

# GENERALIZATION OF 3D BUILDING DATA

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## ABSTRACT

Today, more and more (semi-) automatic tools and techniques are getting available, that allow for an efficient capture of more and more detailed 3D city models. With the availability of such data, the question rises, how these typically huge data sets can efficiently be handled, manipulated, analysed and visualized. Concerning visualization, the Level of Detail (LOD) concept from Computer Graphic provides a mechanism to only present that information, that is currently visible in an adequate resolution level. The problem, however, is how such a multi-scale representation of buildings can be automatically gained. This generation is a generalization problem. In the paper a concept is sketched, that relies on the representation of buildings in terms of Constructive Solid Geometry (CSG). Firstly, the complex building shape has to be transformed into CSG, which involves a segmentation of the building into its relevant parts. Secondly, generalization mechanisms can operate on the CSG-tree. Finally, the transition between neighbouring generalization levels is achieved using a differential scheme, where only the differences between adjacent generalization levels are stored, instead of the whole models.

## 1. INTRODUCTION

### 1.1 Motivation

Three-dimensional models of cities and landscapes are getting increasingly popular and widely used. The most important applications are models for propagation of noise, electromagnetic waves and pollutants in the air. The main driving forces for the capture of 3D city models have been telecommunication companies that need such models for the planning of the distribution of their antennas.

In addition to these calculation models, 3D city models are also used for visualizations. It is for instance possible to visualize whole towns, which is especially important for new architectural projects, that can thus be visualized in the context of the existing situation. A rather new field are 3D city information systems, where tourists can either visit a city virtually before a trip, or use the 3D-system as a guide during their trip. In addition, in car navigation, that currently relies on the visualization of 2D maps, 3D visualization are being introduced – especially in Japan: On complex road junctions, a 2D-map alone does not give an unambiguous presentation of the situation. Here, sophisticated and rich 3D-presentations of the spatial situation are helpful in order to give a more realistic impression and thus lead to a more save guidance.

There are different requirements concerning the level of detail of the 3D models: whereas 3D information systems and architecture needs detailed, photo realistic visualizations, they are lower for tourist information purposes, and still lower for simulations [Brenner 1999]. Thus, such models have to be available at different levels of detail on order to satisfy various needs. Furthermore, on-line visualization of detailed 3D datasets require a lot of rendering time. Thus typically only those levels of details are transmitted and rendered on the

screen, that are currently needed for the visualization. The generation of the different levels of detail is a generalization problem.

### 1.2 Overview of paper

The paper reports on on-going research concerning the generalization of highly detailed 3D buildings. It presents a step-by-step procedure consisting of a segmentation of the building parts into its constituting details, that are then stored in terms of a CSG representation. These segments are subsequently generalized. The possibility of storing the different generalization levels in a multi-scale structure is described in detail.

## 2. BASICS AND STATE OF THE ART

### 2.1 Why is simplification and generalization necessary?

The aim of computer graphics is to create photo-realistic visualizations. Simplifications are needed to reduce the amount of data, so that is possible to calculate the visualization in real-time.

For surface simplification, vertex-, edge, and face-reductions are used. The user should not see the difference between the original model and the simplified one in the optical presentation. Therefore, only non-recognizable details can be omitted. By increasing the distance, an object will contract to a point before it will be invisible.

The disadvantage of photo-realistic presentations is the large number of presented details. The user is distracted from the essential parts. The possibility to recognize the parts of interest is deteriorated by the uninteresting details.

In cartography, there are additional aims. Single features must either be clearly distinguishable and visible or not visible at all.

Thus there are discrete gaps, where the representation changes from one level of detail to the next. The main characteristics of an object will be saved until it cannot be visualized anymore. There are different generalization methods: First of all, there is the possibility to select objects based on their thematic contents. Then, geometric generalization procedures are used: besides simplification there are also emphasizing, selection, displacement, aggregation and classification (e.g. [Shea & McMaster, 1989], or [Hake, Grünreich & Meng, 2002]). The main task that is solved in a cartographic presentation is the fact that important objects are clearly visualized, whereas the unimportant details are suppressed. Thus, it is possible to understand and comprehend a spatial situation at a glance, without being distracted by too many details.

## **2.2 Why is it necessary to generalise interactively scaleable and thematically selectable representations at all?**

The question is, why to generalize interactive representations at all, as the user can influence them so easily: There is the possibility to flexibly zoom to objects as well as to select and unselect information, to inspect the interesting details.

In order to perceive an object, it must be identified and localised. Therefore, one typically gets an overview of the area in a small scale. However, without generalization the interesting objects could be already unrecognisable, since they are too small at that scale. With emphasizing and classification, this problem can be solved.

Furthermore, the user should get the ability to generate static visualizations (for instance printed maps). In this case, obviously manipulations (selection or scaling) are no longer possible – still the important information has to be visible. For the generation of such static representations and visualizations, cartographic generalization has proven to be suitable.

## **2.3 Multi-resolution-models**

Scale dependent data has to be visualized and analysed with different scales. For each scale another degree of simplification or generalization is needed. This derivation of simplified and generalised models is typically time consuming, as in most cases it involves complex geometric operations. Therefore, the generation of the simplification is much more cost intensive than calculating the visualization. Thus in most cases, simplification and generalization cannot be done at real-time. There are approaches that however mainly aim at the transition of small scale differences [Lehto, & Kilpeläinen, 2000].

The Level of Detail concept (LOD) from computer graphics is designed to calculate and store several models of increasing simplification for every object. Depending on the scale for the visualization (or the distance of the observer from the objects) the appropriate model is selected and used and so calculation time is saved.

In the domain of visualization of 3D surfaces, mesh simplification or triangulation methods are used ([Hoppe 1997], [De Floriani & Puppo 1995], [Schmalstieg 1997], [Schröder 1992], or [Heckbert & Garland, 1997] for a summary). These different techniques mainly depend on geometric properties. However, a mere geometric consideration does not respect the relative importance of objects. Similar to generalization approaches in cartography, objects have to be generalized according to their importance, not (only) with respect to their geometric size. In order to integrate semantic and geometric generalization, object-based methods are being applied, which are usually realized by knowledge-based systems [Mackaness et al. 97].

An approach that uses rules similar to cartographic generalization is presented in [Sester & Klein 1999]. Mayer [2000] uses a method from image processing – scale space theory – for the generalization of buildings. Typical approaches in building generalization design three levels of detail: the highly detailed object as first level, a bounding cuboid as a second level, followed by the centroid of the cuboid as third, most coarse level (e.g. [Coors 2001, Könniger & Bartels 1998, Kofler 1998]).

## **3. APPROACH FOR 3D-BUILDING SIMPLIFICATION**

### **3.1 Scenario – working hypothesis**

The approach presented in this paper is based on the following assumption: the building is described in a highly detailed form. The data are taken from construction plans or from a fine surveying. The aim is to use the data for a virtual tour through a town. The visualization is not intended to be photo-realistic, but has to comply with cartographic standards. Besides simplification by smoothing and omitting other generalization operations such as emphasizing, aggregation, classification and displacement are used. However, these operations require information about the importance of the objects. In the ideal case, this information can be taken from attributes. In most cases, however, importance has to be extracted from geometry (size, form) and topology (singularity).

Generalization of one building cannot be done without respecting its surrounding. A single building will typically be generalised in another way than buildings in low- and high-density-areas. The main constraint for all generalization approaches is to observe minimum measures and preserve important characteristics. The methods proposed in this paper are useful for the generalization of single buildings. Such generalizations are needed when going from the highest detail levels to a mid detail. For further generalizations, generalization of groups of objects – mainly aggregation – has to be taken into account, additionally.

### **3.2 Input data formats**

There are different kinds of possibilities for the 3D modelling of buildings, e.g. boundary representation, parametric description, spatial enumeration or constructive solid geometry (CSG). The simplest way to describe a building geometry is to use boundary representation. Such a representation can be transformed from all the other modelling schemes.

The objects' boundary can be parameterised by a triangulated network. Usually, coordinated points will be connected by straight lines and form planar triangles. There is also the option of using NURBS for surface parametrization, which, however, in this case is not necessary, as most buildings are bounded by planar faces. In this way, the planar face that the building borders primarily consist of will be fractionised into several triangles, leading to many small faces.

Another way to model a building is to directly parameterise the boundary. This allows that the main characteristics of building faces (horizontal, vertical, orthogonal and coplanar) can directly be introduced in the data model [Thiemann 2001].

### **3.3 Procedure**

The proposed procedure consists of the following steps: The building has to be segmented into its elementary parts. These parts will be generalized by distinguishing between important and unimportant structures. The results of the generalization steps are stored in a multi-scale data structure. In the following sections, these steps are described in more detail.

### 3.3.1 Feature detection

Chimneys, balconies, windows and doors are features that stick out of the facades, or form holes in the boundary. These features have to be extracted and separated from the main body of the building. In addition, features can also be split in a main part and feature-features. There are two different methods:

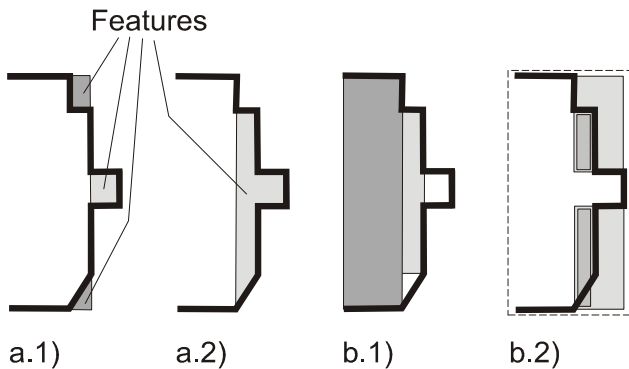


Figure 1: Two possibilities for feature detection: a: two different results of intersection with boundary planes b: Circumscription of elementary primitives: enclosing (b.1), wrapping (b.2).

- The building is intersected with one or more planes of its boundary. This has effects for all concave and convex parts. All bumps, holes and notches will be detected. The features will be ranked in quality order [Heckbert et al. 2001] The ranking process can also take the special characteristic of buildings into account. Figure 1a.1) visualizes the effect of detecting convex and concave building structures. In Figure 1a.2) larger features are being detected. In the ranking process, the size of the added or removed parts is taken into account
- The building is first circumscribed with enclosing or wrapping primitive solids like cylinder, prism and pyramid. Unmask building areas and mask no-building areas will be examined in next iterations. The prominent property of buildings, namely being composed of vertical walls, can easily be modelled with standing prisms. Figure 1b) demonstrates circumscription with 1b.1) only enclosing, and 1b.2) only warping primitives.

### 3.3.2 Segmentation into main body and features – derivation of a CSG-representation

The building will be modelled as a combination of the main body and the features. These parts are combined using Boolean operators especially union and difference and in some cases intersection. The sequence of operations is stored in a (CSG-) tree.

It is allowed that the parts (features) overlap. In this case, the Boolean operations are not reversible. Without overlapping, union and difference are reverse operations.

$$\text{If } A \cup B = C \text{ and } A \cap B = \emptyset, \\ \text{then } C \setminus A = B \text{ and } C \setminus B = A, \text{ respectively.}$$

### 3.3.3 Generalization

A local and global analysis decides – depending on the scale – which parts of the building must be emphasized, merged or removed. These operations have to consider that exaggeration, aggregation and classification can lead to the necessity of displacement. The analysis will be based on given constraints concerning minimal object properties: the size of a building plane, the volume of an extrusion or notch, as well as the local

neighbourhood of such phenomena influence the selection of appropriate generalization methods.

These generalizations can be executed with CSG-operations based on the following methods:

Generalization Operation	Realization with CSG
Omitting	Remove features
Displacement	Move anchor point, rotate orientation
Emphasis	Scale parameters
Aggregation:	Replacement of n features by one feature
Typification	Replacement of m features by n features
Symbolising	Is not used in this abstraction level of building generalization

Different levels of generalization can be achieved by selecting different values for the control parameters determining minimal constraints.

### 3.3.4 Saving the results of generalization

The result of generalization is a sequence of models for different scales. To limit the number of generated models, for larger scale ranges the same highly detailed model can be used. If only a few generalization levels are used, typically there will be many differences between these successive generalization levels of one object. While zooming in and out, details pop up or disappear abruptly when the model changes. This is known as “popping effect”. Such abrupt changes attract the attention of the observer, what is considered as distracting and uncomfortable.

To avoid the popping effect, there are some strategies:

- Many different models will be generated. Thus only few small differences between neighboured models occur.
- With slow deformations, scalings, translations and rotations the model changes appear being continuous. Details, that will be removed, can be contracted to a geometrically lower dimension and vice versa: An edge can be contracted to a vertex, an area to an edge and a volume to an area. This is known as “geomorphs”. For computer graphics; Hugues Hoppe’s progressive meshes are based on this strategy [Hoppe 1996].

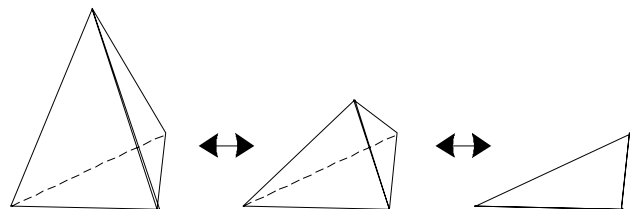


Figure 2: Geomorphing: Contracting a line, two faces and the whole tetraeder to a triangle.

- Typification denotes the process of replacing a number of objects by a smaller number of objects. As this is a discrete process, it is not defined which object in one representation is related to which object in the next generalization step. A

seemingly continues change can be generated by cross fading using decreasing/increasing transparency of the two generalization levels involved.

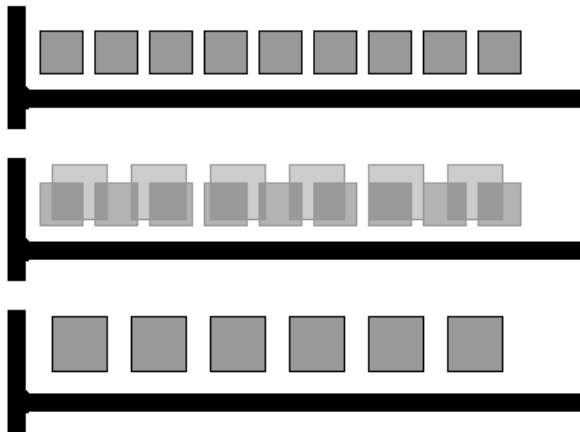


Figure 3: Fading; taken from [van Kreveld, 2001]: the nine objects from the first row are replaced by the six objects in the lower row.

Consequently, it is better to generate as much models as possible in order to achieve visually continuous changes in representation. This however leads to a huge amount of data, when each intermediate model is stored. To reduce the amount of data, instead of the whole models only the differences between them are stored. The models can be calculated by sequentially adding and deleting details, respectively. Figure 4 visualizes this concept: between generalization levels (LOD's), only the difference operations are stored (e.g. adding or deleting objects or object parts). It is assumed, that storing (small) differences between adjacent LOD's involves smaller amounts of data, and can thus be performed in real time.

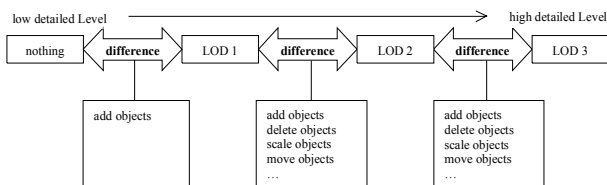


Figure 4: Differential multi-scale data structure: storing only differences between adjacent levels of detail.

If this data structure is designed from low to the high detailed level, incremental loading and transferring of the data will be possible. Data have only to be read until the requested level of detail is reached. Such techniques are well known in image processing, e.g. the progressive updating of GIF image in the Internet. They are being proposed also for vector data, e.g. by [Bertolucci & Egenhofer, 2000]. This leads to a reduced number of data to be transferred, which is especially important for mobile applications.

For visualization, a data model is needed, which enables a fast change between the neighbored models. When approaching an object, models that are more detailed are needed. When moving away, in turn, the less detailed models can be used again. The visualization of these models has to be possible in real-time. Therefore, only a boundary representation is suited, as today's rendering engines are optimised for drawing triangulated surfaces.

For the analysis, interpretation and manipulation of the 3D objects, however, a CSG representation is more suitable,

especially when it comes to generalization operations. However, the conversion from CSG to boundary representation is always possible (the reverse conversion is not trivial). Thus, in this approach, the generation of the generalization space is performed off-line and based on CSG, whereas the rendering is done with a boundary representation of the data.

An important prerequisite is that the Geomorphs run exactly synchronized, so that the main characteristics of buildings (horizontality, verticality, etc.) can be preserved. If the data model includes these characteristics implicitly, it is straightforward to ensure it. Such a data model is described in [Thiemann 2001].

In this work, a continuous scale representation based on a differential CSG model will be developed. For visualization, it can be converted into several boundary representations. If required, a multi-scale boundary representation will be created.

#### 4. DISCUSSION AND OUTLOOK

In the next steps of this research, these concepts will be implemented. First, feature splitting and generalization will be realized. Then, the automatic generalization based on minimal constraints is implemented. Based on such a mechanism, investigations concerning the necessary number of generalization levels for different application scenarios will be conducted.

Finally, the generalization of adjacent buildings, building blocks and bigger housing areas will be studied, where special problems arise, like the definition of a simplified roof of two adjacent buildings.

#### 5. REFERENCES

Berlotto, M. & Egenhofer M. [1999], Progressive Vector Transmission, Transactions of the ACMGIS99, Kansas City, MO, pp. 152-157.

Brenner, C. [1999], Interactive modeling tools for 3D building reconstruction, Photogrammetric Week 99, Fritsch/Spiller (eds.), Wichmann, pp. 23-34.

Coors, V. 2001: Feature-preserving Simplification in Web-based 3D-GIS. 1st International Symposium on Smart Graphics, <http://www.dfki.de/~krueger/sg2001>.

De Floriani, L. & E. Puppo [1995]: Hierarchical Triangulation for Multiresolution Surface Description. ACM Transactions on Graphics 14(4), pp. 363-411.

Hake, G., D. Grünreich & L. Meng [2001]. Kartographie. De Gruyter Verlag.

Heckbert, P., Ribelles, J., Garland, M., Stahovich, T., Srivastava, V. [2001]: Finding and Removing Features from Polyhedra. Proceedings of DETC'01.

Heckbert, P. & M. Garland [1997]: Survey of Polygonal Surface Simplification Algorithms, Technical report, School of Computer Science, Carnegie Mellon University, Pittsburgh, Multi-resolution Surface Modeling Course Siggraph, 97, <http://www.cs.cmu.edu/~ph>.

Hoppe, H., [1997], View-dependent refinement of progressive meshes, Computer Graphics (SIGGRAPH '97 Proceedings), 1997, pages 189-198.

Kofler, M. [1998]: R-Trees for Visualizing and Organizing large 3D Databases. Doctoral Thesis, University of Graz.

Könninger, A. & S. Bartel [1998], 3D-GIS for Urban Purposes, *GeoInformatica*, Vol., Nr. 1, pp. 79-103.

Lehto, L. & T. Kilpeläinen, 2000. Real-time Generalization of Geodata in the WEB, in: 'International Archives of Photogrammetry and Remote Sensing', Vol. 33, Part B4, ISPRS, Amsterdam, 2000, pp. 559-566.

Mayer, H. [2000], Three Dimensional Generalization of Buildings Based on Scale-Spaces, *in: 'International Archives of Photogrammetry and Remote Sensing'*, Vol. 33, Part B4, ISPRS Amsterdam, 2000.

Schmalstieg, D.[1997]: Lodestar - An Octree-Based Level of Detail Generator for VRML. in: *Proceedings of SIGGRAPH Symposium on VRML*.

Schröder, W. J., Zarge, J. A., Lorensen W. E., [1992], Decimation of Triangle Meshes, *Computer Graphics*, 26, 2, July 1992, pages 65-69.

Sester, M. & A. Klein [1999]: Rule Based Generalization of Buildings for 3D-Visualization, *Proceedings of the International Cartographic Conference (ICA)*, Ottawa.

Shea, K. & McMaster, R. [1989], Cartographic generalization in a digital environment: when and how to generalize, in: 'Ninth International Symposium on Computer-Assisted Cartography', Baltimore, Maryland, pp. 56-67.

Thiemann, F. [2001]: Parametrisierung, Modellierung und Ausgleichung von 3D Gebäudedaten für das Facility-Management. Diploma Thesis, Institute for Geodesy and Geo-Information, Technical University of Berlin.

van Kreveld, M. [2001], Smooth Generalization for Continuous Zooming, *Proceedings of the ICC*, Beijing, China, 2001.