proj command line option, 53
-V
  proj command line option, 54
-W<n>
  cs2cs command line option, 44
  geod command line option, 46
  proj command line option, 54
--3d
  projinfo command line option, 58
--area name_or_code
  projinfo command line option, 56
--aux-db-path path
  projinfo command line option, 58
--bbox west_long,south_lat,east_long,north_lat
  projinfo command line option, 56
--boundcrs-to-wgs84

projinfo command line option, 58
--c-ify
  projinfo command line option, 58
--crs-extent-use none|both|intersection|smallest
  projinfo command line option, 57
--grid-check none|discard_missing|sort
  projinfo command line option, 57
--height=<height>
  cct command line option, 41
--help
  command line option, 48
--identify
  projinfo command line option, 58
--list
  command line option, 48
--main-db-path path
  projinfo command line option, 58
--output <file>
  command line option, 48
--output=<output file name>
  cct command line option, 41
--pivot-crs always|if_no_direct_transformation|never|{auth:code[,auth:code]*}
  projinfo command line option, 57
--quiet
  command line option, 48
--single-line
  projinfo command line option, 58
--skip-lines=<n>
  cct command line option, 41
--spatial-test contains|intersects
  projinfo command line option, 57
--summary
  projinfo command line option, 56
--time=<time>
  cct command line option, 41
--verbose
  cct command line option, 42
  command line option, 48
--version
  cct command line option, 42
  command line option, 48
-a
  geod command line option, 46
-b
  proj command line option, 53
-c <x,y,z,t>
  cct command line option, 41
-d <n>
  cct command line option, 41
  cs2cs command line option, 43
  proj command line option, 53
-e <string>
  cs2cs command line option, 43
  proj command line option, 53
-f <format>
  cs2cs command line option, 44
  geod command line option, 46
  proj command line option, 54
-h
  command line option, 48
-i
  proj command line option, 53
-k crs|operation|ellipsoid
  projinfo command line option, 56
-l
  command line option, 48
-lp
  cs2cs command line option, 44
  proj command line option, 53
-l<|=id>
  cs2cs command line option, 44
  proj command line option, 53
-lid
  cs2cs command line option, 44
  proj command line option, 53
-le
  cs2cs command line option, 44
  geod command line option, 46
  proj command line option, 53
-lp
  cs2cs command line option, 44
  proj command line option, 53
-lu
  cs2cs command line option, 44
  geod command line option, 46
  proj command line option, 53
-m <mult>
  proj command line option, 54
-o
  proj command line option, 53
-o <file>
  command line option, 48
-o <output file name>
  cct command line option, 41
-o formats
  projinfo command line option, 56
-p
  geod command line option, 46
-q
  command line option, 48
  projinfo command line option, 56
-r
  cs2cs command line option, 44
  proj command line option, 53
-s
  cs2cs command line option, 44
  proj command line option, 53
-s <n>
cct command line option, 41
-show-superseded
  projinfo command line option, 57
-t <time>
  cct command line option, 41
-t<a>
  cs2cs command line option, 43
  geod command line option, 46
  proj command line option, 53
-v
  cct command line option, 42
  command line option, 48
  cs2cs command line option, 44
  proj command line option, 54
-w<n>
  cs2cs command line option, 44
  geod command line option, 46
  proj command line option, 54
-z <height>
  cct command line option, 41

A

accept <x y [z [t]]>
  command line option, 49

C

cct, 41

A

accept <x y [z [t]]>
  command line option, 49

C

cct command line option
  -I, 41
  --height=<height>, 41
  --output=<output file name>, 41
  --skip-lines=<n>, 41
  --time=<time>, 41
  --verbose, 42
  --version, 42
  -c <x, y, z, t>, 41
  -d <n>, 41
  -o <output file name>, 41
  -s <n>, 41
  -t <time>, 41
  -v, 42
  -z <height>, 41

command line option
  +M=<value>, 121
  +R=<value>, 62, 64, 66, 69–71, 73, 75, 76, 78, 81, 84, 85, 87, 89, 90, 92–99, 101, 103, 104, 106–110, 114–
  116, 118, 121, 124, 127, 128, 130, 131, 133, 136, 137, 139, 141, 143, 144, 146, 147, 149–151, 153, 157, 158,
  227, 228, 231, 233, 234, 236–241, 244–247
  +W=<value>, 121, 137
  abridged, 270
  +alpha=<value>, 175, 179, 227
  +aperture=<value>, 129
  +approx, 215, 229
  +azi=<value>, 129, 133, 222
+convention=coordinate_frame/position_vector, 262, 271
+czech, 132
+da=<value>, 270
+datum=<value>, 251
+deg=<value>, 267
+df=<value>, 270
+dh=<value>, 261
+dlat=<value>, 261
+dlon=<value>, 261
+drx=<value>, 263
+dry=<value>, 263
+drz=<value>, 263
+ds=<value>, 263
+dt=<value>, 259
+dx=<value>, 263, 270
+dy=<value>, 263, 270
+dz=<value>, 263, 270
+ellps=<value>, 62, 64, 69, 76, 78, 81, 87, 101, 103, 104, 111, 114, 119, 124, 126, 135, 137, 141–144, 146, 153, 156, 158, 186, 198, 200, 202, 204, 206, 208, 216, 224, 227, 229, 243, 249, 251, 267, 270
+exact, 263
+fwd_c=<c_1, c_2,..., c_N>, 268
+fwd_origin=<northing, easting>, 268
+fwd_u=<u_11, u_12,..., u_ij,..., u_mn>, 268
+fwd_v=<v_11, v_12,..., v_ij,..., v_mn>, 268
+gamma=<value>, 179
+grids=<list>, 273, 275
+guam, 64
+h=<value>, 114, 169, 222
+h_0=<value>, 202
+inv, 277
+inv_c=<c_1, c_2,..., c_N>, 268
+inv_origin=<northing, easting>, 268
+inv_u=<u_11, u_12,..., u_ij,..., u_mn>, 268
+inv_v=<v_11, v_12,..., v_ij,..., v_mn>, 268
+k_0=<value>, 64, 67, 131, 141, 153, 175, 179, 204, 208, 210, 216, 219
+lat_0=<value>, 64, 66, 69, 81, 100, 130, 133, 135, 141, 142, 171, 179, 181, 198, 206, 208, 215, 224
+lat_1=<value>, 61, 76, 85, 89, 101, 105, 127, 137, 141, 143, 144, 161, 162, 164, 174, 175, 179, 184, 212, 220, 235, 247
+lat_2=<value>, 61, 89, 101, 105, 127, 141, 161, 162, 164, 174, 175, 179, 184, 212, 222, 235
+lat_3=<value>, 89
+lat_b, 66
+lat_ts=<value>, 64, 67, 100, 153, 201, 206, 238, 245, 246
+lon_1=<value>, 89, 174, 175, 179, 220
+lon_2=<value>, 89, 174, 175, 179, 220
+lon_3=<value>, 89
+lonb=<value>, 175, 179
+lsat=<value>, 146
+m=<value>, 176
+mode=<string>, 129
+multiplier=<value>, 275
PROJ coordinate transformation software library, Release 6.3.1

+n=<value>, 109, 176, 226, 228
+no_cut, 66
+no_off, 179
+no_rot, 179
+north_square, 126
+ns, 73
+o_alpha=<value>, 174
+o_lat_c=<value>, 174
+o_lat_p=<latitude>, 173
+o_lon_c=<value>, 174
+o_lon_p=<longitude>, 173
+o_proj=<projection>, 173
+omit_fwd, 277
+omit_inv, 278
+order=<list>, 248
+orient=<string>, 129
+path=<value>, 146, 158
+phdg_0=<value>, 202
+plat_0=<value>, 202
+plon_0=<value>, 202
+px=<value>, 271
+py=<value>, 271
+pz=<value>, 271
+q=<value>, 227
+range=<value>, 268
+resolution=<value>, 129
+rot_xy, 124
+rx=<value>, 263, 271
+ry=<value>, 263, 271
+rz=<value>, 263, 271
+s11=<value>, 257
+s12=<value>, 257
+s13=<value>, 257
+s21=<value>, 257
+s22=<value>, 257
+s23=<value>, 257
+s31=<value>, 257
+s32=<value>, 257
+s33=<value>, 258
+s=<value>, 263, 271
+south, 143, 224, 229
+south_square, 126
+step, 277
+sweep=<axis>, 114
+t_epoch=<time>, 273, 275
+t_epoch=<value>, 259, 263
+t_final=<time>, 273, 275
+t_in=<unit>, 255
+t_out=<unit>, 255
+theta=<value>, 176, 263
+tilt=<value>, 222
+toff=<value>, 257
+towgs84=<list>, 251
+transpose, 263
+tscale=<value>, 258
+uneg, 268
+v_1, 253, 254
+v_2, 253, 254
+v_3, 253, 254
+v_4, 253, 254
+vneg, 268
+x=<value>, 263, 271
+xoff=<value>, 257
+xy_grids=<list>, 259
+xy_in=<unit> or <conversion_factor>, 255
+xy_out=<unit> or <conversion_factor>, 255
+y=<value>, 263, 271
+yoff=<value>, 257
+z=<value>, 263, 271
+z_grids=<list>, 259
+z_in=<unit> or <conversion_factor>, 255
+z_out=<unit> or <conversion_factor>, 255
+zoff=<value>, 257
+zone=<value>, 229
--help, 48
--list, 48
--output <file>, 48
--quiet, 48
--verbose, 48
--version, 48
-h, 48
-l, 48
-o <file>, 48
-q, 48
-v, 48
accept <x y [z [t]]>, 49
direction <direction>, 50
echo <text>, 51
expect <x y [z [t]]> | <error code>, 49
ignore <error code>, 51
operation <+args>, 49
require_grid <grid_name>, 51
roundtrip <n> <tolerance>, 50
skip, 51
tolerance <tolerance>, 50
cs2cs command line option
-E, 44
-I, 43
-W<n>, 44
-d <n>, 43
-e <string>, 43
-f <format>, 44
-1p, 44
-1<e[^id]>, 44
-1d, 44
-1e, 44
-1p, 44
-1u, 44
-r, 44
-s, 44
-t<a>, 43
-v, 44
-w<n>, 44

D
direction <direction>
   command line option, 50

E
echo <text>
   command line option, 51
environment variable
   PROJ_DEBUG, 34
   PROJ_LIB, 6, 7, 9, 22, 23, 33, 34, 45, 54, 57, 295, 566
expect <x y [z [t]]> | <error code>
   command line option, 49

G
general_api_design (C++ type), 357
general_properties (C++ type), 357
GeoAPI (C++ type), 359
geod command line option
-1F <format>, 46
-1I, 46
-1W<n>, 46
-1a, 46
-1f <format>, 46
-1e, 46
-1p, 46
-1u, 46
-t<a>, 46
-w<n>, 46
gie, 48

I
ignore <error code>
   command line option, 51
iso19111_types::PJ_CATEGORY (C++ enum), 321
iso19111_types::PJ_CATEGORY_COORDINATE_OPERATION (C++ enumerator), 321
iso19111_types::PJ_CATEGORY_CRS (C++ enumerator), 321
iso19111_types::PJ_CATEGORY_DATUM (C++ enumerator), 321
iso19111_types::PJ_CATEGORY_ELLIPSOID (C++ enumerator), 321
iso19111_types::PJ_CATEGORY_PRIME_MERIDIAN (C++ enumerator), 321
iso19111_types::PJ_COMP_EQUIVALENT (C++ enumerator), 322
PROJ coordinate transformation software library, Release 6.3.1

iso19111_types::PJ_COMP_EQUVALENT_EXCEPT_AXIS_ORDER_GEOGCRS (C++ enumerator), 322
iso19111_types::PJ_COMP STRICT (C++ enumerator), 322
iso19111_types::PJ_COMPARISON_CRITERION (C++ enum), 322
iso19111_types::PJ_COORDINATE_SYSTEM TYPE (C++ enum), 324
iso19111_types::PJ_CRS EXTENT BOTH (C++ enumerator), 323
iso19111_types::PJ_CRS EXTENT_INTERSECTION (C++ enumerator), 323
iso19111_types::PJ_CRS EXTENT NONE (C++ enumerator), 323
iso19111_types::PJ_CRS EXTENT_SMALLEST (C++ enumerator), 323
iso19111_types::PJ_CS_TYPE CARTESIAN (C++ enumerator), 324
iso19111_types::PJ_CS_TYPE DATETIMETEMPORAL (C++ enumerator), 324
iso19111_types::PJ_CS_TYPE ELLIPSOIDAL (C++ enumerator), 324
iso19111_types::PJ_CS_TYPE ORDINAL (C++ enumerator), 324
iso19111_types::PJ_CS_TYPE PARAMETRIC (C++ enumerator), 324
iso19111_types::PJ_CS_TYPE SPHERICAL (C++ enumerator), 324
iso19111_types::PJ_CS_TYPE TEMPORALCOUNT (C++ enumerator), 324
iso19111_types::PJ_CS_TYPE TEMPORALMEASURE (C++ enumerator), 324
iso19111_types::PJ_CS_TYPE UNKNOWN (C++ enumerator), 324
iso19111_types::PJ_CS_TYPE_VERTICAL (C++ enumerator), 324
iso19111_types::PJ_GUESSED NOT WKT (C++ enumerator), 321
iso19111_types::PJ_GUESSED WKT1 ESRI (C++ enumerator), 321
iso19111_types::PJ_GUESSED WKT1 GDAL (C++ enumerator), 321
iso19111_types::PJ_GUESSED WKT2 2015 (C++ enumerator), 321
iso19111_types::PJ_GUESSED WKT2 2018 (C++ enumerator), 321
iso19111_types::PJ_GUESSED WKT2 2019 (C++ enumerator), 321
iso19111_types::PJ_GUESSED_WKT_DIALECT (C++ enum), 321
iso19111_types::PJ_PROJ 4 (C++ enumerator), 324
iso19111_types::PJ_PROJ 5 (C++ enumerator), 324
iso19111_types::PJ_PROJ STRING TYPE (C++ enum), 324
iso19111_types::PJ_TYPE (C++ enum), 321
iso19111_types::PJ_TYPE_BOUND_CRS (C++ enumerator), 322
iso19111_types::PJ_TYPE_COMPOUND_CRS (C++ enumerator), 322
iso19111_types::PJ_TYPE_CONCATENATED_OPERATION (C++ enumerator), 322
iso19111_types::PJ_TYPE_CONVERSION (C++ enumerator), 322
iso19111_types::PJ_TYPE_CRS (C++ enumerator), 322
iso19111_types::PJ_TYPE_DISTRIBUTED_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOCENTRIC_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOCENTRIC_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGRAPHIC_2D_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGRAPHIC_3D_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGRAPHIC_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGRAPHIC_REFERENCE_FRAME (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGEOGRAPHIC_2D_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGEOGRAPHIC_3D_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGEOGRAPHIC_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGEOGRAPHIC_REFERENCE_FRAME (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGEOGRAPHIC_2D_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGEOGRAPHIC_3D_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGEOGRAPHIC_CRS (C++ enum), 322
iso19111_types::PJ_TYPE_GEOGEOGRAPHIC_REFERENCE_FRAME (C++ enum), 322
iso19111_types::PJ_WKT1_ESRI (C++ enumerator), 323
iso19111_types::PJ_WKT1_GDAL (C++ enumerator), 323
iso19111_types::PJ_WKT2_2015 (C++ enumerator), 323
iso19111_types::PJ_WKT2_2015_SIMPLIFIED (C++ enumerator), 323
iso19111_types::PJ_WKT2_2018 (C++ enumerator), 323
iso19111_types::PJ_WKT2_2018_SIMPLIFIED (C++ enumerator), 323
iso19111_types::PJ_WKT2_2019 (C++ enumerator), 323
iso19111_types::PJ_WKT2_2019_SIMPLIFIED (C++ enumerator), 323
iso19111_types::PJ_WKT_TYPE (C++ enum), 323
iso19111_types::PJ_WKT_TYPE (C++ enum), 323
iso19111_types::PROJ_CRS_EXTENT_USE (C++ enum), 323
iso19111_types::PROJ_CRS_EXTENT_USE (C++ enum), 323
iso19111_types::PROJ_GRID_AVAILABILITY_DISCARD_OPERATION_IF_MISSING_GRID (C++ enumerator), 323
iso19111_types::PROJ_GRID_AVAILABILITY_IGNORED (C++ enum), 323
iso19111_types::PROJ_GRID_AVAILABILITY_USE (C++ enum), 323
iso19111_types::PROJ_GRID_AVAILABILITY_USED_FOR_SORTING (C++ enum), 323
iso19111_types::PROJ_INTERMEDIATE_CRS_USE (C++ enum), 324
iso19111_types::PROJ_INTERMEDIATE_CRS_USE_ALWAYS (C++ enum), 324
iso19111_types::PROJ_INTERMEDIATE_CRS_USE_IF_NO_DIRECT_TRANSFORMATION (C++ enum), 324
iso19111_types::PROJ_INTERMEDIATE_CRS_USE_NEVER (C++ enum), 324
iso19111_types::PROJ_SPATIAL_CRITERION (C++ enum), 324
iso19111_types::PROJ_SPATIAL_CRITERION_PARTIAL_INTERSECTION (C++ enum), 324
iso19111_types::PROJ_SPATIAL_CRITERION STRICT_CONTAINMENT (C++ enum), 324
ISO_19111 (C++ type), 358
ISO_19111_2007 (C++ type), 359
ISO_19111_2019 (C++ type), 358
ISO_19115 (C++ type), 359

operation <+args>
    command line option, 49
osgeo::proj::common (C++ type), 360
osgeo::proj::common::Angle (C++ class), 360
osgeo::proj::common::Angle::Angle (C++ function), 360
osgeo::proj::common::ANGULAR (C++ enumerator), 365
osgeo::proj::common::DataEpoch (C++ class), 360
osgeo::proj::common::DataEpoch::coordinateEpoch (C++ function), 361
osgeo::proj::common::DateTime (C++ class), 361
osgeo::proj::common::DateTime::create (C++ function), 361
osgeo::proj::common::DateTime::isISO_8601 (C++ function), 361
osgeo::proj::common::DateTime::toString (C++ function), 361
osgeo::proj::common::IdentifiedObject (C++ class), 361
osgeo::proj::common::IdentifiedObject::alias (C++ function), 362
osgeo::proj::common::IdentifiedObject::ALIAS_KEY (C++ member), 362
osgeo::proj::common::IdentifiedObject::aliases (C++ function), 361
osgeo::proj::common::IdentifiedObject::DEPRECATED_KEY (C++ member), 362
osgeo::proj::common::IdentifiedObject::getEPSGCode (C++ function), 362
osgeo::proj::common::IdentifiedObject::identifiers (C++ function), 361
osgeo::proj::common::IdentifiedObject::IDENTIFIERS_KEY (C++ member), 362
osgeo::proj::common::IdentifiedObject::isDeprecated (C++ function), 362
osgeo::proj::common::IdentifiedObject::name (C++ function), 361
osgeo::proj::common::IdentifiedObject::NAME_KEY (C++ member), 362
osgeo::proj::common::IdentifiedObject::nameStr (C++ function), 361
osgeo::proj::common::IdentifiedObject::remarks (C++ function), 361

Index 587
osgeo::proj::common::IdentifiedObject::REMARKS_KEY (C++ member), 362
osgeo::proj::common::IdentifiedObjectNNPtr (C++ type), 360
osgeo::proj::common::IdentifiedObjectPtr (C++ type), 360
osgeo::proj::common::Length (C++ class), 362
osgeo::proj::common::Length::Length (C++ function), 363
osgeo::proj::common::LINEAR (C++ enumerator), 365
osgeo::proj::common::Measure (C++ class), 363
osgeo::proj::common::Measure::_isEquivalentTo (C++ function), 363
osgeo::proj::common::Measure::convertToUnit (C++ function), 363
osgeo::proj::common::Measure::getSIValue (C++ function), 363
osgeo::proj::common::Measure::operator== (C++ function), 363
osgeo::proj::common::Measure::operator!= (C++ function), 363
osgeo::proj::common::Measure::unit (C++ function), 363
osgeo::proj::common::Measure::value (C++ function), 363
osgeo::proj::common::NONE (C++ enumerator), 365
osgeo::proj::common::ObjectDomain (C++ class), 364
osgeo::proj::common::ObjectDomain::create (C++ function), 364
osgeo::proj::common::ObjectDomain::domainOfValidity (C++ function), 364
osgeo::proj::common::ObjectDomain::scope (C++ function), 364
osgeo::proj::common::ObjectDomainNNPtr (C++ type), 360
osgeo::proj::common::ObjectDomainPtr (C++ type), 360
osgeo::proj::common::PARAMETRIC (C++ enumerator), 365
osgeo::proj::common::Scale (C++ class), 365
osgeo::proj::common::SCALE (C++ enumerator), 365
osgeo::proj::common::Scale::Scale (C++ function), 365
osgeo::proj::common::TIME (C++ enumerator), 365
osgeo::proj::common::Type (C++ enum), 365
osgeo::proj::common::UnitOfMeasure::ARC_SECOND (C++ member), 367
osgeo::proj::common::UnitOfMeasure::ARC_SECOND_PER_YEAR (C++ member), 367
osgeo::proj::common::UnitOfMeasure::code (C++ function), 366
osgeo::proj::common::UnitOfMeasure::codeSpace (C++ function), 366
osgeo::proj::common::UnitOfMeasure::conversionToSI (C++ function), 366
osgeo::proj::common::UnitOfMeasure::DEGREE (C++ member), 367
osgeo::proj::common::UnitOfMeasure::GRAD (C++ member), 367
osgeo::proj::common::UnitOfMeasure::METRE (C++ member), 366
osgeo::proj::common::UnitOfMeasure::METRE_PER_YEAR (C++ member), 366
osgeo::proj::common::UnitOfMeasure::MICRORADIAN (C++ member), 367
osgeo::proj::common::UnitOfMeasure::name (C++ function), 366
osgeo::proj::common::UnitOfMeasure::NONE (C++ member), 366
osgeo::proj::common::UnitOfMeasure::operator!= (C++ function), 366
osgeo::proj::common::UnitOfMeasure::operator== (C++ function), 366
osgeo::proj::common::UnitOfMeasure::PARTS_PER_MILLION (C++ member), 366
osgeo::proj::common::UnitOfMeasure::PPM_PER_YEAR (C++ member), 366
osgeo::proj::common::UnitOfMeasure::Radian (C++ member), 366
osgeo::proj::common::UnitOfMeasure::SCALE_UNITY (C++ member), 366
osgeo::proj::common::UnitOfMeasure::SECOND (C++ member), 367
osgeo::proj::common::UnitOfMeasure::type (C++ function), 366
osgeo::proj::common::UnitOfMeasure::UnitOfMeasure (C++ function), 366
osgeo::proj::common::UnitOfMeasure::YEAR (C++ member), 367
osgeo::proj::common::UnitOfMeasure::NNPtr (C++ type), 360
osgeo::proj::common::UnitOfMeasure::Ptr (C++ type), 360
osgeo::proj::common::UNKNOWN (C++ enumerator), 365
osgeo::proj::crs (C++ type), 402
osgeo::proj::crs::BoundCRS (C++ class), 404
osgeo::proj::crs::BoundCRS::baseCRS (C++ function), 404
osgeo::proj::crs::BoundCRS::baseCRSWithCanonicalBoundCRS (C++ function), 404
osgeo::proj::crs::BoundCRS::create (C++ function), 405
osgeo::proj::crs::BoundCRS::createFromNadgrids (C++ function), 405
osgeo::proj::crs::BoundCRS::createFromTOWGS84 (C++ function), 405
osgeo::proj::crs::BoundCRS::hubCRS (C++ function), 404
osgeo::proj::crs::BoundCRS::transformation (C++ function), 405
osgeo::proj::crs::BoundCRS::NNPtr (C++ type), 402
osgeo::proj::crs::BoundCRSPtr (C++ type), 402
osgeo::proj::crs::CompoundCRS (C++ class), 405
osgeo::proj::crs::CompoundCRS::componentReferenceSystems (C++ function), 406
osgeo::proj::crs::CompoundCRS::create (C++ function), 406
osgeo::proj::crs::CompoundCRS::identify (C++ function), 406
osgeo::proj::crs::CompoundCRS::NNPtr (C++ type), 403
osgeo::proj::crs::CompoundCRSPtr (C++ type), 403
osgeo::proj::crs::CRS (C++ class), 406
osgeo::proj::crs::CRS::canonicalBoundCRS (C++ function), 407
osgeo::proj::crs::CRS::createBoundCRSToWGS84IfPossible (C++ function), 407
osgeo::proj::crs::CRS::demoteTo2D (C++ function), 408
osgeo::proj::crs::CRS::extractGeodeticCRS (C++ function), 406
osgeo::proj::crs::CRS::extractGeographicCRS (C++ function), 406
osgeo::proj::crs::CRS::extractVerticalCRS (C++ function), 407
osgeo::proj::crs::CRS::getNonDeprecated (C++ function), 408
osgeo::proj::crs::CRS::identify (C++ function), 407
osgeo::proj::crs::CRS::promoteTo3D (C++ function), 408
osgeo::proj::crs::CRS::stripVerticalComponent (C++ function), 407
osgeo::proj::crs::CRS::NNPtr (C++ type), 402
osgeo::proj::crs::CRSPtr (C++ type), 402
osgeo::proj::crs::DerivedCRS (C++ class), 408
osgeo::proj::crs::DerivedCRS::baseCRS (C++ function), 409
osgeo::proj::crs::DerivedCRS::derivingConversion (C++ function), 409
osgeo::proj::crs::DerivedCRS::NNPtr (C++ type), 403
osgeo::proj::crs::DerivedCRSPtr (C++ type), 402
osgeo::proj::crs::DerivedCRSTemplate (C++ class), 409
osgeo::proj::crs::DerivedCRSTemplate::baseCRS (C++ function), 409
osgeo::proj::crs::DerivedCRSTemplate::BaseNNPtr (C++ type), 409
osgeo::proj::crs::DerivedCRSTemplate::create (C++ function), 409
osgeo::proj::crs::DerivedCRSTemplate::CSNNPtr (C++ type), 409
osgeo::proj::crs::DerivedCRSTemplate::NNPtr (C++ type), 409
osgeo::proj::crs::DerivedEngineeringCRS (C++ class), 410
osgeo::proj::crs::DerivedEngineeringCRS::baseCRS (C++ function), 410
osgeo::proj::crs::DerivedEngineeringCRS::create (C++ function), 410
osgeo::proj::crs::DerivedGeodeticCRSNNPtr (C++ type), 403
osgeo::proj::crs::DerivedGeodeticCRSPtr (C++ type), 403
osgeo::proj::crs::DerivedGeographicCRS (C++ class), 410
osgeo::proj::crs::DerivedGeographicCRS::baseCRS (C++ function), 411
osgeo::proj::crs::DerivedGeographicCRS::create (C++ function), 411
osgeo::proj::crs::DerivedGeographicCRSNNPtr (C++ type), 403
osgeo::proj::crs::DerivedGeographicCRSPtr (C++ type), 403
osgeo::proj::crs::DerivedParametricCRS (C++ class), 411
osgeo::proj::crs::DerivedParametricCRSNNPtr (C++ type), 404
osgeo::proj::crs::DerivedParametricCRSPtr (C++ type), 404
osgeo::proj::crs::DerivedProjectedCRS (C++ class), 411
osgeo::proj::crs::DerivedProjectedCRS::baseCRS (C++ function), 411
osgeo::proj::crs::DerivedProjectedCRS::create (C++ function), 412
osgeo::proj::crs::DerivedProjectedCRSNNPtr (C++ type), 403
osgeo::proj::crs::DerivedProjectedCRSPtr (C++ type), 403
osgeo::proj::crs::DerivedTemporalCRS (C++ class), 412
osgeo::proj::crs::DerivedTemporalCRS::baseCRS (C++ function), 412
osgeo::proj::crs::DerivedTemporalCRS::create (C++ function), 412
osgeo::proj::crs::DerivedTemporalCRSNNPtr (C++ type), 403
osgeo::proj::crs::DerivedTemporalCRSPtr (C++ type), 403
osgeo::proj::crs::DerivedVerticalCRS (C++ class), 412
osgeo::proj::crs::DerivedVerticalCRS::baseCRS (C++ function), 412
osgeo::proj::crs::DerivedVerticalCRS::create (C++ function), 412
osgeo::proj::crs::DerivedVerticalCRSNNPtr (C++ type), 403
osgeo::proj::crs::DerivedVerticalCRSPtr (C++ type), 403
osgeo::proj::crs::EngineeringCRS (C++ class), 412
osgeo::proj::crs::EngineeringCRS::create (C++ function), 413
osgeo::proj::crs::EngineeringCRS::datum (C++ function), 413
osgeo::proj::crs::EngineeringCRS::datum (C++ function), 413
osgeo::proj::crs::EngineeringCRSNPtr (C++ type), 403
osgeo::proj::crs::EngineeringCRSPtr (C++ type), 403
osgeo::proj::crs::GeodeticCRS (C++ class), 413
osgeo::proj::crs::GeodeticCRS::create (C++ function), 414, 415
osgeo::proj::crs::GeodeticCRS::datum (C++ function), 413
osgeo::proj::crs::GeodeticCRS::ellipsoid (C++ function), 413
osgeo::proj::crs::GeodeticCRS::identify (C++ function), 414
osgeo::proj::crs::GeodeticCRS::isGeocentric (C++ function), 414
osgeo::proj::crs::GeodeticCRS::primeMeridian (C++ function), 413
osgeo::proj::crs::GeodeticCRS::velocityModel (C++ function), 413
osgeo::proj::crs::GeodeticCRSNPtr (C++ type), 402
osgeo::proj::crs::GeodeticCRSPtr (C++ type), 402
osgeo::proj::crs::GeographicCRS (C++ class), 415
osgeo::proj::crs::GeographicCRS::coordinateSystem (C++ function), 416
osgeo::proj::crs::GeographicCRS::create (C++ function), 416
osgeo::proj::crs::GeographicCRS::demoteTo2D (C++ function), 416
osgeo::proj::crs::GeographicCRSNPtr (C++ type), 402
osgeo::proj::crs::GeographicCRSPtr (C++ type), 402
osgeo::proj::crs::ParametricCRS (C++ class), 417
osgeo::proj::crs::ParametricCRS::coordinateSystem (C++ function), 417
osgeo::proj::crs::ParametricCRS::create (C++ function), 417
osgeo::proj::crs::ParametricCRS::datum (C++ function), 417
osgeo::proj::crs::ParametricCRS::datum (C++ function), 417
osgeo::proj::crs::ParametricCRSNPtr (C++ type), 403
osgeo::proj::crs::ParametricCRSPtr (C++ type), 403
osgeo::proj::crs::ProjectedCRS (C++ class), 417
osgeo::proj::crs::ProjectedCRS::baseCRS (C++ function), 418
osgeo::proj::crs::ProjectedCRS::coordinateSystem (C++ function), 418
osgeo::proj::crs::ProjectedCRS::create (C++ function), 419
osgeo::proj::ProjectedCRS::demoteTo2D (C++ function), 418
osgeo::proj::ProjectedCRS::identify (C++ function), 418
osgeo::proj::ProjectedCRS::ProjectedCRSNNPtr (C++ type), 403
osgeo::proj::ProjectedCRS::ProjectedCRSPtr (C++ type), 403
osgeo::proj::SingleCRS (C++ class), 419
osgeo::proj::SingleCRS::coordinateSystem (C++ function), 419
osgeo::proj::SingleCRS::datum (C++ function), 419
osgeo::proj::SingleCRS::datumEnsemble (C++ function), 419
osgeo::proj::SingleCRS::ProjectedCRSNNPtr (C++ type), 402
osgeo::proj::SingleCRS::ProjectedCRSPtr (C++ type), 402
osgeo::proj::TemporalCRS (C++ class), 419
osgeo::proj::TemporalCRS::coordinateSystem (C++ function), 420
osgeo::proj::TemporalCRS::datum (C++ function), 420
osgeo::proj::TemporalCRS::ProjectedCRSNNPtr (C++ type), 403
osgeo::proj::TemporalCRS::ProjectedCRSPtr (C++ type), 403
osgeo::proj::TemporalCRS::TemporalCRS::create (C++ function), 420
osgeo::proj::TemporalCRS::datum (C++ function), 420
osgeo::proj::TemporalCRS::TemporalCRS::ProjectedCRSNNPtr (C++ type), 403
osgeo::proj::TemporalCRS::TemporalCRS::ProjectedCRSPtr (C++ type), 403
osgeo::proj::VerticalCRS (C++ class), 420
osgeo::proj::VerticalCRS::coordinateSystem (C++ function), 420
osgeo::proj::VerticalCRS::create (C++ function), 421
osgeo::proj::VerticalCRS::datum (C++ function), 420
osgeo::proj::VerticalCRS::VerticalCRS::geoidModel (C++ function), 420
osgeo::proj::VerticalCRS::identify (C++ function), 421
osgeo::proj::VerticalCRS::velocityModel (C++ function), 421
osgeo::proj::VerticalCRS::VerticalCRS::ProjectedCRSNNPtr (C++ type), 402
osgeo::proj::VerticalCRS::VerticalCRS::ProjectedCRSPtr (C++ type), 402
osgeo::proj::cs (C++ type), 380
osgeo::proj::cs::AxisDirection (C++ class), 381
osgeo::proj::cs::AxisDirection::AFT (C++ member), 383
osgeo::proj::cs::AxisDirection::AWAY_FROM (C++ member), 383
osgeo::proj::cs::AxisDirection::CLOCKWISE (C++ member), 383
osgeo::proj::cs::AxisDirection::COLUMN_NEGATIVE (C++ member), 382
osgeo::proj::cs::AxisDirection::COLUMN_POSITIVE (C++ member), 382
osgeo::proj::cs::AxisDirection::COUNTER_CLOCKWISE (C++ member), 383
osgeo::proj::cs::AxisDirection::DISPLAY_DOWN (C++ member), 383
osgeo::proj::cs::AxisDirection::DISPLAY_LEFT (C++ member), 383
osgeo::proj::cs::AxisDirection::DISPLAY_RIGHT (C++ member), 383
osgeo::proj::cs::AxisDirection::DISPLAY_UP (C++ member), 383
osgeo::proj::cs::AxisDirection::DOWN (C++ member), 382
osgeo::proj::cs::AxisDirection::EAST (C++ member), 381
osgeo::proj::cs::AxisDirection::EAST_NORTH_EAST (C++ member), 381
osgeo::proj::cs::AxisDirection::EAST_SOUTH_EAST (C++ member), 382
osgeo::proj::cs::AxisDirection::FORWARD (C++ member), 383
osgeo::proj::cs::AxisDirection::FUTURE (C++ member), 383
osgeo::proj::cs::AxisDirection::GEOCENTRIC_X (C++ member), 382
osgeo::proj::cs::AxisDirection::GEOCENTRIC_Y (C++ member), 382
osgeo::proj::cs::AxisDirection::GEOCENTRIC_Z (C++ member), 382
osgeo::proj::cs::AxisDirection::NORTH (C++ member), 381
osgeo::proj::cs::AxisDirection::NORTH_EAST (C++ member), 381
osgeo::proj::cs::AxisDirection::NORTH_NORTH_EAST (C++ member), 381
osgeo::proj::cs::AxisDirection::NORTH_NORTH_WEST (C++ member), 382
osgeo::proj::cs::AxisDirection::NORTH_WEST (C++ member), 382
osgeo::proj::cs::AxisDirection::PAST (C++ member), 383
osgeo::proj::cs::AxisDirection::PORT (C++ member), 383
osgeo::proj::cs::AxisDirection::ROW_NEGATIVE (C++ member), 382

Index 591
<table>
<thead>
<tr>
<th>Class/Function</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>osgeo::proj::cs::AxisDirection::ROW_POSITIVE</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::SOUTH</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::SOUTH_EAST</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::SOUTH_SOUTH_EAST</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::SOUTH_SOUTH_WEST</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::SOUTH_WEST</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::STARBOARD</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::TOWARDS</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::UNSPECIFIED</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::UP</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::WEST</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::WEST_NORTH_WEST</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::AxisDirection::WEST_SOUTH_WEST</td>
<td>C++ member</td>
</tr>
<tr>
<td>osgeo::proj::cs::CartesianCS</td>
<td>C++ class</td>
</tr>
<tr>
<td>osgeo::proj::cs::CartesianCS::create</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CartesianCS::createEastingNorthing</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CartesianCS::createGeocentric</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CartesianCS::createNorthingEasting</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CartesianCS::createNorthPoleEastingSouthNorthingSouth</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CartesianCS::createSouthPoleEastingNorthNorthingNorth</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CartesianCS::createWestingSouthing</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CoordinateSystem</td>
<td>C++ class</td>
</tr>
<tr>
<td>osgeo::proj::cs::CoordinateSystem::axisList</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CoordinateSystemAxis</td>
<td>C++ class</td>
</tr>
<tr>
<td>osgeo::proj::cs::CoordinateSystemAxis::abbreviation</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CoordinateSystemAxis::direction</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CoordinateSystemAxis::maximumValue</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CoordinateSystemAxis::meridian</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CoordinateSystemAxis::minimumValue</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::CoordinateSystemAxis::unit</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::Date&amp;TimeTemporalCS</td>
<td>C++ class</td>
</tr>
<tr>
<td>osgeo::proj::cs::DateTimeTemporalCS::create</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::EllipsoidALCS</td>
<td>C++ class</td>
</tr>
<tr>
<td>osgeo::proj::cs::EllipsoidALCS::create</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::EllipsoidALCS::createLatitudeLongitude</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::EllipsoidALCS::createLatitudeLongitudeEllipsoidHeight</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::EllipsoidALCS::createLongitudeLatitude</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::EllipsoidALCS::createLongitudeLatitudeEllipsoidHeight</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::EllipsoidALCS::createLongitudeLatitudeEllipsoidHeight</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::EllipsoidALCS::createLongitudeLatitudeEllipsoidHeight</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::EllipsoidALCS::createLongitudeLatitudeEllipsoidHeight</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::EllipsoidALCS::createLongitudeLatitudeEllipsoidHeight</td>
<td>C++ function</td>
</tr>
<tr>
<td>osgeo::proj::cs::EllipsoidALCS::createLongitudeLatitudeEllipsoidHeight</td>
<td>C++ function</td>
</tr>
</tbody>
</table>
osgeo::proj::cs::Meridian::create (C++ function), 388
osgeo::proj::cs::Meridian::longitude (C++ function), 388
osgeo::proj::cs::MeridianNNPtr (C++ type), 380
osgeo::proj::cs::OrdinalCS (C++ class), 388
osgeo::proj::cs::OrdinalCS::create (C++ function), 389
osgeo::proj::cs::OrdinalCSNNPtr (C++ type), 381
osgeo::proj::cs::OrdinalCSPtr (C++ type), 381
osgeo::proj::cs::ParametricCS (C++ class), 389
osgeo::proj::cs::ParametricCS::create (C++ function), 389
osgeo::proj::cs::ParametricCSNNPtr (C++ type), 381
osgeo::proj::cs::ParametricCSPtr (C++ type), 381
osgeo::proj::cs::SphericalCS (C++ class), 389
osgeo::proj::cs::SphericalCS::create (C++ function), 389
osgeo::proj::cs::SphericalCSNNPtr (C++ type), 380
osgeo::proj::cs::SphericalCSPtr (C++ type), 380
osgeo::proj::cs::TemporalCountCS (C++ class), 390
osgeo::proj::cs::TemporalCountCS::create (C++ function), 390
osgeo::proj::cs::TemporalCountCSNNPtr (C++ type), 381
osgeo::proj::cs::TemporalCountCSPtr (C++ type), 381
osgeo::proj::cs::TemporalCS (C++ class), 390
osgeo::proj::cs::TemporalCSNNPtr (C++ type), 381
osgeo::proj::cs::TemporalCSPtr (C++ type), 381
osgeo::proj::cs::TemporalMeasureCS (C++ class), 390
osgeo::proj::cs::TemporalMeasureCS::create (C++ function), 390
osgeo::proj::cs::TemporalMeasureCSNNPtr (C++ type), 381
osgeo::proj::cs::TemporalMeasureCSPtr (C++ type), 381
osgeo::proj::cs::VerticalCS (C++ class), 391
osgeo::proj::cs::VerticalCS::create (C++ function), 391
osgeo::proj::cs::VerticalCS::createGravityRelatedHeight (C++ function), 391
osgeo::proj::cs::VerticalCSNNPtr (C++ type), 380
osgeo::proj::cs::VerticalCSPtr (C++ type), 380
osgeo::proj::datum (C++ type), 391
osgeo::proj::datum::Datum (C++ class), 392
osgeo::proj::datum::Datum::anchorDefinition (C++ function), 393
osgeo::proj::datum::Datum::conventionalRS (C++ function), 393
osgeo::proj::datum::Datum::publicationDate (C++ function), 393
osgeo::proj::datum::DatumEnsemble (C++ class), 393
osgeo::proj::datum::DatumEnsemble::create (C++ function), 394
osgeo::proj::datum::DatumEnsemble::datums (C++ function), 393
osgeo::proj::datum::DatumEnsemble::positionalAccuracy (C++ function), 393
osgeo::proj::datum::DatumEnsembleNNPtr (C++ type), 391
osgeo::proj::datum::DatumEnsemblePtr (C++ type), 391
osgeo::proj::datum::DatumNNPtr (C++ type), 391
osgeo::proj::datum::DatumPtr (C++ type), 391
osgeo::proj::datum::DynamicGeodeticReferenceFrame (C++ class), 394
osgeo::proj::datum::DynamicGeodeticReferenceFrame::create (C++ function), 394
osgeo::proj::datum::DynamicGeodeticReferenceFrame::deformationModelName (C++ function), 394
osgeo::proj::datum::DynamicGeodeticReferenceFrame::frameReferenceEpoch (C++ function), 394
osgeo::proj::datum::DynamicGeodeticReferenceFrameNNPtr (C++ type), 392
osgeo::proj::datum::DynamicGeodeticReferenceFramePtr (C++ type), 392
osgeo::proj::datum::DynamicVerticalReferenceFrame (C++ class), 395
osgeo::proj::datum::DynamicVerticalReferenceFrame::create (C++ function), 395
osgeo::proj::datum::DynamicVerticalReferenceFrame::deformationModelName (C++ function), 395
osgeo::proj::datum::DynamicVerticalReferenceFrame::frameReferenceEpoch (C++ function), 395
osgeo::proj::datum::DynamicVerticalReferenceFrame::DynamicVerticalReferenceFrameNNPtr (C++ type), 392
osgeo::proj::datum::DynamicVerticalReferenceFrame::DynamicVerticalReferenceFramePtr (C++ type), 392
osgeo::proj::datum::Ellipsoid (C++ class), 395
osgeo::proj::datum::Ellipsoid::celestialBody (C++ function), 396
osgeo::proj::datum::Ellipsoid::computedInverseFlattening (C++ function), 396
osgeo::proj::datum::Ellipsoid::computeSemiMinorAxis (C++ function), 396
osgeo::proj::datum::Ellipsoid::createFlattenedSphere (C++ function), 397
osgeo::proj::datum::Ellipsoid::createSphere (C++ function), 397
osgeo::proj::datum::Ellipsoid::createTwoAxis (C++ function), 397
osgeo::proj::datum::Ellipsoid::identified (C++ function), 396
osgeo::proj::datum::Ellipsoid::inverseFlattening (C++ function), 396
osgeo::proj::datum::Ellipsoid::isSphere (C++ function), 396
osgeo::proj::datum::Ellipsoid::semiMajorAxis (C++ function), 396
osgeo::proj::datum::Ellipsoid::semiMedianAxis (C++ function), 396
osgeo::proj::datum::Ellipsoid::semiMinorAxis (C++ function), 396
osgeo::proj::datum::Ellipsoid::squaredEccentricity (C++ function), 396
osgeo::proj::datum::Ellipsoid::EllipsoidNNPtr (C++ type), 391
osgeo::proj::datum::Ellipsoid::EllipsoidPtr (C++ type), 391
osgeo::proj::datum::EngineeringDatum (C++ class), 398
osgeo::proj::datum::EngineeringDatum::create (C++ function), 398
osgeo::proj::datum::EngineeringDatum::EngineeringDatumNNPtr (C++ type), 392
osgeo::proj::datum::EngineeringDatum::EngineeringDatumPtr (C++ type), 392
osgeo::proj::datum::GeodeticReferenceFrame (C++ class), 398
osgeo::proj::datum::GeodeticReferenceFrame::create (C++ function), 399
osgeo::proj::datum::GeodeticReferenceFrame::GeodeticReferenceFrameNNPtr (C++ type), 391
osgeo::proj::datum::GeodeticReferenceFrame::GeodeticReferenceFramePtr (C++ type), 391
osgeo::proj::datum::GeodeticReferenceFrame::ellipse (C++ function), 398
osgeo::proj::datum::GeodeticReferenceFrame::primeMeridian (C++ function), 398
osgeo::proj::datum::GeodeticReferenceFrame::GeodeticReferenceFrameNNPtr (C++ type), 391
osgeo::proj::datum::GeodeticReferenceFrame::GeodeticReferenceFramePtr (C++ type), 391
osgeo::proj::datum::ParametricDatum (C++ class), 399
osgeo::proj::datum::ParametricDatum::create (C++ function), 399
osgeo::proj::datum::ParametricDatum::ParametricDatumNNPtr (C++ type), 392
osgeo::proj::datum::ParametricDatum::ParametricDatumPtr (C++ type), 392
osgeo::proj::datum::PrimeMeridian (C++ class), 399
osgeo::proj::datum::PrimeMeridian::create (C++ function), 400
osgeo::proj::datum::PrimeMeridian::longitude (C++ function), 400
osgeo::proj::datum::PrimeMeridian::PrimeMeridianNNPtr (C++ type), 391
osgeo::proj::datum::PrimeMeridian::PrimeMeridianPtr (C++ type), 391
osgeo::proj::datum::RealizationMethod (C++ class), 400
osgeo::proj::datum::TemporalDatum (C++ class), 400
osgeo::proj::datum::TemporalDatum::calendar (C++ function), 401
osgeo::proj::datum::TemporalDatum::TemporalDatumNNPtr (C++ type), 400
osgeo::proj::datum::TemporalDatum::TemporalDatumPtr (C++ type), 400
osgeo::proj::datum::TemporalDatum::temporalOrigin (C++ function), 401
osgeo::proj::datum::TemporalDatum::TemporalDatumNNPtr (C++ type), 392
osgeo::proj::datum::TemporalDatum::TemporalDatumPtr (C++ type), 392
osgeo::proj::datum::VerticalReferenceFrame (C++ class), 401
osgeo::proj::datum::VerticalReferenceFrame::create (C++ function), 402
osgeo::proj::datum::VerticalReferenceFrame::realizationMethod (C++ function), 401
osgeo::proj::datum::VerticalReferenceFrame::VerticalReferenceFrameNNPtr (C++ type), 392
osgeo::proj::datum::VerticalReferenceFrame::VerticalReferenceFramePtr (C++ type), 392
osgeo::proj::Ellipsoid::CLARKE_1866 (C++ member), 397
osgeo::proj::Ellipsoid::EARTH (C++ member), 397
osgeo::proj::Ellipsoid::GRS1980 (C++ member), 397
osgeo::proj::Ellipsoid::WGS84 (C++ member), 397
osgeo::proj::Extent::WORLD (C++ member), 375
osgeo::proj::GeodeticCRS::EPSG_4978 (C++ member), 415
osgeo::proj::GeodeticReferenceFrame::EPSG_6267 (C++ member), 399
osgeo::proj::GeodeticReferenceFrame::EPSG_6269 (C++ member), 399
osgeo::proj::GeodeticReferenceFrame::EPSG_6326 (C++ member), 399
osgeo::proj::GeographicCRS::EPSG_4267 (C++ member), 417
osgeo::proj::GeographicCRS::EPSG_4269 (C++ member), 417
osgeo::proj::GeographicCRS::EPSG_4326 (C++ member), 417
osgeo::proj::GeographicCRS::EPSG_4807 (C++ member), 417
osgeo::proj::GeographicCRS::EPSG_4979 (C++ member), 417
osgeo::proj::Identifier::AUTHORITY_KEY (C++ member), 378
osgeo::proj::Identifier::CODE_KEY (C++ member), 378
osgeo::proj::Identifier::CODESPACE_KEY (C++ member), 378
osgeo::proj::Identifier::DESCRIPTION_KEY (C++ member), 378
osgeo::proj::Identifier::EPSG (C++ member), 378
osgeo::proj::Identifier::OGC (C++ member), 378
osgeo::proj::Identifier::URI_KEY (C++ member), 378
osgeo::proj::Identifier::VERSION_KEY (C++ member), 378
osgeo::proj::io (C++ type), 477
osgeo::proj::io::_WKT1_ESRI (C++ enumerator), 496
osgeo::proj::io::_WKT1_GDAL (C++ enumerator), 496
osgeo::proj::io::_WKT1_GDAL_EPSG_STYLE (C++ enumerator), 496
osgeo::proj::io::_WKT2_2015 (C++ enumerator), 496
osgeo::proj::io::_WKT2_2015_SIMPLIFIED (C++ enumerator), 496
osgeo::proj::io::_WKT2_2018 (C++ enumerator), 496
osgeo::proj::io::_WKT2_2018_SIMPLIFIED (C++ enumerator), 496
osgeo::proj::io::_WKT2_2019 (C++ enumerator), 496
osgeo::proj::io::_WKT2_2019_SIMPLIFIED (C++ enumerator), 496
osgeo::proj::io::AuthorityFactory (C++ class), 479
osgeo::proj::io::AuthorityFactory::create (C++ function), 490
osgeo::proj::io::AuthorityFactory::createCompoundCRS (C++ function), 483
osgeo::proj::io::AuthorityFactory::createConversion (C++ function), 482
osgeo::proj::io::AuthorityFactory::createCoordinateOperation (C++ function), 483
osgeo::proj::io::AuthorityFactory::createCoordinateReferenceSystem (C++ function), 483
osgeo::proj::io::AuthorityFactory::createCoordinateSystem (C++ function), 482
osgeo::proj::io::AuthorityFactory::createDatum (C++ function), 481
osgeo::proj::io::AuthorityFactory::createEllipsoid (C++ function), 481
osgeo::proj::io::AuthorityFactory::createExtent (C++ function), 481
osgeo::proj::io::AuthorityFactory::createFromCoordinateReferenceSystemCodes (C++ function), 483, 485
osgeo::proj::io::AuthorityFactory::createFromCRSCodesWithIntermediates (C++ function), 487
osgeo::proj::io::AuthorityFactory::createGeodeticCRS (C++ function), 482
osgeo::proj::io::AuthorityFactory::createGeodeticDatum (C++ function), 481
osgeo::proj::io::AuthorityFactory::createGeographicCRS (C++ function), 482
osgeo::proj::io::AuthorityFactory::createObject (C++ function), 480
osgeo::proj::io::AuthorityFactory::createObjectsFromName (C++ function), 490
osgeo::proj::io::AuthorityFactory::createPrimeMeridian (C++ function), 481
osgeo::proj::io::AuthorityFactory::createProjectedCRS (C++ function), 483
osgeo::proj::io::AuthorityFactory::createUnitOfMeasure (C++ function), 480
osgeo::proj::io::AuthorityFactory::createVerticalCRS (C++ function), 482
osgeo::proj::io::AuthorityFactory::createVerticalDatum (C++ function), 482
osgeo::proj::io::AuthorityFactory::CRSInfo (C++ class), 490
osgeo::proj::io::AuthorityFactory::CRSInfo::areaName (C++ member), 491
osgeo::proj::io::AuthorityFactory::CRSInfo::authName (C++ member), 491
osgeo::proj::io::AuthorityFactory::CRSInfo::bbox_valid (C++ member), 491
osgeo::proj::io::AuthorityFactory::CRSInfo::code (C++ member), 491
osgeo::proj::io::AuthorityFactory::CRSInfo::deprecated (C++ member), 491
osgeo::proj::io::AuthorityFactory::CRSInfo::east_lon_degree (C++ member), 491
osgeo::proj::io::AuthorityFactory::CRSInfo::name (C++ member), 491
osgeo::proj::io::AuthorityFactory::CRSInfo::north_lat_degree (C++ member), 491
osgeo::proj::io::AuthorityFactory::CRSInfo::projectionMethodName (C++ member), 491
osgeo::proj::io::AuthorityFactory::CRSInfo::south_lat_degree (C++ member), 491
osgeo::proj::io::AuthorityFactory::CRSInfo::type (C++ member), 491
osgeo::proj::io::AuthorityFactory::databaseContext (C++ function), 485
osgeo::proj::io::AuthorityFactory::getAuthority (C++ function), 484
osgeo::proj::io::AuthorityFactory::getAuthorityCodes (C++ function), 484
osgeo::proj::io::AuthorityFactory::getCRSInfoList (C++ function), 484
osgeo::proj::io::AuthorityFactory::getDescriptionText (C++ function), 484
osgeo::proj::io::AuthorityFactory::getOfficialNameFromAlias (C++ function), 489
osgeo::proj::io::AuthorityFactory::identifyBodyFromSemiMajorAxis (C++ function), 481
osgeo::proj::io::AuthorityFactory::listAreaOfUseFromName (C++ function), 490
osgeo::proj::io::AuthorityFactoryNNPtr (C++ type), 477
osgeo::proj::io::AuthorityFactoryPtr (C++ type), 477
osgeo::proj::io::cloneWithProps (C++ function), 478
osgeo::proj::io::COMPOUND_CRS (C++ enumerator), 480
osgeo::proj::io::CONCATENATED_OPERATION (C++ enumerator), 480
osgeo::proj::io::Convention (C++ enum), 494
osgeo::proj::io::Convention_ (C++ enum), 496
osgeo::proj::io::CONVERSION (C++ enumerator), 480
osgeo::proj::io::COORDINATE_OPERATION (C++ enumerator), 480
osgeo::proj::io::createFromUserInput (C++ function), 478
osgeo::proj::io::CRS (C++ enumerator), 479
osgeo::proj::io::DatabaseContext (C++ class), 491
osgeo::proj::io::DatabaseContext::create (C++ function), 492
osgeo::proj::io::DatabaseContext::getAuthorities (C++ function), 491
osgeo::proj::io::DatabaseContext::getDatabaseStructure (C++ function), 491
osgeo::proj::io::DatabaseContext::getMetadata (C++ function), 478
osgeo::proj::io::DatabaseContext::getPath (C++ function), 491
osgeo::proj::io::DatabaseContextNNPtr (C++ type), 477
osgeo::proj::io::DatabaseContextPtr (C++ type), 477
osgeo::proj::io::DATUM (C++ enumerator), 479
osgeo::proj::io::ELLIPSOID (C++ enumerator), 479
osgeo::proj::io::FactoryException (C++ class), 492
osgeo::proj::io::FormatException (C++ class), 492
osgeo::proj::io::GEOCENTRIC_CRS (C++ enumerator), 480
osgeo::proj::io::GEOCENTRIC_CRS (C++ enumerator), 480
osgeo::proj::io::GEOCENTRIC_REFERENCE_FRAME (C++ enumerator), 479
osgeo::proj::io::GEOGRAPHIC_2D_CRS (C++ enumerator), 480
osgeo::proj::io::GEOGRAPHIC_3D_CRS (C++ enumerator), 480
osgeo::proj::io::GEOGRAPHIC_CRS (C++ enumerator), 480
osgeo::proj::io::IJSONExportable (C++ class), 492
osgeo::proj::io::IJSONExportable::exportToJSON (C++ function), 492
osgeo::proj::io::IPROJStringExportable (C++ class), 492
osgeo::proj::io::IPROJStringExportable::exportToPROJString (C++ function), 493
osgeo::proj::io::IPROJStringExportablePtr (C++ type), 477
osgeo::proj::io::IPROJStringExportable::exportToWKT (C++ function), 493
osgeo::proj::io::JSONFormatter (C++ class), 493
osgeo::proj::io::JSONFormatter::create (C++ function), 494
osgeo::proj::io::JSONFormatter::setIndentationWidth (C++ function), 494
osgeo::proj::io::JSONFormatter::setMultiLine (C++ function), 494
osgeo::proj::io::JSONFormatter::setSchema (C++ function), 494
osgeo::proj::io::JSONFormatter::toString (C++ function), 494
osgeo::proj::io::JSONFormatterNNPtr (C++ type), 477
osgeo::proj::io::JSONFormatterPtr (C++ type), 477
osgeo::proj::io::NoSuchAuthorityCodeException (C++ class), 494
osgeo::proj::io::NoSuchAuthorityCodeException::getAuthority (C++ function), 494
osgeo::proj::io::NoSuchAuthorityCodeException::getAuthorityCode (C++ function), 494
osgeo::proj::io::NOT_WKT (C++ enumerator), 499
osgeo::proj::io::ObjectType (C++ enum), 479
osgeo::proj::io::OutputAxisRule (C++ enum), 496
osgeo::proj::io::ParsingException (C++ class), 494
osgeo::proj::io::PRIME_MERIDIAN (C++ enumerator), 479
osgeo::proj::io::PROJ_4 (C++ enumerator), 494
osgeo::proj::io::PROJ_5 (C++ enumerator), 494
osgeo::proj::io::PROJStringFormatter (C++ class), 494
osgeo::proj::io::PROJStringFormatter::create (C++ function), 495
osgeo::proj::io::PROJStringFormatter::setUseApproxTMerc (C++ function), 495
osgeo::proj::io::PROJStringFormatter::toString (C++ function), 495
osgeo::proj::io::PROJStringFormatter::setUseApproxTMerc (C++ function), 495
osgeo::proj::io::PROJStringFormatter::setUsePROJ4InitRules (C++ function), 495
osgeo::proj::io::PROJStringFormatter::warningList (C++ function), 495
osgeo::proj::io::TRANSFORMATION (C++ enumerator), 480
osgeo::proj::io::VERTICAL_CRS (C++ enumerator), 480
osgeo::proj::io::WKT1_ESRI (C++ enumerator), 499
osgeo::proj::io::WKT1_GDAL (C++ enumerator), 499
osgeo::proj::io::WKT2 (C++ enumerator), 496
osgeo::proj::io::WKT2_2015 (C++ enumerator), 499
osgeo::proj::io::WKT2_2018 (C++ enumerator), 499
osgeo::proj::io::WKT2_2019 (C++ enumerator), 499
osgeo::proj::io::WKT2_SIMPLIFIED (C++ enumerator), 496
osgeo::proj::io::WKTMFormat (C++ class), 495
osgeo::proj::io::WKTMFormat::create (C++ function), 497
osgeo::proj::io::WKTMFormat::isStrict (C++ function), 497
osgeo::proj::io::WKTMFormat::setIndentationWidth (C++ function), 497
osgeo::proj::io::WKTMFormat::setMultiLine (C++ function), 497
Index 597
osgeo::proj::io::WKTFormatter::setOutputAxis (C++ function), 497
osgeo::proj::io::WKTFormatter::setStrict (C++ function), 497
osgeo::proj::io::WKTFormatter::toString (C++ function), 497
osgeo::proj::io::WKTFormatterNNPtr (C++ type), 477
osgeo::proj::io::WKTFormatterPtr (C++ type), 477
osgeo::proj::io::WKTGuesedDialect (C++ enum), 499
osgeo::proj::io::WKTNode (C++ class), 497
osgeo::proj::io::WKTNode::addChild (C++ function), 498
osgeo::proj::io::WKTNode::children (C++ function), 498
osgeo::proj::io::WKTNode::countChildrenOfName (C++ function), 498
osgeo::proj::io::WKTNode::createFrom (C++ function), 498
osgeo::proj::io::WKTNode::lookForChild (C++ function), 498
osgeo::proj::io::WKTNode::toString (C++ function), 498
osgeo::proj::io::WKTNode::value (C++ function), 498
osgeo::proj::io::WKTNode::WKTNode (C++ function), 498
osgeo::proj::io::WKTParser::attachDatabaseContext (C++ function), 499
osgeo::proj::io::WKTParser::createFromWKT (C++ function), 499
osgeo::proj::io::WKTParser::guessDialect (C++ function), 499
osgeo::proj::io::WKTParser::setStrict (C++ function), 499
osgeo::proj::io::WKTParser::warningList (C++ function), 499
osgeo::proj::io::YES (C++ enumerator), 496
osgeo::proj::metadata (C++ type), 372
osgeo::proj::metadata::Citation (C++ class), 373
osgeo::proj::metadata::Citation::Citation (C++ function), 374
osgeo::proj::metadata::Citation::title (C++ function), 374
osgeo::proj::metadata::Extent (C++ class), 374
osgeo::proj::metadata::Extent::contains (C++ function), 374
osgeo::proj::metadata::Extent::create (C++ function), 375
osgeo::proj::metadata::Extent::createFromBBOX (C++ function), 375
osgeo::proj::metadata::Extent::description (C++ function), 374
osgeo::proj::metadata::Extent::geographicElements (C++ function), 374
osgeo::proj::metadata::Extent::intersection (C++ function), 374
osgeo::proj::metadata::Extent::intersects (C++ function), 374
osgeo::proj::metadata::Extent::temporalElements (C++ function), 374
osgeo::proj::metadata::Extent::verticalElements (C++ function), 374
osgeo::proj::metadata::ExtentNNPtr (C++ type), 373
osgeo::proj::metadata::ExtentPtr (C++ type), 373
osgeo::proj::metadata::GeographicBoundingBox (C++ class), 375
osgeo::proj::metadata::GeographicBoundingBox::contains (C++ function), 376
osgeo::proj::metadata::GeographicBoundingBox::create (C++ function), 376
osgeo::proj::metadata::GeographicBoundingBox::eastBoundLongitude (C++ function), 375
osgeo::proj::metadata::GeographicBoundingBox::intersection (C++ function), 376
osgeo::proj::metadata::GeographicBoundingBox::intersects (C++ function), 376
osgeo::proj::metadata::GeographicBoundingBox::northBoundLatitude (C++ function), 376
osgeo::proj::metadata::GeographicBoundingBox::southBoundLatitude (C++ function), 375
osgeo::proj::metadata::GeographicBoundingBox::westBoundLongitude (C++ function), 375
osgeo::proj::metadata::GeographicBoundingBox::NNPtr (C++ type), 373
osgeo::proj::metadata::GeographicBoundingBoxPtr (C++ type), 373
osgeo::proj::metadata::GeographicExtent (C++ class), 376
osgeo::proj::metadata::GeographicExtent::contains (C++ function), 376
osgeo::proj::metadata::GeographicExtent::intersection (C++ function), 376
osgeo::proj::metadata::GeographicExtent::intersects (C++ function), 376
osgeo::proj::metadata::GeographicExtentNNPtr (C++ type), 373
osgeo::proj::metadata::GeographicExtentPtr (C++ type), 373
osgeo::proj::metadata::Identifier (C++ class), 376
osgeo::proj::metadata::Identifier::authority (C++ function), 377
osgeo::proj::metadata::Identifier::code (C++ function), 377
osgeo::proj::metadata::Identifier::codeSpace (C++ function), 377
osgeo::proj::metadata::Identifier::create (C++ function), 377
osgeo::proj::metadata::Identifier::description (C++ function), 377
osgeo::proj::metadata::Identifier::isEquivalentName (C++ function), 377
osgeo::proj::metadata::Identifier::uri (C++ function), 377
osgeo::proj::metadata::Identifier::version (C++ function), 377
osgeo::proj::metadata::IdentifierNNPtr (C++ type), 373
osgeo::proj::metadata::IdentifierPtr (C++ type), 373
osgeo::proj::metadata::PositionalAccuracy (C++ class), 378
osgeo::proj::metadata::PositionalAccuracy::create (C++ function), 378
osgeo::proj::metadata::PositionalAccuracy::value (C++ function), 378
osgeo::proj::metadata::PositionalAccuracyNNPtr (C++ type), 373
osgeo::proj::metadata::PositionalAccuracyPtr (C++ type), 373
osgeo::proj::metadata::TemporalExtent (C++ class), 378
osgeo::proj::metadata::TemporalExtent::contains (C++ function), 379
osgeo::proj::metadata::TemporalExtent::create (C++ function), 379
osgeo::proj::metadata::TemporalExtent::intersects (C++ function), 379
osgeo::proj::metadata::TemporalExtent::start (C++ function), 379
osgeo::proj::metadata::TemporalExtent::stop (C++ function), 379
osgeo::proj::metadata::TemporalExtentNNPtr (C++ type), 373
osgeo::proj::metadata::TemporalExtentPtr (C++ type), 373
osgeo::proj::metadata::VerticalExtent (C++ class), 379
osgeo::proj::metadata::VerticalExtent::contains (C++ function), 379
osgeo::proj::metadata::VerticalExtent::create (C++ function), 380
osgeo::proj::metadata::VerticalExtent::intersects (C++ function), 379
osgeo::proj::metadata::VerticalExtent::maximumValue (C++ function), 379
osgeo::proj::metadata::VerticalExtent::minimumValue (C++ function), 379
osgeo::proj::metadata::VerticalExtent::unit (C++ function), 379
osgeo::proj::metadata::VerticalExtentNNPtr (C++ type), 373
osgeo::proj::metadata::VerticalExtentPtr (C++ type), 373
osgeo::proj::operation:: ALWAYS (C++ enumerator), 457
osgeo::proj::operation:: BOOLEAN (C++ enumerator), 463
osgeo::proj::operation:: BOTH (C++ enumerator), 456
osgeo::proj::operation::ConcatenatedOperation (C++ class), 423
osgeo::proj::operation::ConcatenatedOperation::create (C++ function), 424
osgeo::proj::operation::ConcatenatedOperation::createComputeMetadata (C++ function), 424
osgeo::proj::operation::ConcatenatedOperation::gridsNeeded (C++ function), 424
osgeo::proj::operation::ConcatenatedOperation::inverse (C++ function), 424
osgeo::proj::operation::ConcatenatedOperation::operations (C++ function), 424
osgeo::proj::operation::ConcatenatedOperationNNPtr (C++ type), 423
osgeo::proj::operation::ConcatenatedOperationPtr (C++ type), 423
osgeo::proj::operation::Conversion (C++ class), 424
osgeo::proj::operation::Conversion::convertToOtherMethod (C++ function), 425
osgeo::proj::operation::Conversion::create (C++ function), 425
osgeo::proj::operation::Conversion::createAlbersEqualArea (C++ function), 428
osgeo::proj::operation::Conversion::createAmericanPolyconic (C++ function), 447
osgeo::proj::operation::Conversion::createAxisOrderReversal (C++ function), 454
osgeo::proj::operation::Conversion::createAzimuthalEquidistant (C++ function), 431
osgeo::proj::operation::Conversion::createBonne (C++ function), 432
osgeo::proj::operation::Conversion::createCassiniSoldner (C++ function), 433
osgeo::proj::operation::Conversion::createChangeVerticalUnit (C++ function), 453
osgeo::proj::operation::Conversion::createEckertI (C++ function), 434
osgeo::proj::operation::Conversion::createEckertII (C++ function), 434
osgeo::proj::operation::Conversion::createEckertIII (C++ function), 434
osgeo::proj::operation::Conversion::createEckertIV (C++ function), 435
osgeo::proj::operation::Conversion::createEckertV (C++ function), 435
osgeo::proj::operation::Conversion::createEckertVI (C++ function), 435
osgeo::proj::operation::Conversion::createEqualEarth (C++ function), 452
osgeo::proj::operation::Conversion::createEquidistantConic (C++ function), 433
osgeo::proj::operation::Conversion::createEquidistantCylindrical (C++ function), 435
osgeo::proj::operation::Conversion::createGall (C++ function), 436
osgeo::proj::operation::Conversion::createGaussSchreiberTransverseMercator (C++ function), 426
osgeo::proj::operation::Conversion::createGeographicGeocentric (C++ function), 454
osgeo::proj::operation::Conversion::createGeostationarySatelliteSweepX (C++ function), 437
osgeo::proj::operation::Conversion::createGeostationarySatelliteSweepY (C++ function), 438
osgeo::proj::operation::Conversion::createGnomonic (C++ function), 438
osgeo::proj::operation::Conversion::createGoodeHomolosine (C++ function), 437
osgeo::proj::operation::Conversion::createGuamProjection (C++ function), 432
osgeo::proj::operation::Conversion::createHeightDepthReversal (C++ function), 454
osgeo::proj::operation::Conversion::createHotineObliqueMercatorTwoPointNaturalOrigin (C++ function), 440
osgeo::proj::operation::Conversion::createHotineObliqueMercatorVariantA (C++ function), 438
osgeo::proj::operation::Conversion::createHotineObliqueMercatorVariantB (C++ function), 439
osgeo::proj::operation::Conversion::createInternationalMapWorldPolyconic (C++ function), 442
osgeo::proj::operation::Conversion::createInterruptedGoodeHomolosine (C++ function), 437
osgeo::proj::operation::Conversion::createKrovak (C++ function), 443
osgeo::proj::operation::Conversion::createKrovakNorthOriented (C++ function), 443
osgeo::proj::operation::Conversion::createLabordeObliqueMercator (C++ function), 442
osgeo::proj::operation::Conversion::createLambertAzimuthalEqualArea (C++ function), 444
osgeo::proj::operation::Conversion::createLambertConicConformal_1SP (C++ function), 429
osgeo::proj::operation::Conversion::createLambertConicConformal_2SP (C++ function), 429
osgeo::proj::operation::Conversion::createLambertConicConformal_2SP_Belgium (C++ function), 430
osgeo::proj::operation::Conversion::createLambertConicConformal_2SP_Michigan (C++ function), 430
osgeo::proj::operation::Conversion::createLambertCylindricalEqualArea (C++ function), 433
osgeo::proj::operation::Conversion::createLambertCylindricalEqualAreaSpherical
PROJ coordinate transformation software library, Release 6.3.1

(C++ function), 432
osgeo::proj::operation::Conversion::createMercatorVariantA (C++ function), 444
osgeo::proj::operation::Conversion::createMercatorVariantB (C++ function), 445
osgeo::proj::operation::Conversion::createMillerCylindrical (C++ function), 444
osgeo::proj::operation::Conversion::createMollweide (C++ function), 446
osgeo::proj::operation::Conversion::createNewZealandMappingGrid (C++ function), 446
osgeo::proj::operation::Conversion::createObliqueStereographic (C++ function), 446
osgeo::proj::operation::Conversion::createOrthographic (C++ function), 447
osgeo::proj::operation::Conversion::createPolarStereographicVariantA (C++ function), 447
osgeo::proj::operation::Conversion::createPolarStereographicVariantB (C++ function), 448
osgeo::proj::operation::Conversion::createPoleRotationGRIBConvention (C++ function), 453
osgeo::proj::operation::Conversion::createPopularVisualisationPseudoMercator (C++ function), 445
osgeo::proj::operation::Conversion::createQuadrilateralizedSphericalCube (C++ function), 451
osgeo::proj::operation::Conversion::createRobinson (C++ function), 448
osgeo::proj::operation::Conversion::createSinusoidal (C++ function), 448
osgeo::proj::operation::Conversion::createSphericalCrossTrackHeight (C++ function), 451
osgeo::proj::operation::Conversion::createStereographic (C++ function), 449
osgeo::proj::operation::Conversion::createTransverseMercator (C++ function), 426
osgeo::proj::operation::Conversion::createTransverseMercatorSouthOriented (C++ function), 427
osgeo::proj::operation::Conversion::createTunisiaMappingGrid (C++ function), 428
osgeo::proj::operation::Conversion::createTwoPointEquidistant (C++ function), 427
osgeo::proj::operation::Conversion::createUTM (C++ function), 426
osgeo::proj::operation::Conversion::createVanDerGrinten (C++ function), 449
osgeo::proj::operation::Conversion::createVanDerGrinten (C++ function), 452
osgeo::proj::operation::Conversion::createWagnerI (C++ function), 449
osgeo::proj::operation::Conversion::createWagnerII (C++ function), 450
osgeo::proj::operation::Conversion::createWagnerIII (C++ function), 450
osgeo::proj::operation::Conversion::createWagnerIV (C++ function), 450
osgeo::proj::operation::Conversion::createWagnerV (C++ function), 450
osgeo::proj::operation::Conversion::createWagnerVI (C++ function), 451
osgeo::proj::operation::Conversion::createWagnerVII (C++ function), 451
osgeo::proj::operation::Conversion::identify (C++ function), 425
osgeo::proj::operation::Conversion::inverse (C++ function), 425
osgeo::proj::operation::Conversion::isUTM (C++ function), 425
osgeo::proj::operation::ConversionNNPtr (C++ type), 422
osgeo::proj::operation::ConversionPtr (C++ type), 422
osgeo::proj::operation::CoordinateOperation (C++ class), 454
osgeo::proj::operation::CoordinateOperation::coordinateOperationAccuracies (C++ function), 455
osgeo::proj::operation::CoordinateOperation::identify (C++ function), 455
osgeo::proj::operation::CoordinateOperation::inverse (C++ function), 455
osgeo::proj::operation::CoordinateOperation::isPROJInstantiable (C++ function), 455
osgeo::proj::operation::CoordinateOperation::normalizeForVisualization (C++ function), 456
osgeo::proj::operation::CoordinateOperation::gridsNeeded (C++ function), 455
osgeo::proj::operation::CoordinateOperation::hasBallparkTransformation (C++ function), 456
osgeo::proj::operation::CoordinateOperation::interpolationCRS (C++ function), 455
osgeo::proj::operation::CoordinateOperation::inverse (C++ function), 455
osgeo::proj::operation::CoordinateOperation::isPROJInstantiable (C++ function), 455
osgeo::proj::operation::CoordinateOperation::normalizeForVisualization (C++ function), 456

Index 601
osgeo::proj::operation::CoordinateOperation::OPERATION_VERSION_KEY (C++ member), 456
osgeo::proj::operation::CoordinateOperation::operationVersion (C++ function), 455
osgeo::proj::operation::CoordinateOperation::sourceCoordinateEpoch (C++ function), 455
osgeo::proj::operation::CoordinateOperation::sourceCRS (C++ function), 455
osgeo::proj::operation::CoordinateOperation::targetCoordinateEpoch (C++ function), 455
osgeo::proj::operation::CoordinateOperation::targetCRS (C++ function), 455
osgeo::proj::operation::CoordinateOperationContext (C++ class), 456
osgeo::proj::operation::CoordinateOperationContext::create (C++ function), 459
osgeo::proj::operation::CoordinateOperationContext::getAllowUseIntermediateCRS (C++ function), 458
osgeo::proj::operation::CoordinateOperationContext::getAreaOfInterest (C++ function), 457
osgeo::proj::operation::CoordinateOperationContext::getAuthorityFactory (C++ function), 457
osgeo::proj::operation::CoordinateOperationContext::getDesiredAccuracy (C++ function), 457
osgeo::proj::operation::CoordinateOperationContext::getDiscardSuperseded (C++ function), 458
osgeo::proj::operation::CoordinateOperationContext::getGridAvailabilityUse (C++ function), 458
osgeo::proj::operation::CoordinateOperationContext::getIntermediateCRS (C++ function), 459
osgeo::proj::operation::CoordinateOperationContext::getSourceAndTargetCRSExtentUse (C++ function), 457
osgeo::proj::operation::CoordinateOperationContext::getSpatialCriterion (C++ function), 458
osgeo::proj::operation::CoordinateOperationContext::getUsePROJAlternativeGridNames (C++ function), 458
osgeo::proj::operation::CoordinateOperationContext::setAllowUseIntermediateCRS (C++ function), 458
osgeo::proj::operation::CoordinateOperationContext::setAreaOfInterest (C++ function), 457
osgeo::proj::operation::CoordinateOperationContext::setDesiredAccuracy (C++ function), 457
osgeo::proj::operation::CoordinateOperationContext::setDiscardSuperseded (C++ function), 458
osgeo::proj::operation::CoordinateOperationContext::setGridAvailabilityUse (C++ function), 458
osgeo::proj::operation::CoordinateOperationContext::setIntermediateCRS (C++ function), 459
osgeo::proj::operation::CoordinateOperationContext::setSourceAndTargetCRSExtentUse (C++ function), 457
osgeo::proj::operation::CoordinateOperationContext::setSpatialCriterion (C++ function), 457
osgeo::proj::operation::CoordinateOperationContext::setUsePROJAlternativeGridNames (C++ function), 458
osgeo::proj::operation::CoordinateOperationContext::NNPtr (C++ type), 423
osgeo::proj::operation::CoordinateOperationContextPtr (C++ type), 423
osgeo::proj::operation::CoordinateOperationFactory (C++ class), 459
osgeo::proj::operation::CoordinateOperationFactory::create (C++ function), 460
osgeo::proj::operation::CoordinateOperationFactory::createOperation (C++ function),
osgeo::proj::operation::CoordinateOperationFactory::createOperations (C++ function), 460

osgeo::proj::operation::CoordinateOperationFactory::createOperations (C++ function), 460

osgeo::proj::operation::CoordinateOperationFactoryNNPtr (C++ type), 423

osgeo::proj::operation::CoordinateOperationFactoryPtr (C++ type), 423

osgeo::proj::operation::CoordinateOperationNNPtr (C++ type), 422

osgeo::proj::operation::CoordinateOperationPtr (C++ type), 422

osgeo::proj::operation::createApproximateInverseIfPossible (C++ function), 423

osgeo::proj::operation::createPropertiesForInverse (C++ function), 423

osgeo::proj::operation::DISCARD_OPERATION_IF_MISSING_GRID (C++ enumerator), 457

osgeo::proj::operation::exportSourceCRSAndTargetCRSToWKT (C++ function), 423

osgeo::proj::operation::FILENAME (C++ enumerator), 463

osgeo::proj::operation::GeneralOperationParameter (C++ class), 460

osgeo::proj::operation::GeneralOperationParameterNNPtr (C++ type), 422

osgeo::proj::operation::GeneralOperationParameterPtr (C++ type), 422

osgeo::proj::operation::GeneralParameterValue (C++ class), 460

osgeo::proj::operation::GeneralParameterValueNNPtr (C++ type), 422

osgeo::proj::operation::GeneralParameterValuePtr (C++ type), 422

osgeo::proj::operation::getResolvedCRS (C++ function), 423

osgeo::proj::operation::GridAvailabilityUse (C++ enum), 456

osgeo::proj::operation::GridDescription (C++ class), 461

osgeo::proj::operation::GridDescription::available (C++ member), 461

osgeo::proj::operation::GridDescription::directDownload (C++ member), 461

osgeo::proj::operation::GridDescription::fullName (C++ member), 461

osgeo::proj::operation::GridDescription::openLicense (C++ member), 461

osgeo::proj::operation::GridDescription::packageName (C++ member), 461

osgeo::proj::operation::GridDescription::shortName (C++ member), 461

osgeo::proj::operation::GridDescription::url (C++ member), 461

osgeo::proj::operation::IF_NO_DIRECT_TRANSFORMATION (C++ enumerator), 457

osgeo::proj::operation::IGNORE_GRID_AVAILABILITY (C++ enumerator), 457

osgeo::proj::operation::INTEGER (C++ enumerator), 463

osgeo::proj::operation::IntermediateCRSUse (C++ enum), 457

osgeo::proj::operation::INTERSECTION (C++ enumerator), 456

osgeo::proj::operation::InvalidOperation (C++ class), 461

osgeo::proj::operation::isTimeDependent (C++ function), 423

osgeo::proj::operation::MEASURE (C++ enumerator), 463

osgeo::proj::operation::negate (C++ function), 423

osgeo::proj::operation::NEVER (C++ enumerator), 457

osgeo::proj::operation::NONE (C++ enumerator), 456

osgeo::proj::operation::OperationMethod (C++ class), 461

osgeo::proj::operation::OperationMethod::create (C++ function), 462

osgeo::proj::operation::OperationMethod::formula (C++ function), 461

osgeo::proj::operation::OperationMethod::formulaCitation (C++ function), 461

osgeo::proj::operation::OperationMethod::getEpsgCode (C++ function), 462

osgeo::proj::operation::OperationMethod::parameters (C++ function), 461

osgeo::proj::operation::OperationMethodNNPtr (C++ type), 422

osgeo::proj::operation::OperationMethodPtr (C++ type), 422

osgeo::proj::operation::OperationParameter (C++ class), 462

osgeo::proj::operation::OperationParameter::create (C++ function), 462

osgeo::proj::operation::OperationParameter::getEpsgCode (C++ function), 462

osgeo::proj::operation::OperationParameter::getNameForEpsgCode (C++ function), 462

osgeo::proj::operation::OperationParameterNNPtr (C++ type), 422

osgeo::proj::operation::OperationParameterPtr (C++ type), 422

osgeo::proj::operation::OperationParameterValue (C++ class), 462
osgeo::proj::operation::OperationParameterValue::create (C++ function), 463
osgeo::proj::operation::OperationParameterValue::parameter (C++ function), 463
osgeo::proj::operation::OperationParameterValue::parameterValue (C++ function), 463
osgeo::proj::operation::OperationParameterValueNNPtr (C++ type), 422
osgeo::proj::operation::OperationParameterValuePtr (C++ type), 422
osgeo::proj::operation::ParameterValue (C++ class), 463
osgeo::proj::operation::ParameterValue::booleanValue (C++ function), 464
osgeo::proj::operation::ParameterValue::createFilename (C++ function), 465
osgeo::proj::operation::ParameterValue::integerValue (C++ function), 464
osgeo::proj::operation::ParameterValue::stringValue (C++ function), 464
osgeo::proj::operation::ParameterValue::type (C++ function), 464
osgeo::proj::operation::ParameterValue::value (C++ function), 464
osgeo::proj::operation::ParameterValue::valueFile (C++ function), 464
osgeo::proj::operation::ParameterValueNNPtr (C++ type), 422
osgeo::proj::operation::ParameterValuePtr (C++ type), 422
osgeo::proj::operation::PARTIAL_INTERSECTION (C++ enumerator), 456
osgeo::proj::operation::PointMotionOperation (C++ class), 465
osgeo::proj::operation::PointMotionOperationNNPtr (C++ type), 423
osgeo::proj::operation::PointMotionOperationPtr (C++ type), 423
osgeo::proj::operation::SingleOperation (C++ class), 465
osgeo::proj::operation::SingleOperation::createPROJBased (C++ function), 466
osgeo::proj::operation::SingleOperation::gridsNeeded (C++ function), 466
osgeo::proj::operation::SingleOperation::method (C++ function), 465
osgeo::proj::operation::SingleOperation::parameterValue (C++ function), 465
osgeo::proj::operation::SingleOperation::parameterValueMeasure (C++ function), 465, 466
osgeo::proj::operation::SingleOperation::parameterValues (C++ function), 465
osgeo::proj::operation::SingleOperation::validateParameters (C++ function), 466
osgeo::proj::operation::SingleOperationNNPtr (C++ type), 422
osgeo::proj::operation::SingleOperationPtr (C++ type), 422
osgeo::proj::operation::SMALLEST (C++ enumerator), 456
osgeo::proj::operation::SourceTargetCRSExtentUse (C++ enum), 456
osgeo::proj::operation::SpatialCriterion (C++ enum), 456
osgeo::proj::operation::STRING (C++ enumerator), 463
osgeo::proj::operation::Transformation (C++ class), 466
osgeo::proj::operation::Transformation::create (C++ function), 467
osgeo::proj::operation::Transformation::createAbridgedMolodensky (C++ function), 473
osgeo::proj::operation::Transformation::createChangeVerticalUnit (C++ function), 476
osgeo::proj::operation::Transformation::createCoordinateFrameRotation (C++ function), 469
osgeo::proj::operation::Transformation::createGeocentricTranslations (C++ function), 468
osgeo::proj::operation::Transformation::createGeographic2DOffsets (C++ function), 475
osgeo::proj::operation::Transformation::createGeographic2DWithHeightOffsets (C++ function), 475
osgeo::proj::operation::Transformation::createGeographic3DOffsets (C++ function), 475
osgeo::proj::operation::Transformation::createGravityRelatedHeightToGeographic3D (C++ function), 474
osgeo::proj::operation::Transformation::createLongitudeRotation (C++ function), 474
osgeo::proj::operation::Transformation::createMolodensky (C++ function), 473
osgeo::proj::operation::Transformation::createNTv2 (C++ function), 472
osgeo::proj::operation::Transformation::createPositionVector (C++ function), 468
osgeo::proj::operation::Transformation::createTimeDependentCoordinateFrameRotation (C++ function), 470
osgeo::proj::operation::Transformation::createTimeDependentPositionVector (C++ function), 469
osgeo::proj::operation::Transformation::createTOWGS84 (C++ function), 472
osgeo::proj::operation::Transformation::createVERTCON (C++ function), 474
osgeo::proj::operation::Transformation::inverse (C++ function), 467
osgeo::proj::operation::Transformation::sourceCRS (C++ function), 467
osgeo::proj::operation::Transformation::substitutePROJAlternativeGridNames (C++ function), 467
osgeo::proj::operation::Transformation::targetCRS (C++ function), 467
osgeo::proj::operation::TransformationPtr (C++ type), 423
osgeo::proj::util::ArrayOfBaseObject (C++ class), 368
osgeo::proj::util::ArrayOfBaseObject::add (C++ function), 368
osgeo::proj::util::ArrayOfBaseObject::create (C++ function), 368
osgeo::proj::util::ArrayOfBaseObjectNNPtr (C++ type), 367
osgeo::proj::util::ArrayOfBaseObjectPtr (C++ type), 367
osgeo::proj::util::BaseObject (C++ class), 368
osgeo::proj::util::BaseObject::C::operator (C++ function), 368
osgeo::proj::util::BaseObject::create (C++ function), 368
osgeo::proj::util::BaseObjectNNPtr (C++ type), 367
osgeo::proj::util::BaseObjectPtr (C++ type), 367
osgeo::proj::util::Coefficient (C++ class), 368
osgeo::proj::util::Coefficient::C::operator (C++ function), 368
osgeo::proj::util::Coefficient::create (C++ function), 368
osgeo::proj::util::CoefficientNNPtr (C++ type), 367
osgeo::proj::util::CodingScheme (C++ class), 368
osgeo::proj::util::CodingScheme::toString (C++ function), 369
osgeo::proj::util::CodeList (C++ class), 368
osgeo::proj::util::CodeList::toString (C++ function), 369
osgeo::proj::util::Criterion (C++ enum), 370
osgeo::proj::util::Criterion::isEquivalentTo (C++ function), 370
osgeo::proj::util::Exception (C++ class), 369
osgeo::proj::util::Exception::what (C++ function), 369
osgeo::proj::util::GenericName (C++ class), 369
osgeo::proj::util::GenericName::toFullyQualifiedName (C++ function), 369
osgeo::proj::util::GenericName::toString (C++ function), 369
osgeo::proj::util::IComparable (C++ class), 369
osgeo::proj::util::IComparable::isEquivalentTo (C++ function), 370
osgeo::proj::util::InvalidValueTypeException (C++ class), 370
osgeo::proj::util::LocalName (C++ class), 370
osgeo::proj::util::LocalName::scope (C++ function), 370
osgeo::proj::util::LocalName::toFullyQualifiedName (C++ function), 370
osgeo::proj::util::LocalName::toString (C++ function), 370
osgeo::proj::util::LocalNameNNPtr (C++ type), 367
osgeo::proj::util::LocalNamePtr (C++ type), 367
osgeo::proj::util::NameFactory (C++ class), 370
osgeo::proj::util::NameFactory::createGenericName (C++ function), 371
osgeo::proj::util::NameFactory::createLocalName (C++ function), 371
osgeo::proj::util::NameFactory::createNameSpace (C++ function), 371
osgeo::proj::util::NameSpace (C++ class), 371
osgeo::proj::util::NameSpace::isGlobal (C++ function), 371
osgeo::proj::util::NameSpace::name (C++ function), 371
osgeo::proj::util::NameSpaceNNPtr (C++ type), 367
osgeo::proj::util::NameSpacePtr (C++ type), 367
osgeo::proj::util::optional (C++ class), 371
osgeo::proj::util::optional::has_value (C++ function), 372
osgeo::proj::util::optional::operator bool (C++ function), 372
osgeo::proj::util::optional::operator* (C++ function), 372
osgeo::proj::util::optional::operator-> (C++ function), 372
osgeo::proj::util::PropertyMap (C++ class), 372
osgeo::proj::util::PropertyMap::set (C++ function), 372
osgeo::proj::util::STRICT (C++ enumerator), 370
osgeo::proj::util::UnsupportedOperationException (C++ class), 372

PJ (C type), 312
PJ_AREA (C type), 312
PJ_CONTEXT (C type), 312
PJ_COORD (C type), 315
PJ_COORD.PJ_COORD.lp (C member), 316
PJ_COORD.PJ_COORD.lpz (C member), 316
PJ_COORD.PJ_COORD.lpzt (C member), 315
PJ_COORD.PJ_COORD.uv (C member), 316
PJ_COORD.PJ_COORD.uvw (C member), 316
PJ_COORD.PJ_COORD.uvwt (C member), 315
PJ_COORD.PJ_COORD.xy (C member), 316
PJ_COORD.PJ_COORD.xyz (C member), 315
PJ_COORD.PJ_COORD.xyzt (C member), 315
PJ_DIRECTION (C type), 312
PJ_DIRECTION.PJ_FWD (C member), 312
PJ_DIRECTION.PJ_IDENT (C member), 312
PJ_DIRECTION.PJ_INV (C member), 312
PJ_ELLPS (C type), 317
PJ_ELLPS.ell (C member), 317
PJ_ELLPS.id (C member), 317
PJ_ELLPS.major (C member), 317
PJ_ELLPS.name (C member), 317
PJ_FACTORS (C type), 316
PJ_FACTORS.PJ_FACTORS.angular_distortion (C member), 316
PJ_FACTORS.PJ_FACTORS.areal_scale (C member), 316
PJ_FACTORS.PJ_FACTORS.dx_dlam (C member), 317
PJ_FACTORS.PJ_FACTORS.dx_dphi (C member), 317
PJ_FACTORS.PJ_FACTORS.dy_dlam (C member), 317
PJ_FACTORS.PJ_FACTORS.dy_dphi (C member), 317
PJ_FACTORS.PJ_FACTORS.meridian_convergence (C member), 316
PJ_FACTORS.PJ_FACTORS.meridian_parallel_angle (C member), 316
PJ_FACTORS.PJ_FACTORS.meridional_scale (C member), 316
PJ_FACTORS.PJ_FACTORS.parallel_scale (C member), 316
PJ_FACTORS.PJ_FACTORS.tissot_semimajor (C member), 316
PJ_FACTORS.PJ_FACTORS.tissot_semiminor (C member), 317
PJ_GRID_INFO (C type), 319
PJ_GRID_INFO.PJ_GRID_INFO (C member), 319
PJ_GRID_INFO.PJ_GRID_INFO.cs_lat (C member), 320
PJ_GRID_INFO.PJ_GRID_INFO.cs_lon (C member), 320
PJ_GRID_INFO.PJ_GRID_INFO.lowerleft (C member), 320
PJ_GRID_INFO.PJ_GRID_INFO.n_lat (C member), 320
PJ_GRID_INFO.PJ_GRID_INFO.n_lon (C member), 320
PJ_GRID_INFO.PJ_GRID_INFO.upperright (C member), 320
PJ_INFO (C type), 318
PJ_INFO.PJ_INFO.major (C member), 318
PJ_INFO.PJ_INFO.minor (C member), 318
PJ_INFO.PJ_INFO.patch (C member), 319
PJ_INFO.PJ_INFO.release (C member), 318
PJ_INFO.PJ_INFO.searchpath (C member), 319
PJ_INFO.PJ_INFO.version (C member), 318
PJ_INIT_INFO (C type), 320
PJ_INIT_INFO.PJ_INIT_INFO.lastupdate (C member), 320
PJ_LOG_FUNC (C type), 321
PJ_LOG_LEVEL (C type), 320
PJ_LOG_LEVEL.PJ_LOG_DEBUG (C member), 320
PJ_LOG_LEVEL.PJ_LOG_ERROR (C member), 320
PJ_LOG_LEVEL.PJ_LOG_NONE (C member), 320
PJ_LOG_LEVEL.PJ_LOG_TELL (C member), 321
PJ_LOG_LEVEL.PJ_LOG_TRACE (C member), 320
PJ_LP (C type), 312
PJ_LP.PJ_LP.lam (C member), 312
PJ_LP.PJ_LP.phi (C member), 312
PJ_LPZ (C type), 313
PJ_LPZ.PJ_LPZ.lam (C member), 313
PJ_LPZ.PJ_LPZ.phi (C member), 313
PJ_LPZ.PJ_LPZ.z (C member), 313
PJ_LPZT (C type), 314
PJ_LPZT.PJ_LPZT.lam (C member), 314
PJ_LPZT.PJ_LPZT.phi (C member), 314
PJ_LPZT.PJ_LPZT.t (C member), 314
PJ_LPZT.PJ_LPZT.z (C member), 314
PJ_OPERATIONS (C type), 317
PJ_OPERATIONS.id (C member), 317
PJ_OPERATIONS.op (C member), 317
PJ_OPK (C type), 315
PJ_OPK.PJ_OPK.k (C member), 315
PJ_OPK.PJ_OPK.o (C member), 315
PJ_OPK.PJ_OPK.p (C member), 315
PJ_PRIME_MERIDIANS (C type), 318
PJ_PRIME_MERIDIANS.def (C member), 318
PJ_PRIME_MERIDIANS.id (C member), 318
PJ_PROJ_INFO (C type), 319
PJ_PROJ_INFO.PJ_PROJ_INFO.accuracy (C member), 319
PJ_PROJ_INFO.PJ_PROJ_INFO.definition (C member), 319
PJ_PROJ_INFO.PJ_PROJ_INFO.description (C member), 319
PJ_PROJ_INFO.PJ_PROJ_INFO.has_inverse (C member), 319
PJ_PROJ_INFO.PJ_PROJ_INFO.id (C member), 319
PJ_UNITS (C type), 317
PJ_UNITS.factor (C member), 318
PJ_UNITS.id (C member), 318
PJ_UNITS.name (C member), 318
PJ_UNITS.to_meter (C member), 318
PJ_UV (C type), 313
PJ_UV.PJ_UV.u (C member), 313
PJ_UV.PJ_UV.v (C member), 313
PJ_UVW (C type), 313
PJ_UVW.PJ_UVW.u (C member), 313
PJ_UVW.PJ_UVW.v (C member), 313
PJ_UVW.PJ_UVW.w (C member), 314
PJ_UVWT (C type), 314
PJ_UVWT.PJ_UVWT.e (C member), 314
PJ_UVWT.PJ_UVWT.n (C member), 315
PJ_UVWT.PJ_UVWT.t (C member), 315
PJ_UVWT.PJ_UVWT.w (C member), 315
PJ_XY (C type), 312
PJ_XY.PJ_XY.x (C member), 313
PJ_XY.PJ_XY.y (C member), 313
PJ_XYZ (C type), 313
PJ_XYZ.PJ_XYZ.x (C member), 313
PJ_XYZ.PJ_XYZ.y (C member), 313
PJ_XYZ.PJ_XYZ.z (C member), 313
PJ_XYZT (C type), 314
PJ_XYZT.PJ_XYZT.t (C member), 314
PJ_XYZT.PJ_XYZT.x (C member), 314
PJ_XYZT.PJ_XYZT.y (C member), 314
PJ_XYZT.PJ_XYZT.z (C member), 314
proj, 52
proj command line option
  -E, 53
  -I, 53
  -s, 53
  -v, 54
  -W<n>, 54
  -b, 53
  -d <n>, 53
  -e <string>, 53
  -f <format>, 54
  -i, 53
  -lP, 53
  -l<=[id]>, 53
  -ld, 53
  -lu, 53
  -m <mult>, 54
-o, 53
-r, 53
-s, 53
-t, 53
-v, 54
-w<n>, 54
proj_angular_input (C function), 335
proj_angular_output (C function), 335
proj_area_create (C function), 328
proj_area_destroy (C function), 328
proj_area_set_bbox (C function), 328
proj_as_proj_string (C++ function), 342
proj_as_projjson (C++ function), 343
proj_as_wkt (C++ function), 342
proj_cleanup (C function), 336
proj_clone (C++ function), 339
proj_concatoperation_get_step (C++ function), 357
proj_concatoperation_get_step_count (C++ function), 357
proj_context_create (C function), 325
proj_context_destroy (C function), 325
proj_context_errno (C function), 330
proj_context_get_database_metadata (C++ function), 337
proj_context_get_database_path (C++ function), 336
proj_context_guess_wkt_dialect (C++ function), 337
proj_context_set_autoclose_database (C++ function), 336
proj_context_set_database_path (C++ function), 336
proj_coord (C function), 334
proj_coordoperation_create_inverse (C++ function), 356
proj_coordoperation_get_accuracy (C++ function), 356
proj_coordoperation_get_grid_used (C++ function), 355
proj_coordoperation_get_grid_used_count (C++ function), 355
proj_coordoperation_get_method_info (C++ function), 353
proj_coordoperation_get_param (C++ function), 355
proj_coordoperation_get_param_count (C++ function), 354
proj_coordoperation_get_param_index (C++ function), 354
proj_coordoperation_get_towgs84_values (C++ function), 356
proj_coordoperation_has_ballpark_transformation (C++ function), 354
proj_coordoperation_is_instantiable (C++ function), 354
proj_create (C function), 325
proj_create_argv (C function), 326
proj_create_crs_to_crs (C function), 326
proj_create_crs_to_crs_from_pj (C function), 327
proj_create_from_database (C++ function), 337
proj_create_from_name (C++ function), 339
proj_create_from_wkt (C++ function), 337
proj_create_operation_factory_context (C++ function), 346
proj_create_operations (C++ function), 349
proj_crs_get_coordinate_system (C++ function), 351
proj_crs_get_coordoperation (C++ function), 353
proj_crs_get_datum (C++ function), 351
proj_crs_get_geodetic_crs (C++ function), 350
proj_crs_get_horizontal_datum (C++ function), 350
proj_crs_get_sub_crs (C++ function), 350
PROJ_CRS_INFO (C++ class), 324
<table>
<thead>
<tr>
<th>Function Name</th>
<th>Type</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>proj_crs_info_list_destroy</code></td>
<td>C++ function</td>
<td>346</td>
</tr>
<tr>
<td><code>PROJ_CRS_LIST_PARAMETERS</code></td>
<td>C++ class</td>
<td>325</td>
</tr>
<tr>
<td><code>proj_cs_get_axis_count</code></td>
<td>C++ function</td>
<td>351</td>
</tr>
<tr>
<td><code>proj_cs_get_axis_info</code></td>
<td>C++ function</td>
<td>352</td>
</tr>
<tr>
<td><code>proj_cs_get_type</code></td>
<td>C++ function</td>
<td>351</td>
</tr>
<tr>
<td><code>proj_destroy</code></td>
<td>C function</td>
<td>327</td>
</tr>
<tr>
<td><code>proj_dmstor</code></td>
<td>C function</td>
<td>355</td>
</tr>
<tr>
<td><code>proj_ellipsoid_get_parameters</code></td>
<td>C++ function</td>
<td>352</td>
</tr>
<tr>
<td><code>proj_errno</code></td>
<td>C function</td>
<td>330</td>
</tr>
<tr>
<td><code>proj_errno_reset</code></td>
<td>C function</td>
<td>330</td>
</tr>
<tr>
<td><code>proj_errno_restore</code></td>
<td>C function</td>
<td>331</td>
</tr>
<tr>
<td><code>proj_errno_set</code></td>
<td>C function</td>
<td>330</td>
</tr>
<tr>
<td><code>proj_errno_string</code></td>
<td>C function</td>
<td>331</td>
</tr>
<tr>
<td><code>proj_factors</code></td>
<td>C function</td>
<td>334</td>
</tr>
<tr>
<td><code>proj_get_area_of_use</code></td>
<td>C++ function</td>
<td>341</td>
</tr>
<tr>
<td><code>proj_get_authorities_from_database</code></td>
<td>C++ function</td>
<td>345</td>
</tr>
<tr>
<td><code>proj_get_codes_from_database</code></td>
<td>C++ function</td>
<td>345</td>
</tr>
<tr>
<td><code>proj_get_crs_info_list_from_database</code></td>
<td>C++ function</td>
<td>345</td>
</tr>
<tr>
<td><code>proj_get_crs_list_parameters_create</code></td>
<td>C++ function</td>
<td>345</td>
</tr>
<tr>
<td><code>proj_get_crs_list_parameters_destroy</code></td>
<td>C++ function</td>
<td>345</td>
</tr>
<tr>
<td><code>proj_get_ellipsoid</code></td>
<td>C++ function</td>
<td>352</td>
</tr>
<tr>
<td><code>proj_get_id_auth_name</code></td>
<td>C++ function</td>
<td>341</td>
</tr>
<tr>
<td><code>proj_get_id_code</code></td>
<td>C++ function</td>
<td>341</td>
</tr>
<tr>
<td><code>proj_get_name</code></td>
<td>C++ function</td>
<td>340</td>
</tr>
<tr>
<td><code>proj_get_non_deprecated</code></td>
<td>C++ function</td>
<td>340</td>
</tr>
<tr>
<td><code>proj_get_prime_meridian</code></td>
<td>C++ function</td>
<td>353</td>
</tr>
<tr>
<td><code>proj_get_remarks</code></td>
<td>C++ function</td>
<td>341</td>
</tr>
<tr>
<td><code>proj_get_scope</code></td>
<td>C++ function</td>
<td>341</td>
</tr>
<tr>
<td><code>proj_get_source_crs</code></td>
<td>C++ function</td>
<td>343</td>
</tr>
<tr>
<td><code>proj_get_target_crs</code></td>
<td>C++ function</td>
<td>344</td>
</tr>
<tr>
<td><code>proj_get_type</code></td>
<td>C++ function</td>
<td>339</td>
</tr>
<tr>
<td><code>proj_grid_get_info_from_database</code></td>
<td>C++ function</td>
<td>338</td>
</tr>
<tr>
<td><code>proj_grid_info</code></td>
<td>C function</td>
<td>332</td>
</tr>
<tr>
<td><code>proj_identify</code></td>
<td>C++ function</td>
<td>344</td>
</tr>
<tr>
<td><code>proj_info</code></td>
<td>C function</td>
<td>332</td>
</tr>
<tr>
<td><code>proj_init_info</code></td>
<td>C function</td>
<td>332</td>
</tr>
<tr>
<td><code>proj_int_list_destroy</code></td>
<td>C++ function</td>
<td>344</td>
</tr>
<tr>
<td><code>proj_is_crs</code></td>
<td>C++ function</td>
<td>340</td>
</tr>
<tr>
<td><code>proj_is_deprecated</code></td>
<td>C++ function</td>
<td>339</td>
</tr>
<tr>
<td><code>proj_is_equivalent_to</code></td>
<td>C++ function</td>
<td>340</td>
</tr>
<tr>
<td>PROJ_LIB</td>
<td></td>
<td>6, 7, 9, 22, 23, 33, 34, 45, 54, 57, 295, 566</td>
</tr>
<tr>
<td><code>proj_list_destroy</code></td>
<td>C++ function</td>
<td>350</td>
</tr>
<tr>
<td><code>proj_list_ellps</code></td>
<td>C function</td>
<td>332</td>
</tr>
<tr>
<td><code>proj_list_get</code></td>
<td>C++ function</td>
<td>350</td>
</tr>
<tr>
<td><code>proj_list_get_count</code></td>
<td>C++ function</td>
<td>349</td>
</tr>
<tr>
<td><code>proj_list_operations</code></td>
<td>C function</td>
<td>332</td>
</tr>
<tr>
<td><code>proj_list_prime_meridians</code></td>
<td>C function</td>
<td>333</td>
</tr>
<tr>
<td><code>proj_list_units</code></td>
<td>C function</td>
<td>333</td>
</tr>
<tr>
<td><code>proj_log_func</code></td>
<td>C function</td>
<td>331</td>
</tr>
<tr>
<td><code>proj_log_level</code></td>
<td>C function</td>
<td>331</td>
</tr>
<tr>
<td><code>proj_lp_dist</code></td>
<td>C function</td>
<td>333</td>
</tr>
<tr>
<td><code>proj_lpz_dist</code></td>
<td>C function</td>
<td>333</td>
</tr>
<tr>
<td><code>proj_normalize_for_visualization</code></td>
<td>C function</td>
<td>327</td>
</tr>
</tbody>
</table>
proj_operation_factory_context_destroy (C++ function), 346
proj_operation_factory_context_set_allow_use_intermediate_crs (C++ function), 348
proj_operation_factory_context_set_allowed_intermediate_crs (C++ function), 349
proj_operation_factory_context_set_area_of_interest (C++ function), 346
proj_operation_factory_context_set_crs_extent_use (C++ function), 347
proj_operation_factory_context_set_desired_accuracy (C++ function), 346
proj_operation_factory_context_set_discard_superseded (C++ function), 349
proj_operation_factory_context_set_grid_availability_use (C++ function), 347
proj_operation_factory_context_set_spatial_criterion (C++ function), 347
proj_operation_factory_context_set_use_proj_alternative_grid_names (C++ function), 348
proj_pj_info (C function), 332
proj_prime_meridian_get_parameters (C++ function), 353
proj_roundtrip (C function), 334
proj_rtoDMS (C function), 335
PROJ_STRING_LIST (C++ type), 324
proj_string_list_destroy (C++ function), 336
proj_toDeg (C function), 335
proj_torad (C function), 335
proj_trans (C function), 328
proj_trans_array (C function), 330
proj_trans_generic (C function), 328
proj_uom_get_info_from_database (C++ function), 338
proj_xy_dist (C function), 333
proj_xyz_dist (C function), 333
projinfo, 55
projinfo command line option
   --3d, 58
   --area name_or_code, 56
   --aux-db-path path, 58
   --bbox west_long,south_lat,east_long,north_lat, 56
   --boundcrs-to-wgs84, 58
   --c-ify, 58
   --crs-extent-use none|both|intersection|smallest, 57
   --grid-check none|discard_missing|sort, 57
   --identify, 58
   --main-db-path path, 58
   --pivot-crs always|if_no_direct_transformation|never|{auth:code[,auth:code]*}, 57
   --single-line, 58
   --spatial-test contains|intersects, 57
   --summary, 56
   -k crs|operation|ellipsoid, 56
   -o formats, 56
   -q, 56
   -show-superseded, 57
Pseudocylindrical Projection, 567

R
require_grid <grid_name>
   command line option, 51
roundtrip <n> <tolerance>
   command line option, 50
S
skip
    command line option, 51
standards (C++ type), 358

T
tolerance <tolerance>
    command line option, 50

W
WKT1 (C++ type), 359
WKT2 (C++ type), 359
WKT2_2015 (C++ type), 359
WKT2_2019 (C++ type), 359