# GENERALIZATION OF DENSE DIGITAL TERRAIN MODELS WHILE ENHANCING IMPORTANT OBJECTS

K. Kremeike
Institute for Cartography and Geoinformatics, Appelstr. 9a, 30167 Hannover, Germany
katrin.kremeike@ikg.uni-hannover.de

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**ABSTRACT:**

Laser altimetry is a leading technology for the extraction of information of physical surfaces, and hence it is the main source for generating a dense digital surface of the terrain. This results in data sets with a very high density and accuracy. This high quality data sets bring about a massive amount of data, which is hardly manageable or accessible. Particularly the efficient graphic representation of this data in real time appears to be difficult. To reduce the three dimensional information and make it manageable, methods of generalization and simplification are needed. During the process of generalization, important objects within the DTM have to be emphasized, to guarantee their perceptibility. The objects to be emphasized differ according to the intention of the generalization. In the context of a 3D-city modelling, especially buildings and their structures have to be generalized. Whereas for the purpose of terrain surface visualization, special attention has to be given to the enhancement and generalization of topographic objects like dams or streets. For the time being, the main focus of this work is laid on the enhancement and generalization of street objects. The streets in the DTM are enhanced by widening them to either side of the middle axis. Changing the height values within the broadened street brings about discontinuities in the adjacent regions. For this reason, also the height values in this regions have to be adapted, however the extent of the area to be modified has to be defined. In addition, a weighting function for the adaptation has to be chosen. Another option is the displacement and thus a compression of that parts of the surface, which lie between the broadened streets. The different options for the adjustment of the terrain model after the enhancement of the streets are discussed in this paper, and results for the approaches are shown.

**KURZFASSUNG**:

Unter Verwendung der modernen Datenerfassungsmethode des Laserscannings können sehr dichte digitale Geländemodelle für eine hochgenaue Repräsentation der Erdoberfläche bereitgestellt werden. Die hieraus resultierenden hochqualitativen dreidimensionalen Datensätze weisen ein enormes Datenvolumen auf, welches eine effiziente graphische Darstellung in unterschiedlichen Auflösungen erheblich erschwert. Um die Handhabbarkeit dieser Datensätze zu gewährleisten, ist die Datenmenge unter Anwendung von Methoden der Generalisierung und Vereinfachung zu reduzieren. Während des Generalisierungsprozesses gilt es, bedeutende Objekte im Geländemodell hervorzuheben, um ihre Erkennbarkeit in den unterschiedlichen Auflösungen zu gewährleisten. Die hervorzuhebenden Objekte unterscheiden sich hierbei in Abhängigkeit vom Zweck der Generalisierung. Im Zusammenhang mit 3D-Stadtmodellen sind besonders Gebäude und deren Strukturen hervorzuheben. Bei einer Geländevisualisierung sind im Gegensatz dazu vorwiegend topographische Objekte wie Straßen oder Dämme Gegenstand der Betrachtung. Derzeit steht die Betonung und Generalisierung von Straßenobjekten im Mittelpunkt der Untersuchungen. Die Straßen werden im Geländemodell durch Verbreiterung um die Mittelachse hervorgehoben. Durch Veränderung der Höhenwerte innerhalb der verbreiterten Straßen entstehen Diskontinuitäten in den angrenzenden Regionen. Daraus ergibt sich, dass auch die Höhenwerte in diesen Bereichen angepasst werden müssen, wobei die Reichweite der Veränderungen festzulegen ist. Zudem ist eine Gewichtsfunktion für die Anpassung auszuwählen. Eine weitere Möglichkeit stellt die Verdrängung und daraus resultierend ein Zusammenschieben der Oberflächenbereiche dar, welche zwischen den verbreiterten Straßen liegen. In diesem Beitrag werden verschiedenen Möglichkeiten zur Anpassung des Geländemodells nach der Straßenverbreiterung diskutiert sowie erste Ergebnisse vorgestellt.

## 1. INTRODUCTION

Advances in automatic data capturing technology bring about enormous databases of surface models which are often very complex. The use of laser altimetry in particular can result in very dense surface models with millions of points. This massive amount of data is difficult to handle and hence for all applications, a tradeoff exists between the accuracy of the surface model and the time required for processing (Garland, 1999). To reduce processing time to an acceptable degree, simpler approximations of the original model have to be generated. For this purpose, different surface or mesh simplification algorithms are available. During the simplification process, single objects within the surface model become unclear, edges get blurred. Therefore appropriate methods of generalization have to be applied, to guarantee the perceptibility of significant object types.

Generalization is one of the major tasks in cartography (Weibel, 1989). In classical cartography it is considered as a very important component of the graphical design (Hake et al., 2002). With the reduction of scale, objects represented to scale are shifted towards each other. This results in a declining legibility of individual objects. For this reason, minimum sizes are of great importance in the context of thresholds for syntactic pattern recognition. There are several regulations which determine thresholds for minimum widths or distances between objects (Hake et al., 2002).

In digital cartography, the type of representation is not restricted to the output of printed maps. Furthermore, electronic screen displays have to be taken into consideration. In comparison to printed maps, the electronic visualization is limited by the size of the usable area on screen as well as the smaller resolution (Brunner, 2001). The interaction of input and output media has to be taken into account with regards to the resolution and the graphical minimum size has to be determined accordingly.

The preceding considerations point out, that important topographic objects have to be emphasized during generalization to ensure their perceptibility in different scales. In a three-dimensional model this is all the more the case, as objects are easily hidden by a surface representation in the third dimension. After emphasizing certain objects within the model, other objects have to be displaced. The remainder of the article is structured as follows: firstly a survey of significant research work is given, secondly the applied approach for the generalization process is presented. Finally, the article closes with a conclusion and suggestions for future work.

## 2. RELATED WORK

As advances in technology give rise to further growing sizes of data sets, automatic simplification techniques for highly detailed surface models are of considerable interest. Over the past years, several effective techniques have been developed, providing powerful tools for tailoring large datasets to the needs of individual applications and for producing more economical surface models (Garland, 1999). The often cited survey from Cignoni et al. (1998) compares different mesh simplification algorithms and gives a good overview on existing methods. Heckbert & Garland (1997) also present a comprehensive summary on polygonal surface simplification, in which they attempt to categorize previously described algorithms. Luebke (2001) describes and evaluates the most important simplification algorithms from a developers point of view.

Automated cartographic generalization with the aim of consistency and reproducibility of the generalization operation is among the most challenging tasks in digital cartography. For a fairly long time, numerous research work has been concerned with this problem (Buttenfield & McMaster, 1991; Muller et al. 1995). A large amount of research work has especially focused on the generalization of two-dimensional databases (Beard, 1991; Powitz, 1993; Ware & Jones, 1998). The generalization of linear objects is mainly investigated for street objects and river networks (Rusak Mazur & Castner, 1990; Thompson & Richardson, 1995; Jiang & Claramunt, 2002). In this context, selection and simplification of objects are the most frequently discussed issues (Douglas & Peucker, 1973; McMaster, 1987; de Berg et al., 1995; Neyer, 1999).

Another basic operation within the generalization process is the enhancement, which is the enlargement or widening of objects. These operations mainly have the purpose of maintaining legibility, whereas there are scale dependent minimum sizes of lengths and areas to consider (Hake et al., 2002). In the course of enhancement, the geometric correctness of the objects is neglected for the benefit of the enlargement out of scale.

Moreau et al. (1997) present a generic method for the broadening of streets, river networks and other linear objects around their middle axes. This method uses the semantics of the object definition in addition to several automatic rules for the adjustment of the geometries of neighbouring objects. Besides the middle axes, cross sections are implicated during the broadening process. A street can be approximated using a sequence of segments and the relevant widths for this segment characterized by a profile.

In connection with enhancement operations, displacement is a further fundamental generalization process. One of the approaches under examination is based on last square adjustment (Harrie, 1999; Sester, 2001). Others concentrate on finite element methods (Bobrich, 1996; Hojholt, 2000). Additionally research is undertaken in the field of object displacement in raster data sets (Jäger, 1990; Li & Su, 1997).

Generalization operations for three dimensional data sets is primarily investigated in the context of the generalization of buildings (Sester & Klein, 1999; Lal & Meng, 2001; Thiemann, 2002). Furthermore, several research is concerned with relief generalization (Wu, 1981; Weibel, 1989). On the one hand they work with contour lines, on the other hand raster data sets are used.

One possibility for the generalization of surfaces in the raster format is filtering. Low pass filters fill the gaps between homogenous regions. This leads to a fusion of objects, simplifying the existing representation (Bartelme, 2000). For the generalization of raster data, several morphological operators for the widening or reduction of objects exist (Li, 1994). During these procedures, the original pattern is shifted in all directions given by the metric of the operators, which for instance, results in a smoothing of lines.

## 3. GENERALIZATION OF THE DTM

To maintain the perceptibility of street objects in the DTM during the generalization process, they have to be emphasized. These procedure and the resulting problems are discussed in the following. Streets are emphasized in such a manner, that they are still perceivable from a given distance. Thus the distance to choose depends on the “scale”.

### 3.1 Data Sources

**3.1.1 ATKIS DLM:** With the Authoritative Topographic Cartographic Information System called ATKIS, the Federal Republik of Germany holds a nation-wide database for two and three dimensional spatial data (AdV, 1998). One of the products within the framework of ATKIS is the Digital Landscape Model (ATKIS-DLM), which groups topographic objects in logical units with regard to the feature type. The geometric properties of the ATKIS objects such as position, size and shape are expressed through two-dimensional vector based descriptions using primitives like points, lines or faces. Factual data are held within the attributes and relations between objects respectively object parts. The vector data representing the streets is taken from the base-DLM with a scale of 1:25 000, the planimetric accuracy is stated to be better than 3 m.

In the feature type domain of transportation, the ATKIS-object catalogue of the base-DLM holds a feature type group called road traffic, which describes feature types like roads, paths and lanes basically in terms of linear objects. Attributes like function, width or number of lanes express further characteristics.

**3.1.2 Digital Terrain Models:** In comparison to classic stereo Photogrammetry laser scanning is an efficient alternative for generating three dimensional surface information (Knabenschuh, 1999). For a detailed description of this method refer to Baltasavias (1999). Different products are derived from the observed raw data. One of these is the Digital Surface Model (DSM) which includes points from the ground surface as well as points from objects on top of the surface like vegetation or buildings. After classification and selection of the ground points, a high quality Digital Terrain Model (DTM) is derived. The point density of this data sets is up to four points per square meter. The planimetric accuracy is circa 0.5 m (Baltasavias, 1999b; Lohr, 1999), whereas the accuracy in height is stated with 0.15 m (Briese et al., 2001; Wever & Lindenberger, 1999). The data set which was used for the experiments represents a part of the city of Stuttgart, with a resolution of 1 m.

### 3.2 Enhancement of street objects and arising problems

Based on the street objects given in the two dimensional vector data set, the streets are broadened to both sides of their middle axes. The width of the broadened streets is arbitrary. For each raster cell in the buffer created around the axes of the streets, the height value is recalculated based on the course of the street axes. In figure 1 the original dataset is compared to the results of the enhancement for a section from the DTM of the city of Stuttgart. The top image shows the scene with 1 000 000 triangles. In the middle, the number of triangles is reduced to 10 000. It becomes apparent, that in the simplified mesh, the streets are not entirely cognizable. Especially in the centre of the image, the course of the street winding up the hill is not perceptible. The image at the bottom demonstrates that the perceivableness of the enhanced street is superior to the representation without enhancement.

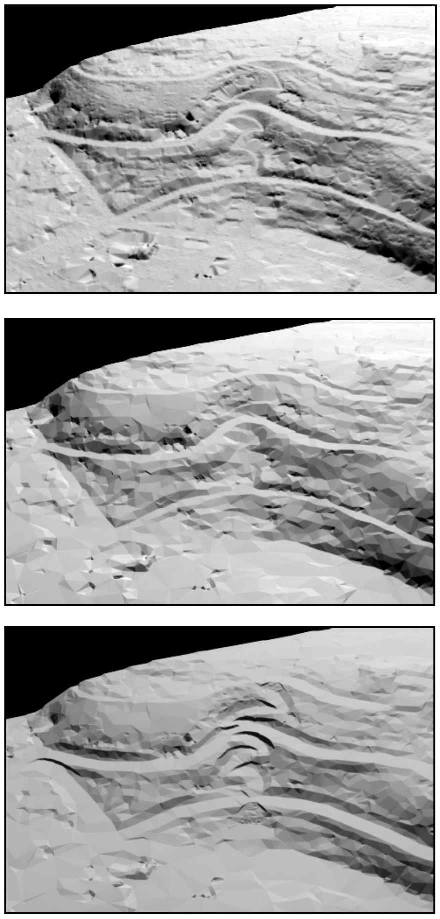

Figure 1: Section from the DTM of Stuttgart; top: 1 000 000 triangles, middle: 10 000 triangles, bottom: 10 000 triangles, broadened streets.

Altering the height values within the broadened streets without considering the adjacent cell values brings about discontinuities between the modified cells and the bordering areas. This is visible in the top image of figure 2, where a closer view of the broadened streets is shown. The margins of the widened streets appear like perforated with toothed edges.

The first idea for solving this problem led to the simple solution of adjusting the regions next to the widened streets using interpolation methods within a given buffer zone. This results in an optically smoother transition from the emphasized street to the surrounding areas. For the adjustment, different interpolation methods can be used. Possible is linear interpolation as well as different sigmoid weighting functions between the border of the widened street and the original cell value in a given distance (Hatger & Kremeike, 2003). In this approach, the original values in the region of adjustment next to the broadened street are not taken into consideration, they simply disappear from the data set. The result of the linear interpolation is shown in the bottom image of figure 2. Here the streets are widened by 10 m to both sides and the adjustment took place within another 10 m. This relatively strong enhancement was chosen to ensure the cognition for an overview illustration.

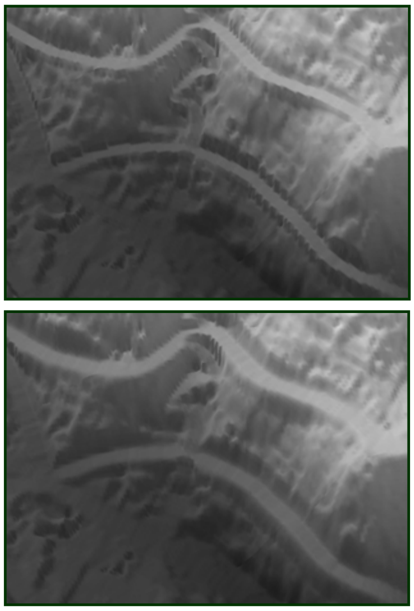

Figure 2: Section from the DTM Stuttgart; resolution 1 m; top: streets broadened around middle axes, bottom: bordering regions adjusted with linear interpolation within a given buffer zone.

In general the widening distance relies on screen resolution and the distance to the observers` position. Furthermore no additional information concerning the relative importance of the streets was taken into consideration. In a more detailed differentiation main roads have to be stronger emphasized than minor streets.

In figure 3, a cross section demonstrates the principle of the enhancement together with the alteration of the adjacent regions. The point positioned in the centre marks the middle axes of the street, the black line shows the original cross section. In grey, the enhancement of the street is illustrated and the dashed black line shows the enhancement in combination with a linear weighting function for the adjustment of the bordering regions.

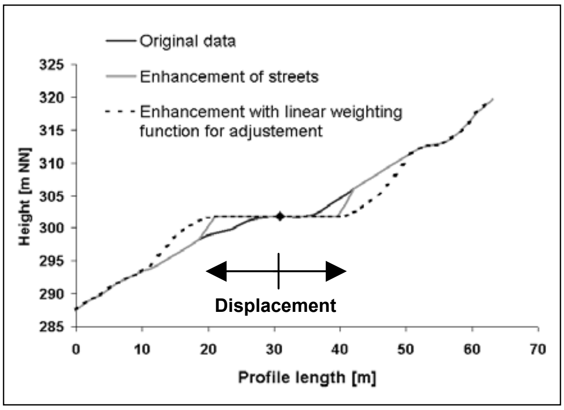


Figure 3: Cross section

The drawback of this solution is the loss of the original height values both within the buffer and the region of interpolation. Only the height of the broadened street and the values within the given distance from the middle axes are taken into account. The adjustment merely takes place in terms of smoothing on the level of representation. The correctness of the data is seriously affected by simply replacing values within the DTM. Thus in the example height values are lost in a corridor of 30 m width. To solve this problem, methods of displacement have to be applied in combination with the enhancement procedure

### 3.3 Displacement

The first issue to consider is the sphere of action in which the adjustment takes place. In the first attempts, when different interpolation approaches were tested, the adjustment took place within fixed ranges. Instead of just smoothing the changeover within this area by newly interpolating, the height values could be displaced within this area to avoid a loss of information (see fig. 3).

Displacement operations can result in deformation within the data set. Deformation in connection with the displacement becomes the more apparent, the smaller the region is in which the modification takes place, because the overall alteration is spread over a wider area. This leads to the conclusion, that a sphere of action with maximum size results in minimal deformation regarding the entire data set. For this reason, the whole DTM has to be taken into consideration for the displacement procedure. The inherent height values have to be moved in such a manner, that no overall height information is lost. In case of objects existing on top of the terrain surface, they have to be preserved in cognizable form. Considering the whole DTM, a region of influence has to be assigned to each street, containing the respective points to edit. These regions are assigned by calculating a Voronoi-diagram for the street segments.

For the raster cells within each polygon, the assigned street object is the one within the shortest distance. Thus each voronoi cell represents the sphere of influence belonging to one particular street section. Hence within each voronoi cell, the DTM is modified depending on the values of the associated middle axes. The calculation of the voronoi diagram was undertaken with *VRONI*, an algorithm implemented by Held (2001). The result of this calculation is shown in figure 4.

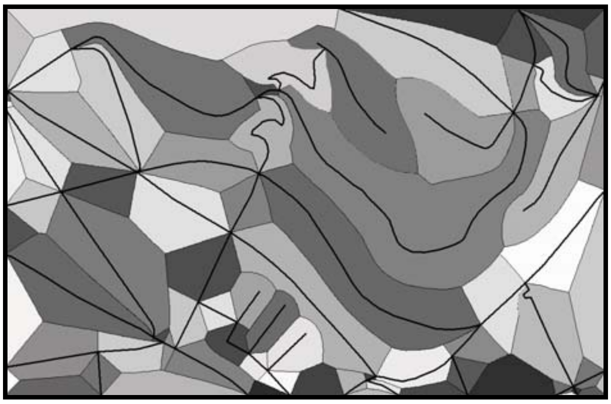

Figure 4: Voronoi cells (in different grey scales) calculated with VRONI (Held, 2001), for the street segments (represented by black lines) for a section of the city of Stuttgart.

In this illustration, the Voronoi cells are marked with different grey scales, the street segments are represented by the black lines passing through the polygons. For every street segment, the cells contained in the appendant voronoi polygon are considered when recalculating the cell values. For these regions an appropriate displacement method has to be chosen.

## 4. CONCLUSIONS AND FUTURE WORK

While generalizing a DTM the enhancement of relevant objects is of great importance. For this reason, the objects have to be enlarged, which leads to problems with adjacent areas and objects. In a first attempt, the adjustment merely was undertaken by smoothing the regions adjacent to the middle axes. This led to a purely visual change involving the loss of information within this regions.
Therefore, displacement methods have to be investigated with regard to their usability in the third dimension. Possibly, least square adjustment or a finite elements approaches used for 2D generalization could be transferred.

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