Session / Séance 22-B

Maps in transition: development of interactive vector-based topographic 3D-maps

Andrea Terribilini

Institute of Cartography, Swiss Federal Institute of Technology (ETH)
ETH Hoenggerberg, 8093 Zurich, Switzerland
Phone: +41-1-633 30 33   Fax: +41-1-633 11 53
E-mail: aterribi@geod.ethz.ch

Abstract

The age of the virtual worlds has begun. In the last years we have witnessed an incredible development of this new technology, which is now commonly used by all the people that will visualise any three-dimensional data. For centuries the main application field of cartography was the two-dimensional visualisation of spatial data. Can cartography also profit from this new technology? A three-dimensional interactive topographic map does not know any spatial, thematic and temporal limitations. It offers the user the possibility to choose its virtual position within the map, permitting a more accurate perception and interpretation of the spatial and other related information. We are convinced that the use of this technology in the domain of cartography domain would significantly improve the quality of cartographic products and open new areas of application. The goal of the presented project is the design and implementation of an efficient system for the generation, visualisation and administration of interactive topographic 3D-masp. Since we are dealing with cartography, our aim is not to achieve realistic landscape rendering, but a true cartographic symbolisation in space.

Introduction

The human perception system (HPS) can perceive and interpret the real world in a very natural way. However the perception of a topographic map seems to be more difficult. In the cartography, many studies have been made in order to understand the basic processes of the HPS and to exploit it to improve the quality of cartographic products making it accessible for no-expert users, too. A lot of rules have been developed in the past years describing how cartographic maps must be represented. A new way to improve the quality of a map without exactly knowing how the information is processed from the HPS, is to produce maps that look more similar to the real world. This does not mean we must achieve realistic landscape rendering, but rather that a map must be produced so that we can be perceive it in a more similar way we perceive the real world. While the real world is three-dimensional, it is reasonable to imagine that a three-dimensional map (3D-map) can be easier understood as a conventional two-dimensional map. What we propose is to produce maps as perspective projection onto a plane of a three-dimensional cartographic model (CM). It is clear that a CM can only be managed with the aid of computer technology. An interactive management-system for the CM can substantially improve the quality of a 3D-map. An interactive 3D-map can allow the user to move in real-time through the CM and to select an optimal view position improving the flow of information from the map to the user. The content of the CM can be easily selected and extended by the user according to his special requirements. Queries and analyses (GIS functionality) about the content of the CM are possible at any moment during the virtual travel through the CM.

This paper focuses essentially on the way we are developing our three-dimensional cartographic model. Its basic components and requirements are described in detail in the next sections.

The three-dimensional Cartographic Model

A cartographic three-dimensional model (CM) can be defined as a three-dimensional abstract description (generalisation) of one or more aspects of the real world or a part of it. The aim of this project is to automatically produce high quality 3D-maps directly from a three-dimensional CM. This is an extension of the two-dimensional principle of “intelligent maps” proposed in [Bär, 99], where maps are directly generated from the original data base, appropriately generalised and visualised. The used three-dimensional model acts a very important part in the production of high quality 3D-maps. One of the main research point of this project is how a CM can automatically be generated from the existing data. Actually, most available data sets are two-dimensional. Thus, it is worth the trouble to produce the cartographic three-dimensional model directly from the two-dimensional data [Zanini, 99]. The main requirements for a CM are listed below:

1. *Reduced data volume*. The data volume necessary to describe a three-dimensional model can be a problem for the current technology and must therefore be reduced to the minimum. This is very important if the CM must be interactively managed.
2. *Vector data structure.* The cartographic model must have a vector data structure. This allows, in opposition to raster-structure, to reduce the data volume that is necessary to describe the model and allows an easier computational analysis of the data set.
3. *Multi-resolution model.* The content of the 3D-map must be represented in such a way that it can be perceived from the human perception system. Because of the perspective projection, the map will not have a constant scale. If not considered, this effect leads to undesirable effects, affecting the quality of the produced 3D-map (minimal dimension, to condensed map content, etc.). To solve this problem we propose to use the level-of-detail technique (LoD). This means that each element contained in the 3D-map must be represented with adequate graphic variables (shape, orientation, colour, etc) depending on the local scale: the closer an element is to the viewer position, the more the element must be represented in detail.

To permit the use of the LoD-technique, the cartographic model is first subdivided into tiles. The main idea is to define the content of each tile for more levels-of-details (high, middle, low) and let the visualisation system represent each tile using the suitable level. Particular attention must be dedicated to the transition zone between adjacent tiles, in order to ensure a continuos transition of the content of the CM. The more levels-of-details are used, the more continuous the transition will be. On the other hand the data volume needed to store the model increase rapidly with the number of levels-of-detail, so that we must agree a compromise. The tiles of our cartographic model can be assembled using the three basic objects shown in Figure 1.

In the next sections, the components (3D Terrain, 3D Map-Element) of the presented cartographic three-dimensional model and the developed visuals system are explained in detail.

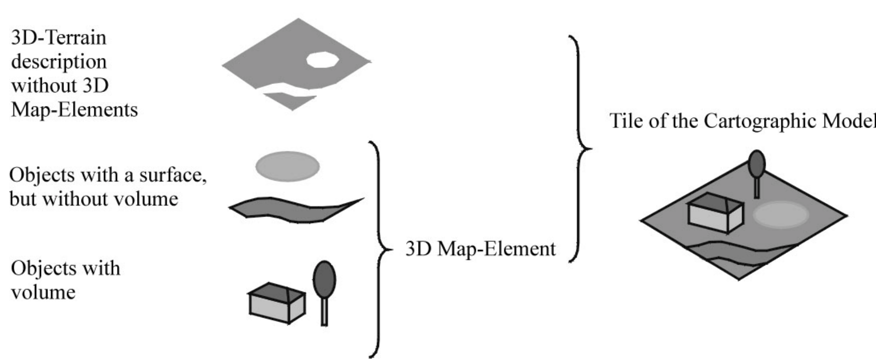

Figure 1. Logical organisation of the three-dimensional cartographic model

Modelling of the topography: the 3D-Terrain

For the description of the terrain surface, we used the digital elevation model of Switzerland (DEM25) provided by the Federal Office of Topography. This model gives the height value as an attribute for a finite set of points that are regularly disposed (25m mesh size) on the horizontal plane (discrete surface description). Because we need a continuous description of the terrain, the surface is modelled using an irregular tessellation description. The continuos surface is approximated using an arrangement of non-overlapping irregular triangles, whose vertices are the original DEM data (triangulated irregular network). A triangulated irregular network (TIN) has two desirables properties:

1. *It can be adaptive*. The irregularity of a TIN allows the resolution to vary over the surface, capturing details only where required (adaptive triangulation).
2. *Progressive refinement*. A TIN can be refined in a progressive way, maintaining the continuity between the adjacent triangles.

However, the construction of a triangulated irregular network starting for a set of points is not unique. We used a Delaunay-triangulation because of its desirable property to generate a set of triangles that are “as equilateral as possible”, avoiding long and thin triangles that will produce undesirable effects by the visualisation process.

To convert the DEM25 into a TIN, a filter was developed. The AdTIN-filter generates a surface description of the original DEM in the form of a TIN with the particularity that the refinement of the triangulation is adapted to the irregularity of the surface (adaptive triangulation). That means that only the *relevant* points of the original DEM are used to produce the final Delaunay-triangulation. A point is classified as *relevant* if its integration in the TIN significantly improves the quality of the surface description. The size of the smallest details (SD) used to describe the surface seems to be an adequate parameter to measure the quality of the surface. With the AdTIN-filter this parameter can be varied in order to produce surfaces with different quality (levels of detail). Figures 4 shows a region (7x5 km^2) extracted from the DEM25 and processed with the AdTIN-filter with different values of SD. The model has an average scale of 1:95000 (calculated using the diagonal of the model). The reduction of the data obtained from processing the DEM25 data with different values for the SD, is listed in the Table 1.

Table 1. Data reduction obtained processing a region of 7x5 km of the DEM25 with the AdTIN-filter

SD in space [m]	*SD on the map[mm]*	*Data reduction [%]*
0	0.00	16
5	0.05	83
10	0.10	91
30	0.30	97

Definition of the region: 708000/115000-715000/120000

This example shows the high redundancy contained in the original model (~16%), as well as the potential data reduction that can be achieved for this scale (~1:95000) without affecting the appearance of the model (~85%).

Since we want to integrate the topography in a multi-resolution CM, the DEM must be subdivided into tiles before it can be processed with the AdTIN-filter. Each tile is then filtered with three different values of SD. The obtained hierarchy of TIN can then be imported into the multi-resolution CM and be used to produce the 3D-map. The combination of raster structure (tiles) and vector structure (TIN) has some desirable properties: first at all the tile structure allows a simple application of the level-of-detail technique, reduces the access time to the data and simplifies the clipping process by the visualisation. Secondly the TIN-structure allows a substantial reduction of the data volume necessary to describe the surface. Since each tile is filtered independently from each other, a continuos surface description can not be ensured. Small gaps can appear between adjacent tiles, especially when represented with different LoD. A simple method to ensure this continuity is to define a transition zone between the tiles (see Figure 2). Outside this zone, the surface of each tile can be processed with the AdTI-filter. Within this zone, the surface is progressively forced to the previously extracted boundary of the tile. Since adjacent tiles are forced to the same boundary, independent of the LoD, the continuity of the surface along the adjacent tiles is ensured. The boundary can be eventually filtered with a line simplification algorithm, in order to reduce its complexity.

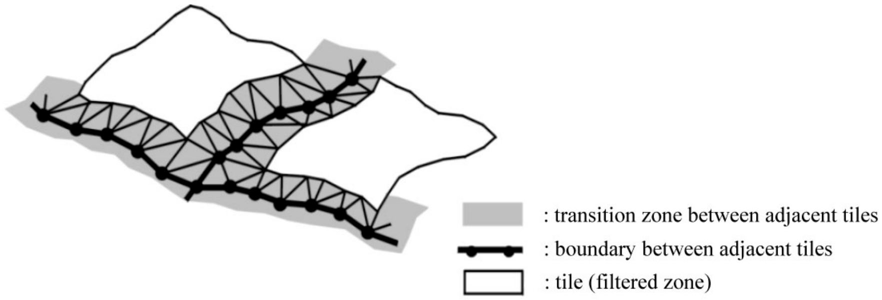

Figure 2. Transition zone between two tiles forcing the continuity of the surface description

The complete workflow showing the main aspects of the AdTIN-filter is shown in the Figure 3.

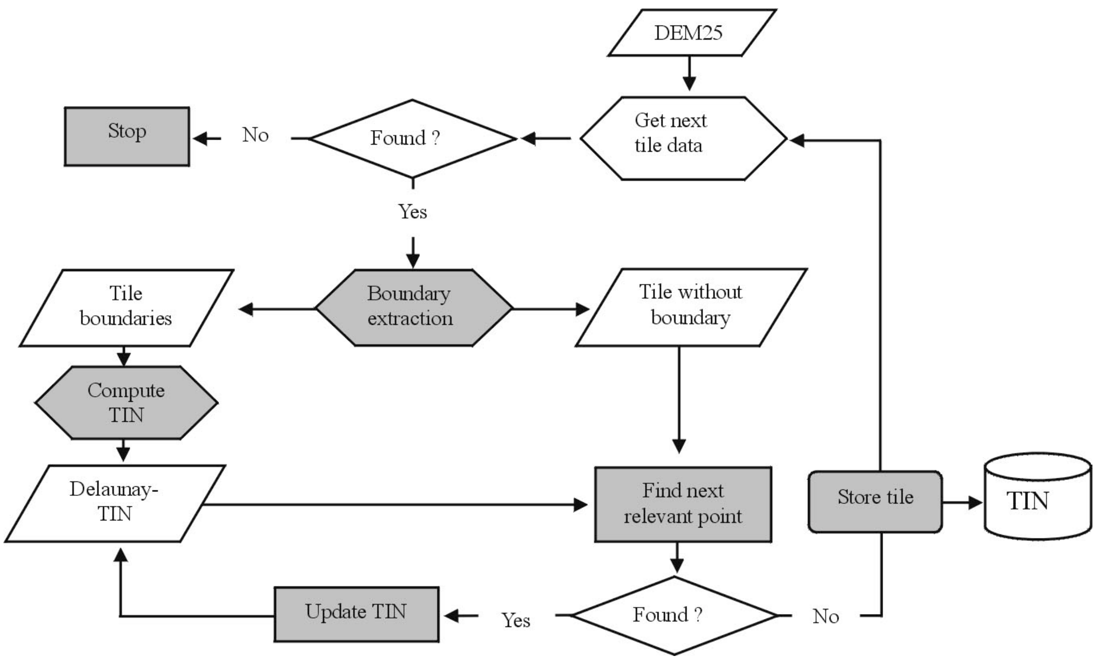

Figure 3. Workflow of the AdTIN-filter

The AdTIN-filter can be very time expensive when dealing with a huge data volume. For this reason, special technical measures must be taken in order to achieve a reasonable computation time:

1. *Computation of the Delaunay triangulation*. To reduce the complexity of the triangulation, only a two-dimensional Delaunay triangulation is used. Therefore, the Delaunay property is valid only for the 1st projection of the TIN (projection onto the horizontal plane). This simplification is possible because the used DEM has a 2.5D structure.

2. *Refinement of the TIN*. The AdTIN-filter adds sequentially to the TIN all of the relevant points found in the original data set of the DEM. The insertion of a new point does not affect the topology of the whole network. Only a restricted set of triangles must be recalculated. In order to speed up the detection and updating process of this set of triangles, the topology of the TIN is stored using a relational data structure (Figure 5).

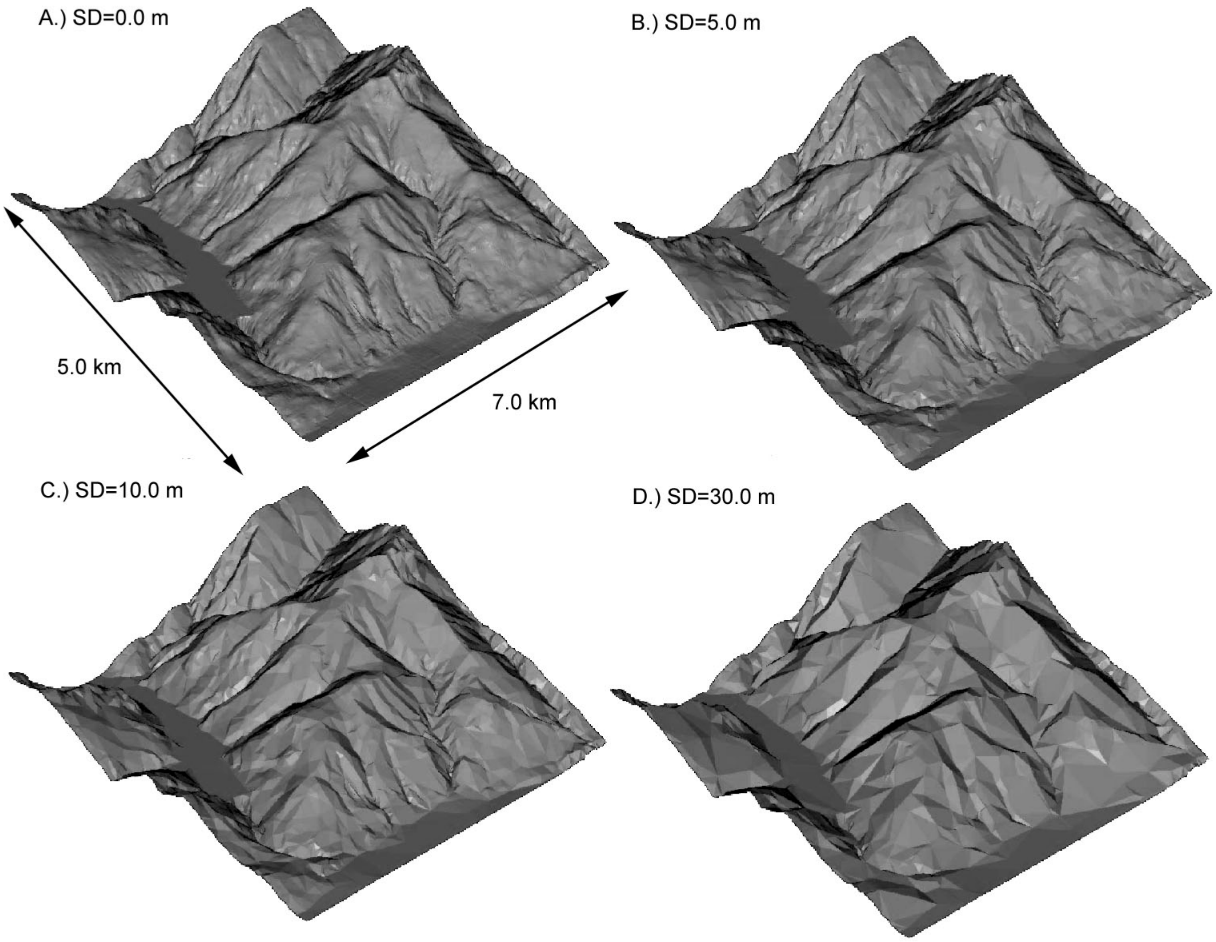

Figure 4. Region extracted from the DEM of Switzerland (708000/115000-715000/120000) and processed with the AdTIN-filter with different values for the size of the smallest detail used to describe the surface (SD). DEM data: DEM25 ©Federal Office of Topography, Wabern.

3. *Selection of relevant points*. To measure the gain of quality of the surface representation caused by the addition of a new point of the TIN, the distance between the surface and the new point is computed. This distance represents approximately the size of the new detail emerging after the addition of the new point into the surface description. If this distance is bigger than a given value (SD) the point is relevant and must be used to describe the surface. This operation can be very time expensive, because each point must be orthogonal projected onto the surface in order to compute its distance from it. However, this operation can be simplified if we can estimate on which triangle of the TIN the point will be projected. In this case, the distance can be simply computed as the distance between the point and the plane defined from the triangle. A method to approximately get this information is to consider only the 1^{st} projection of the TIN (projection onto the horizontal plane). If a point will be projected onto a triangle in the space, there is a high probability that in the 1^{st} projection the point will lie within the triangle.

4. *Access to the TIN*. The interpolation of height values for points within the TIN requires a fast access to every triangle of the TIN. To speed up this operation, the jump-and-walk strategy was used: rather than traverse all the elements of the TIN until the triangle containing the query point is found, the TIN is traversed in a straight line (from an access point to the query point) reducing the computation time. This strategy is only possible if the full topology of the TIN is known (2).

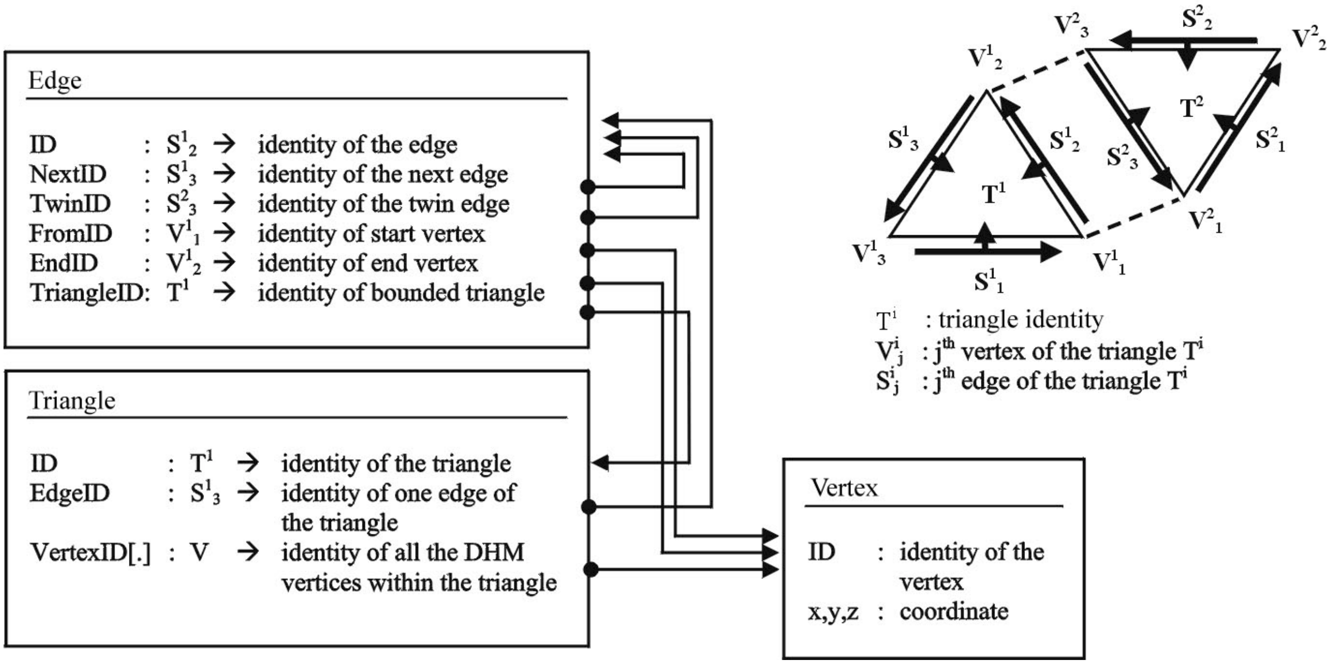

Figure 5. Relational data structure used to store the topology of the TIN

Modelling of the 3D-Element

In this section, a description on how we intend to model and integrate the 3D-Element into the cartographic model is presented. The integration of the 3D-Elements into the CM needs two steps:

1. *Symbolisation in space*. This is one of the main research point of this project: how cartographic two-dimensional symbols must be represented in space. For two-dimensional symbolisation, a lot of rules were defined in the past. On the case of three-dimensional symbolisation however, no theoretic works were so far developed. This process must still be performed manually and requires good cartographic knowledge. We will try to define rules describing this process in order to facilitate and possibly to automate it.[Haeberling, 99].
2. *Symbol generalisation in space*. The three-dimensional symbols (3D map-elements) must be generalised in order to allow a correct representation in the multi-resolution CM. A (partial) automation of this process is planned. The idea is to generalise the 3D Map-Element eliminating those details, that can not be perceived from the human perception system. So we should analyse how an element will be projected onto the map in consideration of the parameter scale, shape, elevation angle, illumination (see Figure 6) [Suter, 97].

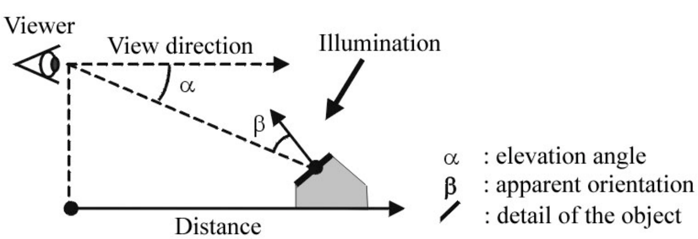

Figure 6. Parameters that can affect the perception of an object in the space

A library containing the definition of all the 3D Map-Elements for the National Map 1:25'000 of Switzerland is in development. The 3D-Element can be defined using a common CAD and then imported into the library (DXF-format). This allows the user to draw and use its own personal library. The content of the National Map 1:25'000 of Switzerland, in vector format, is extracted from the VECTOR25 (©Federal Office of Topography) data set. Since this data set is two-dimensional, it must be transformed into a three-dimensional vector data using the DEM.

Figure 7 shows an example of a CM constructed from the VECTOR25 data set of the region Biel. In this example, only the buildings and the woods have been modelled. The CM was exported in VRLM format and visualised with Cosmo Player (an high-performance, cross-platform VRML 2.0 client designed for viewing virtual worlds).

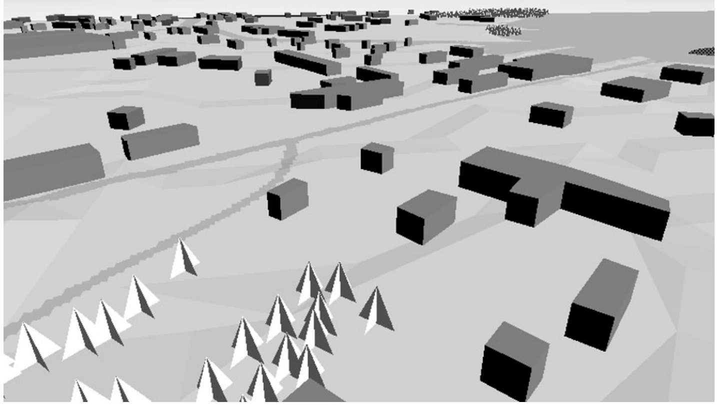

Figure 7. 3D-map produced from the CM of the region Biel (Switzerland). Only one level of detail was used. DEM data: DEM25 ©Federal Office of Topography, Wabern. Map data: VECTOR25 ©Federal Office of Topography)

The visualisation system for the three-dimensional Cartographic Model (CM)

For the visualisation of the CM an appropriate visualisation system (VS) is under development (a prototype is already available). The VS must produce the map as a (perspective) projection of the CM onto a plane (see Figure 8). The VS must have the following properties:

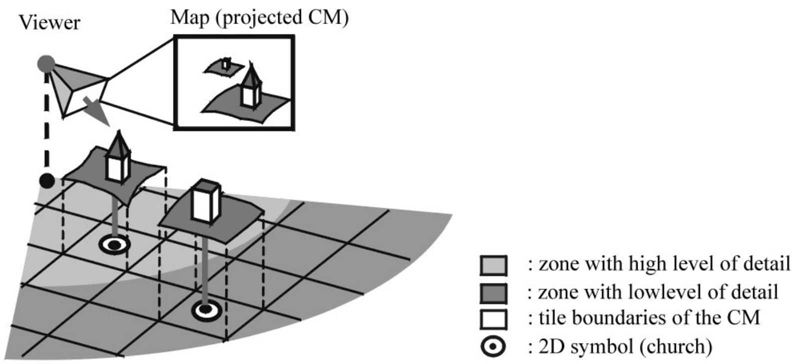

Figure 8. Principle of the multi-resolution visual system

1. *Support multi-resolution representation*. The VS must be able to automatically visualise the content of each tile composing the CM, using the suitable level of detail. The selection of the level of detail for each tile is made by its average scale in the 3D-Map, which depends on its distance from the viewer.
2. *Support multi-viewport representation*. For three-dimensional application it is indispensable to have the possibility to view the same object from different points of view. This allows the user the always have a general survey of the CM.
3. *Real-time visualisation (fly-in)*. This functionality allows the user to interactively select the best view position without losing the general survey of the entire CM. An optimal view position is very important for a correct perception of the information contained in a three-dimensional model [Sieber, 96].
4. *High rendering quality*. The rendering (production of 2D-images from a 3D-model) of three-dimensional models is not a simple process and can only achieved only using elaborated and time expensive algorithms.

5. *Interactivity*. A visualisation system for cartographic applications must be an interactive system in order to permit the users to make queries and fetch additional information about the elements encountered during their virtual travel through the CM.
6. *Import and overlay of external data*. In some case, it can be very helpful for the comprehension of a (three-dimensional) map to overlay additional data (constructive lines, guide-lines, text, etc.).

At the moment, the prototype version of our visualisation system can visualise only the topography of the CM. It allows us to define a shading model (flat or Gouraud, material reflection properties), an illumination model (ambient and diffuse light) and a camera model (position, format, focal length, resolution). It supports multi-resolution representation. With this VS a real-time navigation through the CM is possible, even with common PCs (no special hardware is required).

A sequence of two images of real-time animation computed with our VS is shown in Figure 9. The used DEM was pre-processed with the AdTIN-filter using three levels of detail (SD=25-40-100 m). In the right image the change of level-of-detail, caused by a forward motion, is visible.

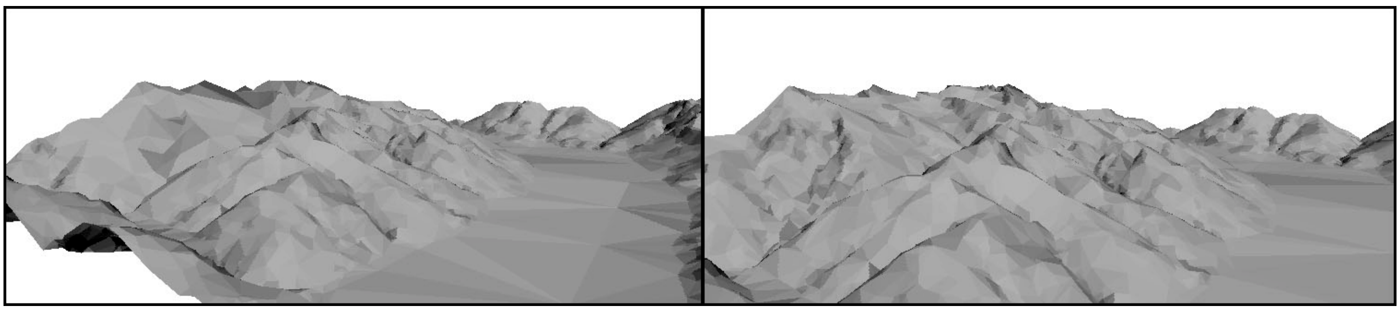

Figure 9. Sequence of two images (flat shading) of an animation generated with the VS. The change of the level of detail caused by a forward motion of the camera is visible. DEM data: DEM25 © Federal Office of Topography.

References

Baer, H.R. (1995). Interaktive Bearbeitung von Gelaendeoberflaechen: Konzepte, Methoden, Versuche. Diss. Philosophische Fakultaet II der Universitaet Zuerich, Zuerich.

Baer, H.R, Sieber, R. (1999). Towards high standard interactive atlases. The “GIS in Multimedia” approach. Swiss Federal Institute of Technology (ETH) Zurich, Zurich.

Bill, R., Fritsch, D. (1991). Grundlagen der Geo-Informationssysteme: Hardware, Software und Daten. Wichmann Verlag GmbH, Karlsruhe.

Bauknecht, K.,Zender, C. A. (1989). Grundzuege der Datenverarbeitung: Methoden und Konzepten fuer Anwendungen. 4. ueberarb. Aufl.. Teubner, Stuttgart.

Carosio, A. (1990). Raumbezogene Informationssysteme I-II: Vorlesungsskript. Institut fuer Geodaesie und Photogrammetrie ETH Zuerich, Zuerich.

Graf, K.C. (1995). Realistic Landscape Rendering Using Remote Sensing Images, Digital Terrain Models and 3D Objects. Diss. Philosophische Fakultaet II der Universitaet Zuerich, Zuerich.

De Berg M. (1997). Computational geometry: algorithms and applications. Berlin, Springer.

Douglas, D.H., Peuker, T.K (1973). Algorithms for the reduction of the number of points required to represent a digitalized lines or its caricatures. Canadian Cartographier, 10, No.2.

Foley, van Dam, Feoner, Hughes (1995). Computer Graphics: Principles and Practice. The Systems Programming Series. 2.nd ed. in C, Addison Wesley.

Gleue, J. (1981). Triangulierung und Interpolation von im R^2 unregelmaessig verteilten Daten. Hahn-Meitner-Institut fuer Kernforschung Berlin GmbH, Berlin.

Gruen, A. (1990). Photogrammetrie I-II-III: Vorlesungsskript. Institut fuer Geodaesie und Photogrammetrie, ETH Zuerich, Zuerich.

Haeberling, Ch. (1999). Symbolisation in topographic 3D-maps: conceptual aspects for user-oriented design, Swiss Federal Institute of Technology (ETH) Zurich, Zurich.

Harrington, S. (1987), Computer Graphics: Corso di Programmazione. McGraw-Hill Libri Italia srl, Milano.

Heller, M. (1990). Triangulation Algorithms for Adaptive Terrain Modelling. Proceeding of the 4th international symposium on spatial data handling, 163-174.

Hurni, L. (1995). Modellhafte Arbeitsablaeufe zur digitalen Erstellung von topographischen und geologischen Karten und 3D-Visualisierungen. Diss. Institut fuer Kartographie, ETH Zuerich, Zuerich.

Hurni, L. (1996). Analyse und Massnahmen zur Verbesserung des VECTOR200 Datensatzes. WK-Dienstleistung beim Stab GGST, Sektion fuer Kartographie und Kartenwesen, EMD, Bern.

Sieber, R. (1996). Visuelle Wahrnehmung dreidimensionaler parametrischer Objekte und Objektgruppen. Eine empirische Untersuchung zur Bestimmung eines optimalen Betrachterstandortes. Diss. Philosophische Fakultaet II der Universitaet Zuerich, Zuerich.

Schneider, B. (1996). Adaptive Interpolation of Digital Terrain Models. Department of Geography, University of Zurich, Zurich.

Spiess, E. (1993). Kartographie Grundzuege: Vorlesungsskript. Institut fuer Kartographie, ETH Zuerich, Zuerich.

Spiess, E. (1997). Computergestuetzte Kartographie: Vorlesungsskript. Institut fuer Kartographie, ETH Zuerich, Zuerich.

Suter, M. (1997). Aspekte der interaktiven real-time 3D-Landschaftsvisualisierung. Remote Sensing Series Vol.29. Department of Geography, University of Zurich, Zurich.

Suter, M. Nueesch, D. (1995). Automated Generation of Visual Simulation Databases Using Remote Sensing and GIS. IEEE Visualisation ’95, 86-93.

Suter, M., Hoffmann H., Nueesch, D. (1996). Visuelle Simulation realer Landschaften als Basis fuer ein virtuelles GIS, Remote Sensing Laboratories, Department of Geography, University of Zurich, Zurich.

Szabo K. et al., (1997). A Virtual Reality based System Environment for Intuitive Walk-Through and Exploration of Large-Scale Tourist Information. MultiMedia Laboratory, Department of Computer Science, University of Zurich, Zurich.

Terribilini, A. (1995). 3D Visualisierung von Gebaeuden: Vertiefungsblock in Geoinformatik. Institut fuer Geodaesie und Photogrammetrie, ETH Zuerich, Zuerich.

Terribilini, A. (1997). 3-Dimensionale Amtliche Vermessung: Diplomarbeit in Geoinformatik. Institut fuer Geodaesie und Photogrammetrie, ETH Zuerich, Zuerich.

Van Krevel M. (1997). Algorithmic foundations of geographic information system, Berlin, Springer.

Zanini, M. (1996). Visualisation of Geographic Raster Data. Research Report 1995/96, Department of Geodetic Sciences, ETH Zurich, Zurich.

Zanini, M. (1999). Dreidimensionale synthetische Landschaften. Wissensbasierte dreidimensionale Rekonstruktion und Visualisierung raumbezogener Informationen. Diss. Department of Geodetic Sciences, ETH Zurich, Zurich.