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A vocabulary for a multiscale process description for fast transmission and continuous visualization of spatial data

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ABSTRACT

With the increasing availability of small mobile computers there is also an increasing demand for visualizing spatial data on those devices. Prominent applications are location based services in general, and car and pedestrian navigation in particular. In order to be able to offer both detail and overview of a spatial situation, the devices have to provide flexible zooming in and out in real-time. The same demands arise from the increasing amounts of data available and accessible by web services through limited bandwidth channels. The presentation of spatial data sets in different zoom levels or resolutions is usually achieved using generalization operations. When larger scale steps have to be overcome, the shape of individual objects typically changes dramatically; also objects may disappear or merge with others to form new objects. As these steps typically are discrete in nature, this leads to visual 'popping effects' when going from one level of detail to the other.

In this paper, we will present an approach to decompose generalization into simple geometric and topologic operations that allow describing the complete generalization chain to generate a multiscale object representation. The goal is to generate a representation without redundancy and to transmit only that information which is needed when scale changes occur. This representation scheme ultimately enables a continuous visualization, where the changes between the representations are visually indistinguishable. We identify elementary generalization operations and apply these concepts for polyline simplification, the generalization of building ground plans and for displacement.

1. Introduction and overview

The presentation of spatial data in different levels of detail (LoDs) is a basic requirement in order to be able to fully understand spatial processes. In cartography it has traditionally been accounted for by the series of topographic maps (e.g. different scales from 1:10.000 to 1:1 Million). For their production, generalization operations are being applied that generate coarse representations from a given detailed data set.

The need for presenting spatial data in different resolutions recently arose again from a completely new domain: in order to present spatial information on small mobile displays—typically user location or navigation instructions—there is a strong need for generalization, because on the small displays only a reduced information content can be visualized at a time. As the small display devices typically do not dispose of large capabilities for storing digital data sets at different resolutions, the need for efficiently transmitting the spatial information from a remote server is evident. The same is true for large data sets accessed via the internet.

This problem was the starting point of our research, which aims at developing a method for incrementally transmitting more and more information in terms of object details to a small mobile device through a possibly limited bandwidth channel by incremental streaming. When a user inspects spatial data using a mobile or internet client, first only the coarsest information is transferred to give an overall impression. Then, objects in the zooming area will be incrementally loaded, until—if the user wishes so—the whole scene is given at the highest level of detail available.

The idea is to pre-compute a sequence of vector representations at different LoDs. These different representations, in our case, are coded efficiently in terms of a set of simple operations (SOs), describing topologic and geometric changes. These operations can be generated by an appropriate adaptation of existing generalization operations. This code is incrementally sent to the client, where it has to be restored and visualized.

The paper is organized as follows: after a review of related work and an analysis of demands for progressive information transmission, a brief classification of generalization algorithms is

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given. Then, the elementary operations to code incremental changes of objects are presented. Different generalization functions are adapted in order to produce a representation in terms of those SOs. A summary and an outlook on future work conclude the paper.

2. Related work and demands for progressive information transmission

The basic requirement for progressive data transmission is that the changes occurring when going from one representation to the next are small enough in order not to be visually noticed. Thus, the user is not disturbed by coarse visible changes like object parts popping up or objects suddenly disappearing.

In order to provide such a smooth transition from one scale to the next, incremental object representations with more and more detail have to be visualized. This would imply that a very dense series of different scale representations is generated that has to be transmitted to the user while he/she is zooming in or out. Besides high demands for the storage of that large number of representations on the server, this also has high requirements concerning the transmission of the data, as a large number of potentially large data sets has to be transmitted. Due to the fact that scale changes of individual objects are not homogeneously distributed in the whole data set, potentially also highly redundant data is sent, i.e. an object is sent again, even if it has not changed from the previous scale. An alternative is to provide only a limited set of representations at dedicated scale levels comparable to the map series of topographic maps. The project GiMoDig aimed at providing a combination of on-line generalization and access to pre-generalized data (Sarjakoski et al., 2002). Bertolotto and Egenhofer (1999) describe an approach for progressively transmitting vector data by pre-computing a sequence of map representations at different LoDs. Another possibility is to send only changes or differences in the data set, which already can reduce the amount of data considerably. Such a mechanism is well known from the progressive transmission of GIF-images over the internet. Thiemann (2002) proposes to use this method for the visualization of 3D building data in different LoDs. A similar approach is given by Yang et al. (2007) for the point reduction operation: they present a scheme for an incremental vertex decimation taking also topological consistency of neighboring objects into account. Between adjacent scales, interpolations or morphing operations can be applied in order to provide a visually smooth transition (van Kreveld, 2001; Cecconi et al., 2002; Nöllenburg et al., 2008).

For the representation of different LoDs of vector geometry hierarchical schemes can be used. One example is the GAP-tree for the coding of area partitions in different LoDs (van Oosterom, 1995). This data structure also allows for a progressive data transfer (van Oosterom, 2005). The binary line generalization (BLG) tree hierarchically decomposes a line using, e.g. the Douglas and Peucker (1973) algorithm. Ai et al. (2004) describe a hierarchical decomposition of objects using a series of convex hulls.

A further option is not to send the changes as such, but a set of operations that describe the object and the changes. This requires that on the client side these instructions can be interpreted in order to correctly restore the object.

In our approach a set of elementary operations is defined that allow for describing geometric and topologic changes in vector data sets. Generalization operations can be decomposed into a sequence of elementary operations leading to a sequential reduction and increase of detail when zooming out or in, respectively. Thus, data coded in a vocabulary of the so-called SOs can be sent to the client, where it is restored again in order to be visualized. Due to the multi-scale property of this coding scheme, only that amount of detail has to be sent which is required by the user. The user can stop the transmission as soon as enough information for the current purpose has been obtained. The system consists of three parts: an off-line pre-processing step that generates the multi-scale code using generalization functions, the transmission of the code to the client, and a process that is able to recover all the intermediate generalization levels in the client. The basic principle of the coding scheme was described in an earlier paper (Brenner and Sester, 2005). In this presentation it is applied to new generalization functions and the coding efficiency is discussed.

3. Generalization operations

In recent years, advancements in the automation of generalization operations can be observed. For a comprehensive overview on automatic generalization see Mackaness et al. (2007). Generalization operations can be characterized by changes occurring to objects which are either discrete or continuous. These changes can affect individual objects and groups of objects, respectively. They result in changes in topology and/or in geometry. In the following, examples for these types of changes are given.

3.1. Discrete changes of individual objects

This situation is characterized by the fact that the topology and the geometry of the object changes. Examples for this class of changes are point reduction operations like the simplification of building ground plans or simplification of lines using, e.g. Douglas–Peucker filtering. Another example is symbolization, where an object is replaced by a new geometry or a symbol. Finally, also the collapse operation can be classified into this category, as the original geometry is replaced by a completely new geometry, e.g. a polygon is replaced by a line or a point.

3.2. Discrete changes of groups of objects

This type of change typically occurs when larger scale ranges have to be traversed and thus the abstraction level and often the type of object changes. An example is typification, where a group of objects is represented by a new group consisting of fewer objects (Müller and Wang, 1992; Regnauld, 1996; Sester, 2007). Another example is the amalgamation where nearby objects are merged to a new object.

3.3. Continuous changes of individual objects

Continuous changes of objects occur when the topology remains the same, however, geometry changes by moving either the whole object or individual points of the object. Displacement is a typical representative for such a change. Algorithms based on continuous optimization have been developed (Hojholt, 1998; Harrie, 2001; Sester, 2005). Also in the case of the enlargement operation only the positions of object vertices change, not affecting the topological structure of the objects. The same is true for continuous simplification of objects, e.g. Gaussian smoothing of lines, where the original object points are relocated.

3.4. Classification of operations

Table 1 gives a classification of generalization operations into these different categories according to the typology presented by