Concepts for Automatic Generalization of Virtual 3D Landscape Models

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This paper discusses concepts for the automatic generalization of virtual 3D landscape models. As complexity, heterogeneity, and diversity of geodata that constitute landscape models are constantly growing, the need for landscape models that generalize their contents to a consistent, coherent level-of-abstraction and information density becomes an essential requirement for applications such as in conceptual landscape design, simulation and analysis, and mobile mapping. We discuss concepts of generalization and working principles as well as the concept of level-of-abstraction. We furthermore present three exemplary automated techniques for generalizing 3D landscape models, including a geometric generalization technique that generates discrete iso-surfaces of 3D terrain models in real-time, a geometric generalization technique for site and building models, and a real-time generalization lens technique.

1 Introduction

Virtual 3D landscape models serve as frameworks for representing geographic and thematic aspects of landscapes. They are based on 3D geodata including high precision terrain and surface models (DTM, DSM), 3D building, site, and city models, 3D vegetation and water models, as well as photographic textures to model the appearance of these components. This way, virtual 3D landscape models achieve a high degree of realism as required by a number of applications in virtual reality, design, and architecture.

A high level of geometric detail and photorealistic appearance, however, is not an ultimate quality of a landscape model: There are numerous applications and systems requiring virtual 3D landscape models that simplify, aggregate, categorize and abstract their contents to a specific coherent level-of-abstraction. These *generalized virtual 3D landscape models* facilitate, for example, understanding landscape form, conceptual design of landscapes, collaborative development of landscape models, and comparison of model variants. Generalization of landscape models also enables their use and reuse for simulation and analysis processes and as computational tools, which commonly require a homogeneous spatial, thematic, and semantic resolution of the model components and information density. Consequently, *landscape generalization* is a technique to cope with compactness, complexity, heterogeneity, and diversity of geodata that constitute today's digital landscape models.

2 Related Work

In cartography, several methods have been developed for map generalization, which represents "a complex decision-making process, which must be intelligently steered by goals and rules from the geographical application domain such that the generalized representation conveys knowledge consistent with the reality" (LAL & MENG 2001).

Cartographic generalization operators are discussed by MCMASTER & SHEA (1992), BREWER & BUTTENFIELD (2007), and LI (2007). More recently, ROTH ET AL. (2008) introduce a typology of multi-scale mapping operators for 2D geospatial features.
As a number of operators with potentially contradicting constraints are applied to the data, focus has been put on how to minimize violation of constraints using optimization techniques (NEUN ET AL. 2009) and how to formalize constraints (FOERSTER 2010). While national mapping agencies currently rely on customized software in the map making, there are also approaches using commercial out-of-the-box software (STOTER 2010).
In the scope of 3D models, generalization techniques are developed for single buildings (KADA 2007, FORBERG 2007) and whole city models (GLANDER & DÖLLNER 2009). In general, the focus is more on specific algorithms to implement generalization operators. However, also approaches to evaluate generalization quality (MAO ET AL. 2010) and for the integration of multiple operators and techniques (GUERCKE & BRENNER 2009) are discussed, recently.
Lens-based focus + context visualization facilitates the exploration of complex information spaces that enable the combination of different levels of structural abstraction. Focus areas within lens volumes are shown in full detail while excluding less important details of the surrounding area. 3D lenses were first introduced in (VIEGA ET AL. 1996), extending the idea of lenses to three dimensional models and scenes. In (ROPINSKI ET AL. 2005), an overview of focus + context visualization with 3D lenses and application examples is given. They present an image-based multi-pass rendering algorithm to separate focus from context regions that supports arbitrarily shaped lenses in real-time, but does not handle overlapping or nested 3D lenses. These shortcomings are addressed by 3D generalization lenses (TRAPP ET AL. 2008), which combine different geometric representations within a single view based on one or more 3D lenses of arbitrary shape. Their technique supports simultaneous use of multiple lenses associated with different abstraction levels, can handle overlapping and nested lenses, and provides interactive lens modification.

3 Landscape Generalization

Landscape generalization denotes a fundamental operation that transforms and presents landscape models at a given level-of-abstraction (LOA). The transformation and presentation techniques are based on a combined use of generalization operators including combination, reclassification, class selection, simplification, collapse, amalgamation, elimination, enhancement, displacement, enlargement, and typification (FOERSTER ET AL. 2010). *Generalization operators* can be applied (1) to the original geodata of a virtual 3D landscape model, i.e., it can be performed in the filtering step of the visualization pipeline (Fig. 1), leading to a *generalized primary landscape model*. It can also be applied (2) to the mapped data, i.e., during the mapping step of the visualization pipeline, leading to a *generalized cartographic landscape model.* Furthermore it can be applied (3) during the rendering step of visualization pipeline, leading to a *generalized graphics representation*. In practice, concrete generalization techniques use a combination of these generalized models, in particular, if they have to provide adaptive, dynamic generalized models for interactive 3D systems, generalization operators for all three steps are required.

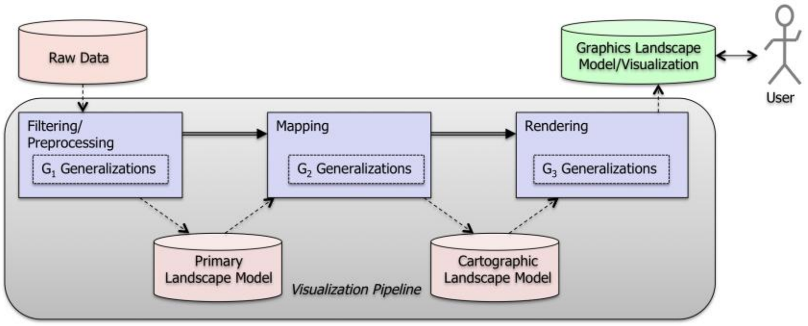

Figure 1: Generalization operators can be applied to all stages of the visualization pipeline.

The *level-of-abstraction* (GLANDER & DÖLLNER 2009) refers to the spatial and thematic granularity at which model contents are represented. It can be dependent on the current 3D camera settings, the current task or process, the user profile, or any other criteria from the underlying application domain. The model contents should be adapted to a given LOA on demand. Since generalization is a typically costly process that can hardly be performed in real-time, a number of LOA variants of a landscape models can be processed and stored. For the implementation of generalization techniques, level-of-detail (LOD) techniques from computer graphics (COHEN & MANOCHA 2005) can be used, but LOD is fundamentally different to LOA since LOD focuses on an optimized computer graphics representation for real-time rendering purposes.

4 Techniques for Landscape Model Generalization

Any technique for landscape model generalization is based on a combined use of generalization operators applied at different steps within the visualization pipeline. For practical applications, a generalization technique should

- operate automatically, i.e., without human intervention;
- provide a set of configuration parameters that help to adapt the resulting generalized model to the specific needs of an application or system;
- define how to use LOA variants within real-time visualization by providing methods to blend between different LOAs and to select LOAs dependent on viewing and camera situations.

The following examples illustrate different approaches of generalization techniques for landscape models.

4.1 Geometric Generalization of Terrain Models by Isocontours

This generalization technique generates 3D stepped terrain models (GLANDER ET AL. 2010), which can be used in schematic terrain visualization to communicate relief structures of mountain landscapes through isocontours (Figure 2).

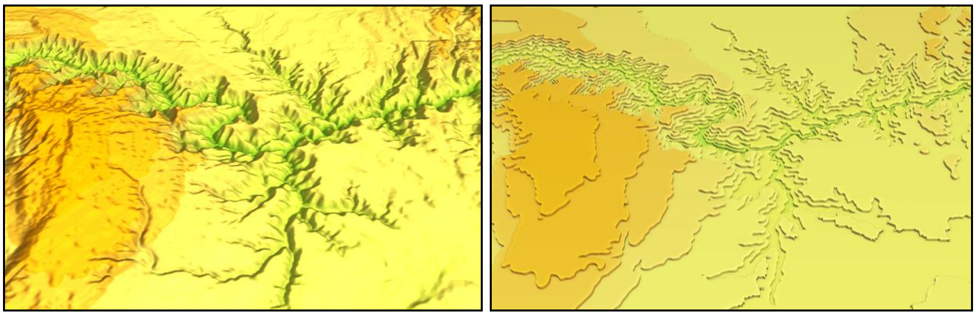

Figure 2: The comparison shows the original 3D DTM (left) and isocontour-based generalized 3D model (right).

A set of typically equally spaced isovalues define height intervals that are highlighted by isocontours on the terrain model. The real-time generalization technique creates schematic visualizations from standard triangle-based terrain models exploiting graphics hardware.
During rendering, the schematic visualization is obtained on-the fly through (1) translating terrain vertices and (2) creating new step geometry (Figure 3). (1) All vertices of the input terrain are translated to their nearest isolevel by setting their height accordingly. This step results in planar triangles except at thresholds between two isovalues. (2) Each input triangle crossing one or more thresholds is replaced by step geometry derived from the triangle's individual configuration. The step geometry is created by computing the intersection points per threshold and creating appropriate triangles. The new geometry adapts to the course of the isoline and thus reproduces it smoothly.
Further, an additional interpolation schema for single vertices facilitates smooth transitions between classical 3D terrain rendering and its stepped variant. A straightforward solution is to linearly blend between the vertices' original heights and their quantized height, using a control parameter γ from [0,1]. The parameter can be defined globally (constant), locally (additional layer) or view dependent. Thus, the technique allows flexible application of the effect including general activation/deactivation, highlighting regions-of-interest and distance-based styling.

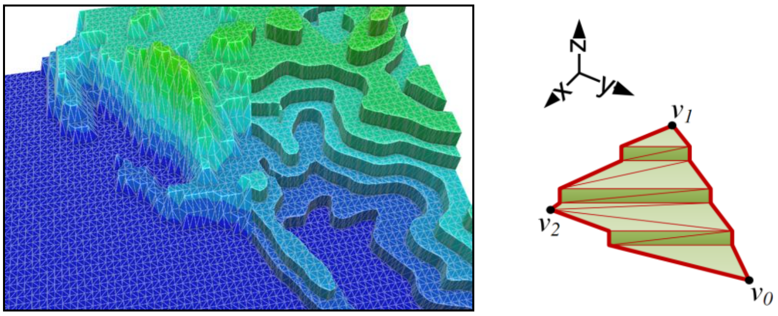

Figure 3: New step geometry is necessary to prevent sloped triangles (left). Newly created sub-triangles help to reproduce the isocontours (right).

4.2 Cell-Based Geometric Generalization

This generalization technique (GLANDER & DÖLLNER 2009) generalizes a given virtual 3D landscape model according to a given hierarchical infrastructure network (e.g., hierarchical street network). That network defines the spatial clustering of geographic space by geographic cells (e.g., city blocks or districts). If a high hierarchy level is used as LOA, the resulting cells will be coarser. At the lowest level, the original model is unchanged. The technique takes as input the original (detailed) 3D model, and generates model variants for each hierarchy level. Thereby, it automatically aggregates single buildings into building blocks formed by the cells, i.e., the partitions of a given infrastructure network, handling separately green space and water areas. Local landmark buildings are detected, e.g., by their geometric properties, and preserved in their appearance (Figure 4).

The 3D terrain model below the building models may have an impact on the generalization: If, on the one hand, the ground height difference between two buildings is too high, this indicates that the buildings should not be aggregated. GUERCKE ET AL. (2011) present a framework to integrate constraints such as this one. If, on the other hand, the terrain model only has small height differences, a straightforward way to represent its curvature is to reflect it in curvature of the cell block's rooftop. Therefore, the polygons need to be refined with additional vertices, where each vertex is offset by the terrain height.

In interactive 3D virtual environments, continuous scale requires seamless transitions between pre-computed, static geometric representations to show the appropriate level of abstraction. For example, when moving through the model, a LOA management based on the camera distance would need to select high detail geometry in near regions, and coarse geometry in far regions. We found that transparency blending works best when switching between different geometries, compared to other approaches such as morphing. With this technique, generalized virtual 3D landscape models can be created with a LOA that is determined by the underlying hierarchical infrastructure network.

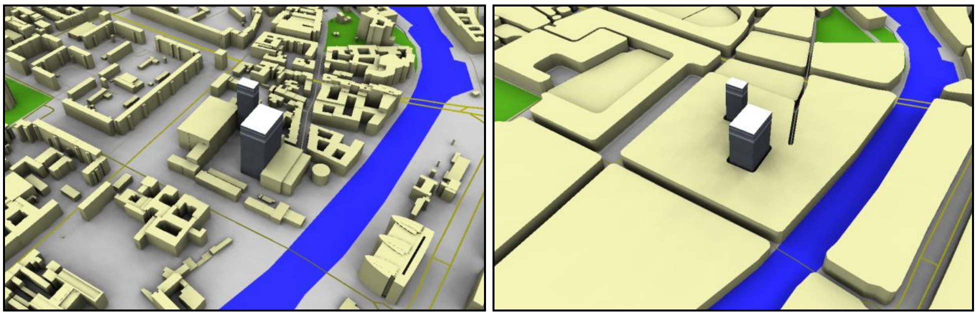

Figure 4: The comparison shows the original (left) and generalized (right) virtual 3D city model. Landmark buildings are highlighted with their original appearance.

4.3 Generalization Lenses

This generalization technique enables the seamless combination of different virtual 3D model variants of the same geographic area (e.g., LOA variants) within a single image using multiple rendering passes (TRAPP ET AL. 2008). It is based on the volumetric clipping technology that enables pixel precise clipping of an arbitrary polygonal scene representation against arbitrary 3D solid clip geometry. This polygonal clip geometry is converted into a layered depth image (LDI) during a preprocessing step. At runtime, the LDI combined with a volumetric depth test is used to determine if a fragment of the rasterized scene geometry is inside or outside the clip geometry represented by the LDI. This test can be implemented efficiently on modern consumer graphics hardware using shader technology. The technique supports simultaneous use of multiple clipping volumes associated with different abstraction levels, can handle overlapping and nested cases, and provides their interactive modification. At runtime, the lens shapes can be scaled, rotated and translated within the scene. The system supports different methods for the lens shape creation. It enables the derivation of complex lens shapes directly from geo-referenced data, such as buffered 2D polygonal shapes and polylines. Further, the lens shapes can also be explicitly using 3D modeling software by importing these through common interchange formats. With respect to the lens interaction, the visualization technique supports scene and camera lenses (Figure 5). While the position of a scene lens is independent from the user's orientation, i.e., fixed with respect to the virtual environment or attached to a moving object in the scene, a camera lens adapts it position with respect to the current user orientation. It can be used to assure that potential foci are always visible. This minimizes the effort for the user to steer the lenses.

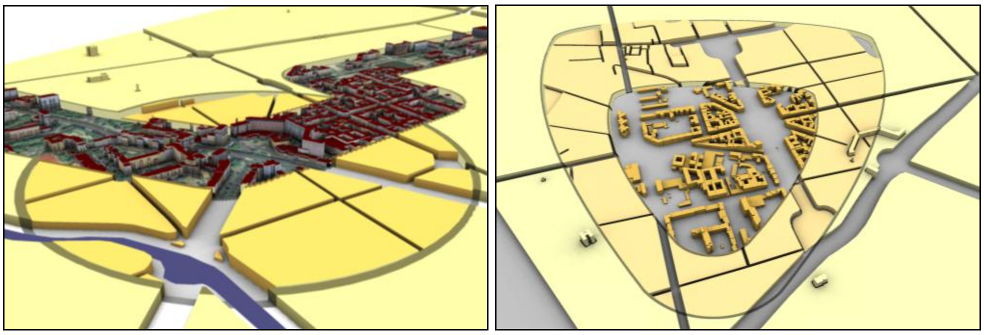

Figure 5: The examples show three variants of a virtual 3D model at different LOA, integrated in a single image. Lenses can be constructed from paths and regions-of-interest (left) or be camera adaptive (right).

5 Applications of Generalized Landscape Models

Possible applications of generalized landscape models include:

- Conceptual Landscape Design: It concentrates on early stages of planning processes that require abstract models to express uncertainty and incompleteness as well as the conceptual characteristics of model elements.
- Simulation & Analysis: 3D simulation and analysis processes require 3D models as input that have an appropriate and consistent spatial and thematic resolution such

as for airflow simulation, waterflooding prediction, hydrologic processes, soil erosion, or vegetative succession.

- Mobile Mapping: Generalized landscape models can directly be used in mobile mapping applications and systems to select an appropriate LOA for given camera settings and display resolution. In particular, generalized landscape models can be seamlessly integrated into a single view, blending between LOA variants in a view-dependent/camera-distance dependent way.

6 Conclusions and Future Work

The automatic generalization of virtual 3D landscape models involves complex model transformation and presentation algorithms composed of a set of generalization operators that are applied within the visualization pipeline at all stages. The challenges include the automation of the algorithms and their systematic and robust implementation. While many concepts can be taken from cartographic 2D generalization, 3D generalization implies additional constraints and methods to achieve consistent, plausible 3D model variants. The presented concepts have been implemented as research prototypes; we are currently working on an extensible library to provide generalization tools as generic components.

Generalized models aim at providing a consistent and coherent level-of-abstraction among all their components. They facilitate many applications of landscape models such as in conceptual landscape design, in simulation and analysis, and in mobile mapping.

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