IMPLEMENTATION OF DATUM TRANSFORMATIONS FOR THE ITALIAN TERRITORY IN GRASS: METHODOLOGY, PROBLEMS AND EXPERIMENTS

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Abstract

This paper describes the creation of new grids for datum transformation in the PROJ4 library, providing a technical insight of the implementation and use issues. The results obtained during their use in GRASS are reported. The grids used in this study were originally developed for the Italian territory, using data published in Bollettino di Geodesia e Scienze Affini for the transformations among ROMA1940, ED1950 and WGS84-ETRF89 datum. The accuracy of the transformations based on these new grids is tested against official data supplied by the Geodetic Division of Italian Geographic Army Institute (IGMI). This comparison, taking also into account already published results regarding performances of other common GIS softwares, shows that GRASS is now the GIS software allowing the highest accuracy in datum transformation within the Italian territory.

1 - Introduction

Nowadays, it is quite frequent that geographic data (including the official cartography) in a national context refer to different datum and different cartographic projections, mostly for historical reasons. This is the main reason for establishing transformation procedures among different datum. In fact, all commercial GIS software supplies these procedures with different approaches and accuracies, while for the GRASS software datum transformations are provided by the (external) PROJ4 library.

For the Italian territory, a new GRASS command to perform such datum transformation has been already implemented and tested (Baiocchi et al., 2004b), since the standard PROJ4 installation just supplies parameters to perform Molodensky or Helmert global transformations, which are too rough (accuracy at tens of meters level) for cartography and territorial data at medium and large scale (1:10000 and larger). For further details about these transformations it is possible to refer to (NIMA, 2000), which includes both theoretical setup and parameter values.

On the other hand, the same PROJ4 library contains grids for datum transformation with an accuracy suited for these scales on the North American territory, therefore it has been decided to investigate whether proper grids for the Italian territory could be inserted in the routine too, starting from public data available on the Bollettino di Geodesia e Scienze Affini (suitably integrated in some areas) already adopted to build the aforementioned GRASS command.

In particular, grids for the Italian territory have been generated by vectorization of the geographic coordinate differences contour maps for the transformation ROMA1940 - ED1950 (Pericoli, 1971) and ROMA1940 - WGS84-ETRF89 (Surace, 1997) and integration with additional surveyed data (in particular in Central Italy). This has led to a regular grid with 132x97=12804 nodes in the WGS84-ETRF89 datum (latitude 5' x longitude 7'30", approximately 10 x 10 km) of latitude/longitude differences between WGS84-ETRF89 and the other datum.

Several problems have been encountered inserting the grids into PROJ4 and then using them in GRASS; the necessary tips to perform these tasks are discussed in § 2 and 3, after a short recall about how the PROJ4 library works with grids. In order to assess the accuracy of the new grid approach for the Italian area, three grids of 347 points regularly distributed over the entire Italian territory, each attaining to one datum (ROMA1940, ED1950, WGS84-ETRF89) have been acquired from the Geodetic Division of Italian Geographic Army Institute (IGMI); therefore a test against official coordinates obtained by IGMI software Verto 2 (Donatelli et al., 2002) has been performed: its results are discussed in § 4.

2 - PROJ4 datum transformations based on the grids

As mentioned before, at present, the only grids for datum transformation available in PROJ4 regard the North American territory. The use of these grids provides an accuracy unattainable in any other country.
Grid nodes are regularly spaced in one datum (reference datum) and are points where geographic coordinate differences are known. To transform the geographic coordinates of a generic point P from one datum to another, PROJ4 applies the following simple procedure (Figure 1):

- it locates the cell point P lies within in its input datum; the vertices of the corresponding cell in the reference datum are points where geographic coordinate differences between input and output datum are known;
- it computes the geographic coordinate differences between input and output datum at point P, estimating a bilinear interpolation within the cell, using as input the (known) differences at cell's vertices;
- it applies the geographic coordinate differences between input and output at P to the input P coordinates, finding point P coordinates in the output datum.

This method allows for very accurate transformations because it accounts for the actual deformations among datum in a finite elements (cells) fashion.

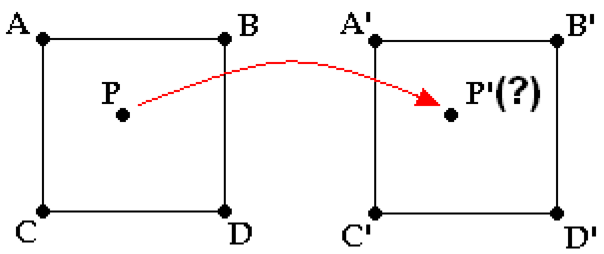

Figure 1 – Transformation of the coordinates through the grids.

Even if the described procedure seems simple, some technicalities regarding the insertion of new grids have to be carefully addressed.
First of all, grids implemented in PROJ4 have to be written in binary format; they may be created as an ASCII file and converted in binary format through a specific utility program (*nad2bin*), provided by the PROJ4 package. Moreover, as mentioned before, grids must be regular in one reference datum, but geographic coordinate differences are not explicitly given at all nodes: they have to be computed from differences between geographic coordinate differences at consecutive nodes in each grid row, starting from the grid origin located in its south-west corner; row number increases from south to north, column number from west to east; this will be detailed hereafter.
The grids used in our case are regular in WGS84-ETRF89 (reference datum) and the ASCII file appears as showed in Figures 2 and 3.
The first line indicates the grid name. In the second line the following values are written, left to right:

- nodes number on each row, since the grid is regular in the reference datum, nodes are aligned along a parallel in this datum;
- rows number;
- the number "1";
- the longitude of the south-west corner;
- the longitude (along a row) nodes spacing;
- the latitude of the south-west corner;
- the latitude (along a column) nodes spacing.

From the third line the differences between geographic coordinate differences at consecutive nodes begin; each row (record) is structured as follows:

$$n°record : \Delta\lambda_1, \Delta\varphi_1, \Delta\lambda_{21}, \Delta\varphi_{21}, \Delta\lambda_{32}, \Delta\varphi_{32}, ..., ..., \Delta\lambda_{n,(n-1)}, \Delta\varphi_{n,(n-1)}$$

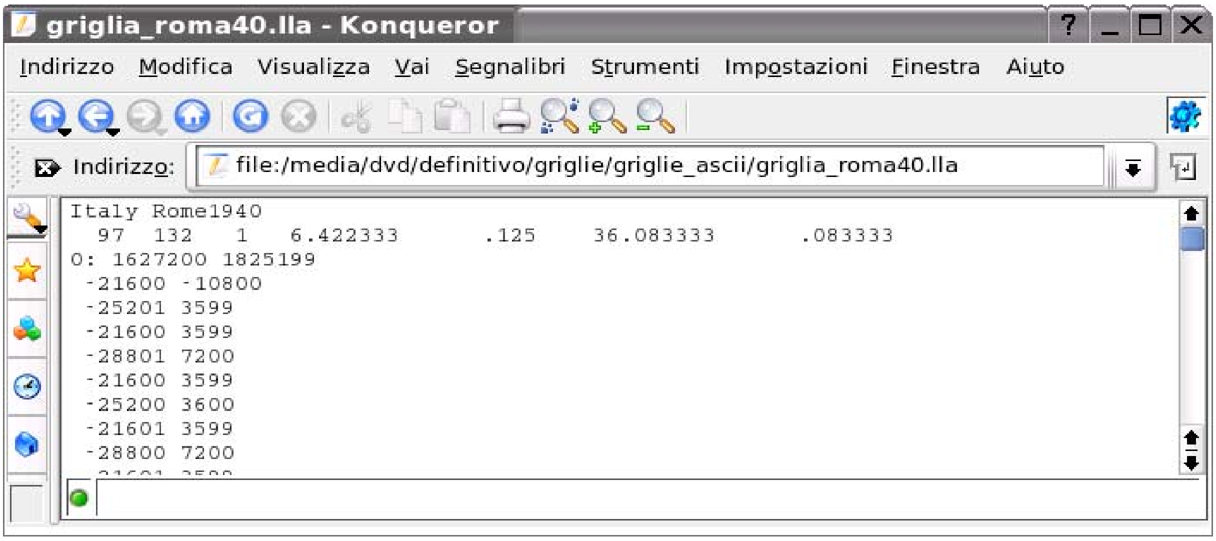

Figure 2 – Grids format in PROJ4.

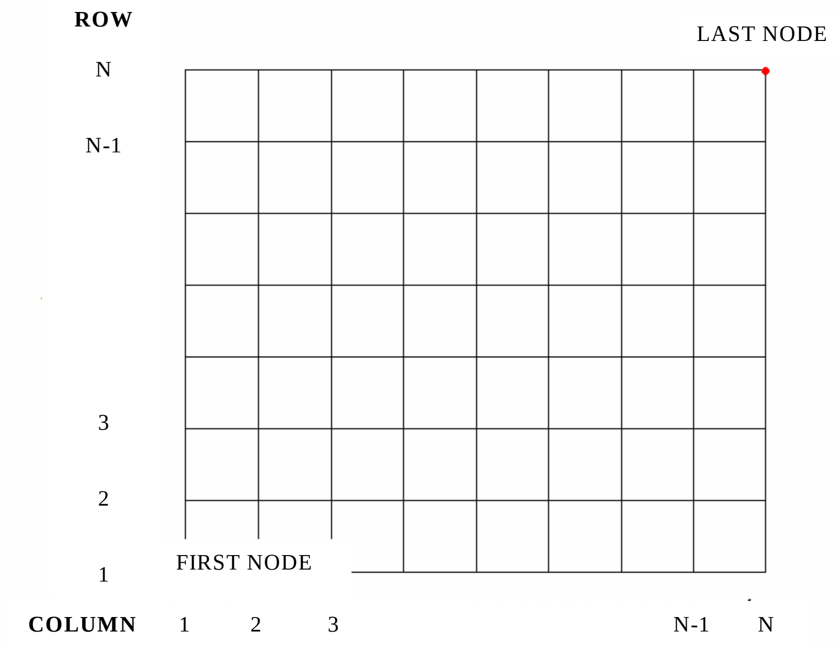

Figure 3 – Rows and columns order in PROJ4 grids.

where:

- n° record: the progressive number of the record, starting from “0“;

- $\Delta\lambda_1 = (\lambda_1^{2nd\_datum} - \lambda_1^{ref\_datum}) \times 3600 \times 10^6$: is the longitude difference at the first row node in microseconds (0.000001”) ($\lambda_1^{2nd\_datum}, \lambda_1^{ref\_datum}$ are in degree), only integer values are accepted;
- $\Delta\varphi_1 = (\varphi_1^{ref\_datum} - \varphi_1^{2nd\_datum}) \times 3600 \times 10^6$: is the latitude difference at the first row node in microseconds (0.000001”) ($\varphi_1^{ref\_datum}, \varphi_1^{2nd\_datum}$ are in degree); only integer values are accepted: one must pay attention to the fact that, due to a quite strange choice, the difference between latitudes is reversed with respect to that of the longitudes;
- $\Delta\lambda_{(i+1),i} = \Delta\lambda_{(i+1)} - \Delta\lambda_i$: is the difference between longitude differences at (i+1)-th and i-th nodes
- $\Delta\varphi_{(i+1),i} = \Delta\varphi_{(i+1)} - \Delta\varphi_i$: is the difference between latitude differences at (i+1)-th and i-th nodes

It is important to remember that between one value and another a blank (empty space) must be placed and each pair of values $\lambda_{(i+1),i}$ $\varphi_{(i+1),i}$ in one record may lie on different row in the ASCII file (Figure 2), i.e. *newline* characters are ignored. Finally, as for grids for datum transformation already available in PROJ4 for the North American territory, reference datum is WGS84.

3 - Grids insertion into GRASS

In our study GRASS version 6.0.0 was used, the OS used being Linux SuSE-9.2.
Grids have been created in ASCII format and then converted into binary format by the *nad2bin* utility (Figure 4). The standard PROJ4 installation places the *nad2bin* binary in the */usr/local/bin* directory: some Linux distributions do not include this directory in the default PATH variable for security reasons, therefore to use this command may be necessary to specify the full path to the binary:

```
/path_to_nad2bin/nad2bin < /path_to_grid_ascii_file/ascii_grid_file_name
/path_to_binary_grid_file/binary_grid_file_name
```

Input is given from the standard input, it may be redirected from a file using “<”.
In the example of Figure 4 *nad2bin* is supposed to be in */usr/local/bin* and the ASCII grid file named *roma40_griglia* in the directory */home/griglie_ascii*. The resulting binary grid file named *roma40_griglia_tab* is created in the */usr/local/grass-6.0.0/etc/nad* directory. To use the binary grid with PROJ4, it must be placed in the binary grid directory of the PROJ4 library: when GRASS is used, it is the same directory that contains the grids for the North American territory already available in PROJ4 (*/GRASS_binary_directory/etc/nad*).

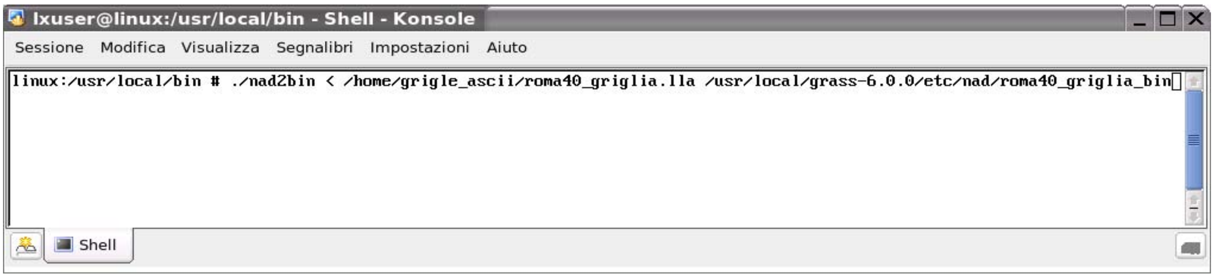

Figure 4 – *nad2bin* syntax example.

The definition of a datum for GRASS is given by two files:

1. *datum.table* which lists the available datum and three translation parameters with respect to WGS84-ETRF89 (Molodensky’s parameters).
2. *datumtrasform.table* which provides additional transformation parameters and/or grid names for each datum, allowing the definition of more than one datum transformation parameters set (of course only one set at once can be selected for a dataset when using GRASS), accounting for different datum definitions. Helmert’s parameters are also given in this file.

These two ASCII file are located in the */usr/local/grass-6.0.0/etc* directory. The *Rome40* datum is already defined in the *datum.table* standard file, if a new datum is being defined it is sufficient to add a new line to this file. To make the new grids available to the user creating a new *location* (a new geographic dataset with a particular datum and projection in GRASS) the file *datumtrasform.table* must be modified, adding a new line for each new grid (Figure 5). When this procedure is complete, the new transformation parameters are available; they can be selected either when a new location is created or subsequently through *g.setproj* command.
Finally, it has to be recalled that transformation by grids requires that all the points to be processed lie within grids boundaries; moreover, for the use of the new Italian grids, it has to be emphasized that all longitudes have to be referred to Greenwich, while ROMA1940 datum usually adopts longitudes referred to Rome-Monte Mario.

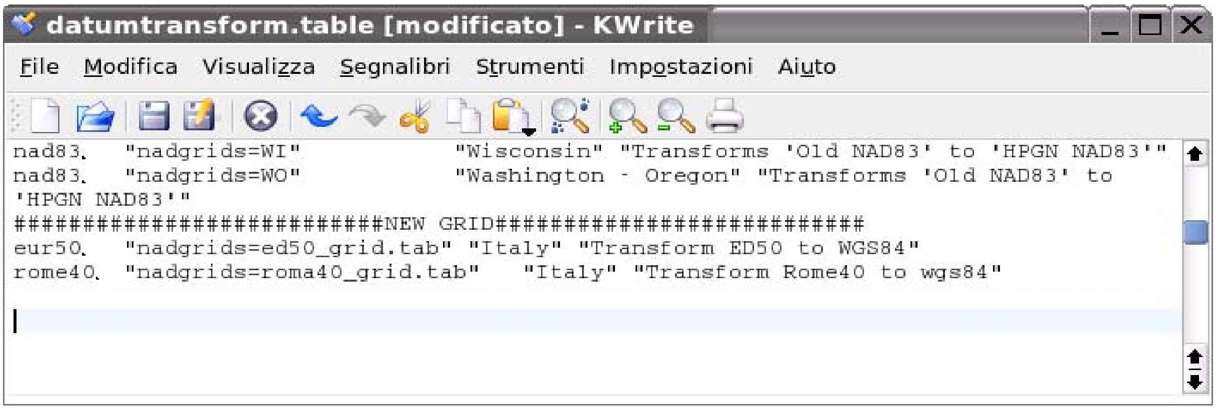

Figure 5 – Modification of *datumtransform.table* file.

4 - Experiments and results

The new grids implemented in PROJ4 and made available in GRASS have been tested over the whole Italian territory by forward and backward transformations between ROMA1940, ED1950 and WGS84-ETRF89 datum.
In particular, 347 points evenly spaced (latitude 20’ x longitude 30’, approximately 40 x 40 km) and distributed on the whole Italian area (Figure 6) have been used in order to evaluate grids accuracy; their transformed coordinates have been compared to the official values obtained by IGMI software Verto 2, assumed as reference values. Test features have been already presented in (Baiocchi et al., 2004a) and results are globally presented in Table 1: they show that an accuracy (RMSE) better than 0.5 m has been achieved in all transformations. This accuracy level is completely suited for managing datum transformation on territorial georeferenced data and cartography at scale as large as 1:2000 without remarkable accuracy loss: this, at present, makes GRASS the GIS software providing the highest accuracy in datum transformation within the Italian territory, given the performances of other commercial GIS softwares (Baiocchi et al., 2002; Baiocchi et al., 2004a).

5 – Conclusions

A procedure to implement new grids for datum transformation in PROJ4 was outlined and used to insert in GRASS grids for transformation among ROMA1940, ED1950 and WGS84-ETRF89 within the Italian territory. Coordinates obtained by the application of the new grids have been checked against official reference values showing that, at present, GRASS is the GIS software allowing the highest accuracy (better than 0.5 m) in datum transformation within the Italian territory.

Figure 6 – Check points.

ROMA1940-WGS84		
(arcsec)	λ	φ
expected value	-0.0054	-0.0006
median	-0.0053	-0.0004
standard deviation	0.0163	0.0098
RMSE	0.0172	0.0098
minimum	-0.0896	-0.0405
maximum	0.0703	0.0496
(meter)	λ	φ
expected value	-0.12	-0.02
median	-0.12	-0.01
standard deviation	0.38	0.30
RMSE	0.40	0.30
minimum	-2.06	-1.25
maximum	1.62	1.53

A

WGS84-ROMA1940		
(arcsec)	λ	φ
expected value	0.0054	0.0006
median	0.0053	0.0004
standard deviation	0.0163	0.0098
RMSE	0.0172	0.0098
minimum	-0.0703	-0.0496
maximum	0.0896	0.0405
(meter)	λ	φ
expected value	0.12	0.02
median	0.12	0.01
standard deviation	0.38	0.30
RMSE	0.40	0.30
minimum	-1.62	-1.53
maximum	2.06	1.25

B

ED1950-WGS84		
(arcsec)	λ	φ
expected value	-0.0030	0.0025
median	-0.0012	0.0003
standard deviation	0.0212	0.0147
RMSE	0.0214	0.0149
minimum	-0.0977	-0.0475
maximum	0.0639	0.0562
(meter)	λ	φ
expected value	-0.07	0.08
median	-0.03	0.01
standard deviation	0.49	0.45
RMSE	0.49	0.46
minimum	-2.25	-1.46
maximum	1.47	1.73

C

WGS84-ED1950		
(arcsec)	λ	φ
expected value	0.0030	-0.0025
median	0.0012	-0.0003
standard deviation	0.0212	0.0147
RMSE	0.0214	0.0149
minimum	-0.0639	-0.0562
maximum	0.0977	0.0475
(meter)	λ	φ
expected value	0.07	-0.08
median	0.03	-0.01
standard deviation	0.49	0.45
RMSE	0.49	0.46
minimum	-1.47	-1.73
maximum	2.25	1.46

D

ROMA1940-ED1950		
(arcsec)	λ	φ
expected value	-0.0024	-0.0032
median	-0.0041	-0.0009
standard deviation	0.0163	0.0141
RMSE	0.0164	0.0144
minimum	-0.0451	-0.0539
maximum	0.0955	0.0527
(meter)	λ	φ
expected value	-0.05	-0.10
median	-0.09	-0.03
standard deviation	0.37	0.43
RMSE	0.38	0.44
minimum	-1.04	-1.66
maximum	2.20	1.62

E

ED1950-ROMA1940		
(arcsec)	λ	φ
expected value	0.0024	0.0032
median	0.0041	0.0009
standard deviation	0.0163	0.0141
RMSE	0.0164	0.0144
minimum	-0.0955	-0.0527
maximum	0.0451	0.0539
(meter)	λ	φ
expected value	0.05	0.10
median	0.09	0.03
standard deviation	0.37	0.43
RMSE	0.38	0.44
minimum	-2.20	-1.62
maximum	1.04	1.66

F

Table 1 – Test results

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