Some generalization practices on relief representation derived from the Topographic Database of Catalonia at scale 1:5000

Blanca Baella, Maria Pla
Institut Cartogràfic de Catalunya
Parc de Montjuïc
E-08038 Barcelona
Telephone 34 93 5671500, FAX 34 93 5671567

Introduction

The Topographic Base of Catalonia at scale 1:5.000 is the basic topographic digital database in vector format, which covers all the country at the largest scale.
At this moment, the Topographic Map of Catalonia at scale 1:10.000 is derived by automatic generalization from this database. This map is distributed on paper and as a digital raster map, but not as a vector database. The data is 2D and the objects of the original database used for creation of networks and other GIS structures are not maintained.
This next product obtained from the Topographic Base of Catalonia at scale 1:5.000, applying automatic generalization, will be the Topographic Base of Catalonia at scale 1:25.000. The project has just started and it is focused on obtaining a 3D database.
The paper presents the workflow of both projects, and it also explains some details about the data structure and the map symbolization, emphasizing the problems introduced by the generalization process in the relief representation.

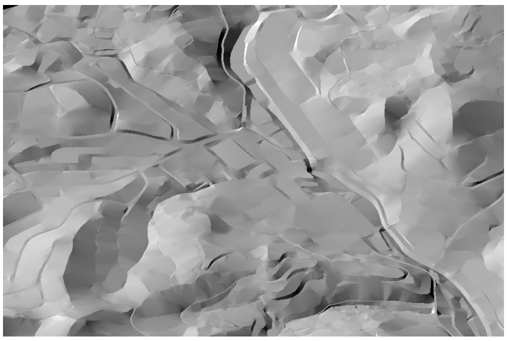
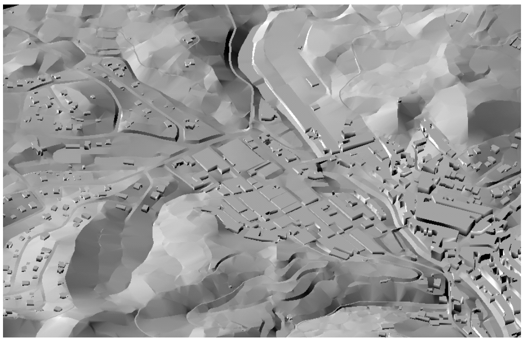
The original data: The Topographic Database of Catalonia at scale 1:5.000

The project of the Topographic Base of Catalonia at scale 1:5.000 was started in 1985. The digital vector data was designed to be stored in 3D, and was digitized using analogical and analytical photogrammetric systems. The information was never structured to create a geographical database for GIS purposes, it was only "spaghetti" data. From the topographic information collected on the terrain, it was obtained a digital terrain model (DTM) in grid format with one point every 15 meters. This DTM was used in the orthophoto rectification and in the generation of shaded relief for maps at smaller scales. This first version was completed in 1995.
In 1996 the updating process was started using digital photogrammetric systems, which allow the superposition of stereo image and vector data. Some changes were introduced in the data structure in order to obtain a database GIS oriented and to facilitate further generalization processes to smaller scales. New design includes polygons, hydrographic and communication networks, blocks in urban areas that help to define street network, classification of map names, etc. To solve the problems derived of the orthophoto rectification using terrain models, the new model of data was designed to store the Digital Terrain Model (DTM) and the Digital Elevation Model (DEM).

Left image shows an orthophoto rectified using a Digital Terrain Model, right image shows the same orthophoto rectified using Digital Elevation Model.

Features for the DTM generation include profiles, breaklines, spot heights, flat areas as pants or lakes and, only in areas with complex terrain, contour lines used to infer breaklines during the generation of the triangulation model. Moreover all the planimetric features captured on the ground are used as breaklines. In the DEM generation, the elevation of areas covered by buildings or bridges substitutes the terrain. Some processes are required to generate special data to avoid vertical triangles, which are not supported by most of the software available.

Left image shows hill shading using the Digital Terrain Model, right image shows the same area using Digital Elevation Model.

DTM data is verified during data capture applying different techniques to detect and correct errors. Crossing tests between breaklines or contour lines allow queuing and assigning correct high value to the erroneous crossing points. Generation of contour lines allows analyzing the result of the interpolation of these elements. Finally, the generation of shaded relieves gives an idea of the quality of the grid and helps to detect small errors. All these verification processes can be repeated until the digitized data become acceptable. The DTM is used to obtain contour lines by interpolation and hill shading generation. The DEM is used for orthophoto rectification.

The generalized products

The Topographic Map of Catalonia at scale 1:10.000

After analyzing the high demand of printed maps of the Topographic Map of Catalonia at scale 1:5.000, the ICC saw that several costumers do need a large number of sheets to cover reduced areas, and concluded that a map at close smaller scale will be quite useful for them. Two aspects were taken in account to decide the smaller scale, 1:10.000, the data availability and the cost to obtain the final product. The production of the Topographic Database of Catalonia at scale 1:5.000 provides data, and the ratio between both scales is low enough to avoid huge costs in the generalization process.
The product obtained is a map, not a database. It doesn't contain more information than the original database, the digital data is 2D, and the objects that allow the creation of networks and other GIS structures, as centerlines or connections, have not been maintained. As the purpose is to obtain a product metrically and aesthetically correct at reduced cost, some particularities in the data are accepted if the result is not visible in the printed map. By example, the software available at the project beginning cannot generalize taking in account the topology. It forces to introduce duplicate lines in shared boundaries that are separately generalized. In some cases these shared lines derive in two different lines as showed in the following figure.

Above image shows the generalization of shared lines in polygon boundaries. The result, where the boundaries are not coincident, is not visible at 1:10.000 scale.

The generation of a database at scale 1:10.000 is not justified because it would have a high cost and it will be close to the original database at scale 1:5.000. The map is distributed on paper and as a digital raster map, but not as a digital vector data.

Workflow, software and productivity

One sheet of the Topographic Map of Catalonia at 1:10.000 is obtained by merging and generalizing four sheets of the Topographic Database at 1:5.000. The workflow of the process is as follows:

AUTOMATIC PROCESS 1 (Windows NT):
- 3D to 2D
- merge of 4 sheets
- elimination
- map names generalization
- marginalia generation
- data preparation for CHANGE (building generalization software)

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AUTOMATIC PROCESS 2 (UNIX):
- translation to CHANGE format
- CHANGE process
  - aggregation of adjacent buildings
  - building simplification

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AUTOMATIC PROCESS 3 (Windows NT):
- translation to DGN format
- topology reconstruction
- small size polygons detection

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MANUAL PROCESS (Windows NT):
- spot height selection
- map names edition
- conflict resolution
- small size polygons resolution
- aesthetic refinement

↓

AUTOMATIC PROCESS 4 (Windows NT):
- simbolization

The UNIX version of the software CHANGE, developed by Prof. D. Grünreich et al. at the Institut of Cartography of the University of Hanover, is used for building aggregation and simplification. Other software systems such as Map Generalizer of Intergraph were tested but results were not satisfactory enough. Operators for elimination, selection, collapse and scaling were developed at the Institut Cartogràfic de Catalunya on top of MicroStation, using C and Visual C++ on Windows NT. The map names are generalized also using software developed at the Institut Cartogràfic de Catalunya that includes an automatic process for selection, scaling and changes in the typography. In addition to the automatic processes, manual tools for interactive generalization were also developed.

So far, 140 map sheets have been produced using this workflow. Average timing is as follows:

PROCESS	TIME	
Total automatic		**7 ‘**
Manual spot height selection	7 h	
Manual map names editing	5 h	
Manual small size polygons resolution		30’
Manual conflict resolution	3 h	30’
Manual aesthetic refinement	4 h	
Total manual	**20 h**	
Data management	1 h	30 ‘
Total per map sheet 1:10.000	**21 h**	**37’**

The Topographic Database of Catalonia at scale 1:25.000

Most of the GIS costumers of ICC are demanding for a topographic database of Catalonia at scale 1:25.000. During this year, the project has started focused on obtaining a 3D database from the Topographic Database of Catalonia at scale 1:5.000. The ratio between both scales and the limitations of the available generalization software are aspects that complicate the generation of a real 3D database by generalization.

Fortunately the commercial software is improving continuously, and offers now the possibility to store, manage, generalize and symbolize 3D data by taking advantage of the topology and the relationship between the objects. At this moment, several commercial software products are being analyzed: DYNAMO from Intergraph is now being tested, and during the next months, LAMPS-2 from Laser Scan will be tested too.

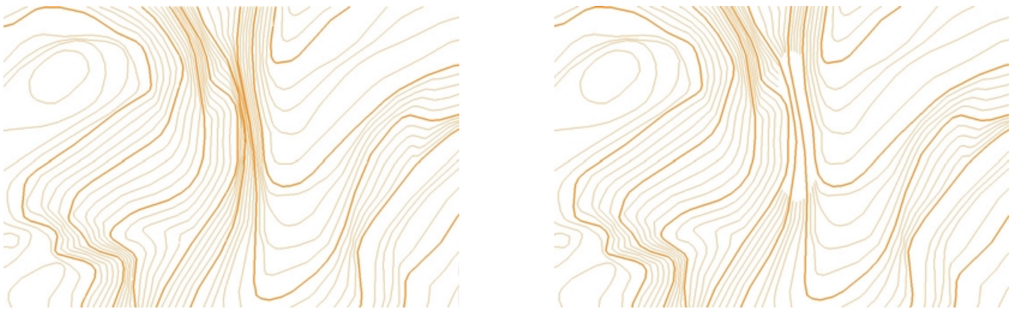
From the generalized database, a printed map with hill shading will be derived using automatic selection and symbolization. The database will also be distributed as digital vector data and the map as digital raster or as paper map.

The relief representation in the Topographic Map at scale 1:10.000

In the generalized map, the relief is represented using three features: contour lines, cliffs and spot heights.

Contour lines and cliffs

In general, the contour lines are the same that appear in the original map: the interval of the contour lines is the same and no line simplification has been applied. The small difference between original and generalized scales allows preserving the original data without applying generalization.
These criteria cannot be applied in the case of cliff areas. In this case the areas with slope higher than 80% are obtained from the original DTM and manually generalized, and they are used to represent inside only the master contour lines.



Left image shows contour lines in a cliff area, right image shows their representation on the map.

Contour labels are automatically scaled. In some cases, they overlap with the map names. Usually names have more priority than labels and the conflicts are solved by displacing the label or removing it.

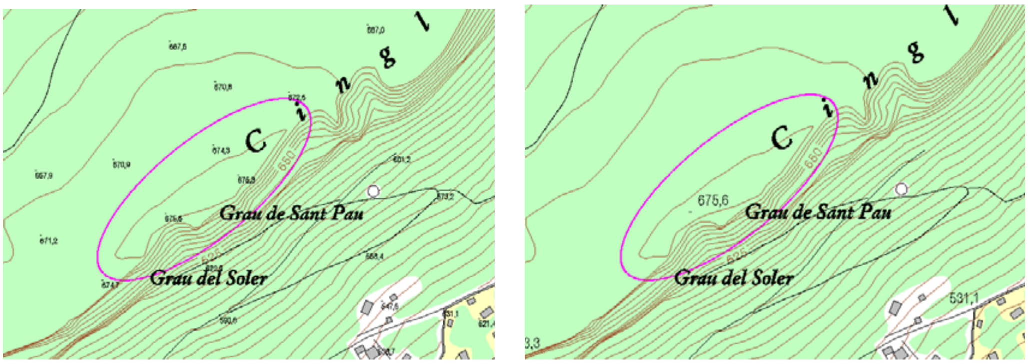
Spot heights

Selection of spot heights can be considered one of the more time consuming tasks. It is performed by looking at the area globally and choosing one by one the spots to be maintained on the final product. The tool developed at the ICC scales automatically the symbol and the text and asks for the best situation of the text, while a minimum distance between the text and the symbol is maintained.

Some of the cartographic rules applied in the selection are summarized in the following points:

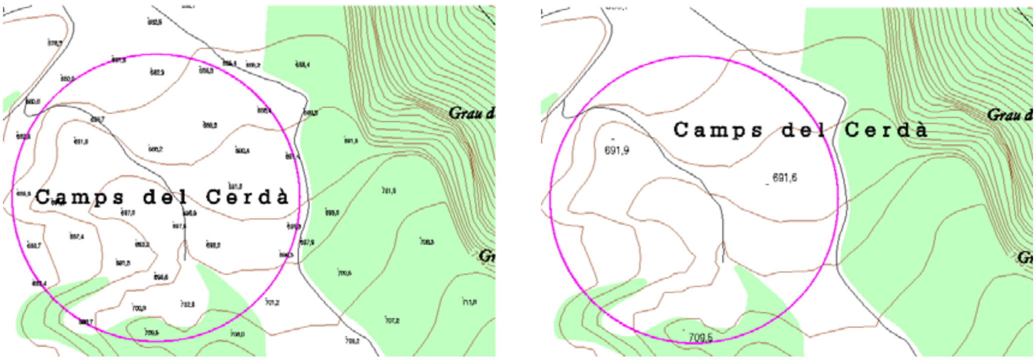
- Spot heights and orography

  - In the peaks or summits, depressions, mountain passes, small islands and capes, one or more spot heights are preserved. The main criteria for selection are keep the most extreme value; the second criteria are keep the most centered position.



Left image shows original spot heights, right image shows their generalization.

  - In open areas like beaches, raised areas, leveled areas and rustic parcels, one or more spot heights are preserved. The selection criteria are based in keeping the most centered ones. In areas too small or too narrow it can be not possible to preserve any spot height.

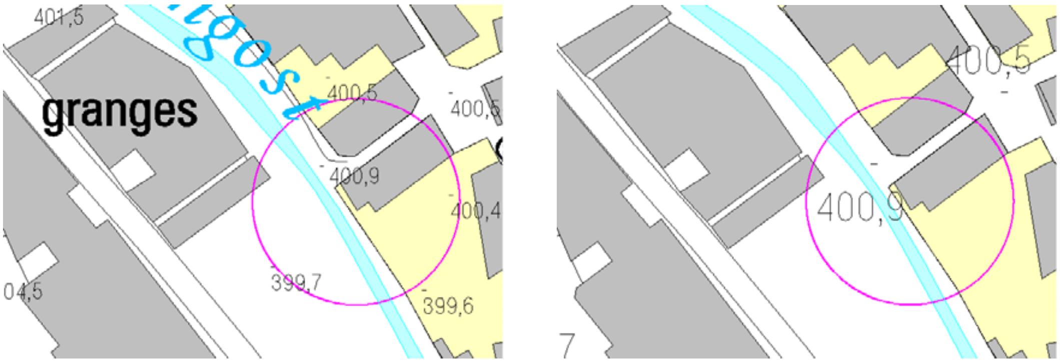


Left image shows original spot heights, right image shows their generalization.

  - Spot heights too close to contour lines don’t have to be maintained, because they don’t give more information of the terrain and could introduce conflicts.

- Spot heights and hydrography

  - In watercourses (usually dry in the Mediterranean area and flooded very occasionally) one or more spot heights are preserved. The main criteria for selection are keep the highest value; the second criteria are keep the most centered position.



Left image shows original spot heights, right image shows their generalization.

- In the dams, in the terrain near the water, only one spot height is preserved to indicate the maximum level of the water, keeping the more centered position. In the dams (building) one or more spot heights are preserved, keeping the highest values.

- Spot heights and population

    - In areas like cemeteries, sport areas, quays and breakwaters, train stations, heliports, airports or areas near to isolated houses one or more spot heights are preserved. The selection keep the most centered spot heights, which can have been maintained because other criteria (intersection of roads, raised areas, etc.).

    - Some spot heights placed in the intersection of main streets or squares must be preserved. There are several criteria to select them:
        - highest and lowest
        - changes in slope
        - street width
        - conflict with the street name
        - regular distribution.

Left image shows original spot heights, right image shows their generalization.

- Spot heights and communications
  - The spot heights placed in the intersection of roads, paths or railways must be preserved.
  - The spot heights placed on top of the bridges must be preserved. The selection takes in account the highest ones.
  - The spot heights placed in the slope changes of roads, paths or railways must be preserved.
  - In the roads, paths or railways, there have to be selected spot heights approximately every 400 meters.
  - Along roads with dual ways, the spot heights selected in one way have to be also maintained in the other way.

Left image shows original spot heights, right image shows their generalization.

- Spot heights and other aspects

  - In many cases the spot heights overlap the generalized map. Usually names do have more priority than spot heights and conflicts are solved by displacing the text of the spot height (never the symbol) or removing it.
  - Accurate distribution of spot heights in terms of placement and global density, has to be established in order to have a homogeneous product.
  - Finally, legibility and aesthetic aspects have to be also taken in account.

Some of these rules could be automated partially. The Institut Cartogràfic de Catalunya is working in the development of tools based in DTM analysis and spatial analysis. For example, in the case of peaks and depressions, the automatic process can help in choosing the spot height with the extreme value. In the case of passes, a more accurate analysis is required to detect the inflexion points and select the extreme value. For the selection of spot heights inside flat areas, spatial analysis will be useful for choosing the best location. Spot heights too close to the contours lines can be eliminated automatically.

The relief representation in the Topographic Database at scale 1:25.000

In the generalized database, the relief is represented using the same type of features than the original database. Original profiles and generalized spot heights, breaklines, flat areas and contour lines are the input data to generate a triangular model from which the contour lines at scale 1:25 000 are interpolated.
Original profiles are preserved in the generalized data to preserve as much as possible the original DTM information.
The planimetric objects that in the original database were considered as breaklines, are maintained as breaklines. In the case of communications or rivers, both margins were breaklines but not the centerline, in the generalized database if the margins disappear, because they define areas too narrow, then the centerline inherits the break line attribution. All breaklines have to be generalized applying line simplification in 3D, to eliminate superfluous points.
Selection of spot heights follows the same rules and methodology as indicated before for the generalization at scale 1:10.000. In practice, the use of generalized data at scale 1:10.000 as original data will reduce the efforts.
Flat areas are generalized applying simplification, collapse, aggregation or elimination depending on the original size and density. The new areas are included as flat areas in the generalized terrain model.
Contour lines used to infer breaklines during the generation of the triangular model are generalized applying line simplification. All the contours are maintained to preserve as much as possible the original DTM information.

Contour lines and contour labels are obtained by interpolation of the triangulation that

models the generalized terrain data, increasing twice the interval.
Cliff areas with slope higher than 80% are obtained from the DTM and manually generalized, and they are used to represent inside only the master contour lines.

The relief representation in the Topographic Map at scale 1:25.000

The map will be obtained by applying automatic symbolization to the generalized database and adding the hill shading generated from the DTM.

The shading will be generated in three steps:

- the regular 5 meters grid DTM generation from the triangular model
- the grid generalization, applying smoothing on the 5 meters DTM grid
- the generation of the shading.

In the grid generalization two goals will be achieved: smoothing and minimization of the staircase due to the pixel size. For the first one, will be applied the algorithm *weighted average with 4 points*. For the second one, a cubic convolution resampling to 2.5 meters will be applied to the smoothed grid, followed by another smoothing operation using the algorithm *weighted average with 2 points*.

The shading is based on the following parameters: sun angle, sun azimuth, sun intensity, ambience and contrast. Finally a gray value modulation will be applied to improve final result.

Conclusions

The availability of automatic generalization tools enables to obtaining new products derived from the basic topographic database at reduced cost. The first example is the generation of Topographic Map of Catalonia at scale 1:10.000 as a product metrically and aesthetically correct. Although it is paper or raster map but not a database, without these tools the project would be unfeasible. The next objective is to derive the Topographic Database at scale 1:25.000, by preserving the GIS characteristics and the spatial relations of the original database.

Aspects related with the relief generalization require more specific analysis and software development in order to automate some manual processes. At this moment, the task for the contour line generalization, the spot height selection and the hill shading parameters optimization are not automatic enough in terms of productivity and costs.

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