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Using Simultaneous Graphic Generalisation in a System for Real-Time Maps

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Abstract.

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1 Introduction

Maps are important tools for visualising geographic locations. Traditionally, printed paper maps have been used, but technological developments have made possible the production of digital maps. Furthermore, the introduction of the Internet and mobile technology has made it possible for a mobile device to communicate with remote databases. This way cartographic data from a remote database, distributed in real-time, can be displayed locally as maps. In this paper we denote this kind of maps as *real-time maps*.

To create good real-time maps the cartographic data often requires to be generalised before it is distributed to the user. This generalisation could either be performed as a pre-process or in real-time. If the generalisation is run as a pre-process batch and interactive generalisation could be used. In this study we concentrate on generalisation performed on demand in real time. Recently, several studies have been dedicated to real-time generalisation applications (Lehto and Kilpeläinen, 2000; van Kreveld, 2001; Jones et al., 2000; Cecconi, 2003). Few studies, however, have been performed to include more complex generalisation routines in real-time environments.

The aim of this study is to use graphic generalisation routines to create real-time maps. The graphic generalisation is performed by optimisation techniques. The idea of optimisation techniques in cartographic generalisation is not new (see e.g. Burghardt and Meier, 1997; Ware and Jones, 1998; Harrie, 1999; Højholt, 2000; Sester, 2000; Bader, 2001; Harrie and Sarjakoski, 2002). This study will not develop these theories any further; instead it concentrates on the requirements for using this type of techniques in a system architecture for real-time maps. More specifically, the aim of this study is to adjust and extend previous implementation of simultaneous graphic generalisation (as presented in Harrie and Sarjakoski, 2002) to be used in a system architecture for real-time maps developed in the EEC-project GiMoDig (see Lehto, 2003; Sarjakoski and Lehto, 2003; GiMoDig, 2004).

The method simultaneous graphic generalisation is only concerned with the graphic part of generalisation (i.e. graphic changes of the symbolisation to make the map more readable, roughly corresponding to the generalisation operators simplification, smoothing, displacement and exaggeration); the method does not include any model generalisation (generalisation due to changes in the conceptual model). In several generalisation problems both model and graphic generalisation are required. However, several parts in the model generalisation (e.g. typification) are difficult to define analytically and, hence, difficult to implement in a fully automatic system. A solution to avoid these hard parts of the generalisation transformation in real time is to use a multiple representation database (Cecconi, 2003; Hampe et al., 2004). In this study we do not consider any model generalisation at all.

The paper starts with a summary of the optimization technique simultaneous graphic generalization. Then follows a summary of a system architecture for real-time maps. Section four describes a prototype system; this system is evaluated in a case study as described in Section 5. The paper concludes with a discussion.

2 Simultaneous graphic generalisation

This section summarizes the theory behind simultaneous graphic generalisation. For a detailed description see Harrie and Sarjakoski (2002).

Simultaneous graphic generalisation aims at computing the optimal solution according to a set of constraints. The following constraints are used:

- Displacement: Spatial conflicts are not allowed.
- Simplification: Line and area objects should not contain more points than necessary to represent their characteristics. The simplification constraints force an *unnecessary point* to lie on the straight line between the two neighbouring points.
- Smoothing: Line and area objects should not be too angular.
- Exaggeration: Objects, and features within objects, should be large enough to be clearly visible.
- Curvature and Segment length: The characteristics of line and area objects must be maintained.
- Stiffness: The internal geometry of some objects must be invariant.
- Crossing: The angle between line objects in junctions must not change.
- Exaggeration: The shape of some objects must be maintained.
- Movement: Points should not move.
- Movement direction: Points on a line should not move in any direction across the line.

One key issue is to find analytical expressions for the constraints. In simultaneous graphic generalisation the number of points is invariant, which enables the formulation of the constraints on point movements. For the sake of computational simplicity, we restrict ourselves to linear equations; that is, all the constraints are of the form:

$$const_{x1} \cdot \Delta x_1 + const_{y1} \cdot \Delta y_1 + \ldots + const_{xn} \cdot \Delta x_n + const_{yn} \cdot \Delta y_n = const_{obs} \quad (1)$$

where

$\Delta x_i , \Delta y_i$	are point movements,
$const_{xx}$	are constant values, and
n	is the total number of points.

All the constraints together constitute an equation system in which the point movements are the unknowns. In matrix form this equation system can be written as:

$$\mathbf{Ax} = \mathbf{l} + \mathbf{v} \quad (2)$$

where

A	is the design matrix,
x	is a vector containing the unknown point movements,
l	is the observation vector (containing the right-hand side of Equation (1)), and
v	is the residual vector.

The residual vector has to be introduced since the Equation system (2) is over-determined (i.e., more constraints than unknowns). The method guarantees that either a movement or a simplification constraint is set up for each *x*- and *y*-coordinate, and normally there are constraints set up for preserving characteristics or improving legibility. That is, there are always at least as many constraints as unknowns, and in realistic applications there are about twice as many constraints as unknowns.

The "best solution" of Equation system (2) is the one that agrees as far as possible with the constraints, i.e. we face a minimisation problem of a function of the residual vector (**v** in Equation system (2)). To solve the equation system the least-squares method is used, which minimises a weighted l_2 norm:

$$\mathbf{v}^T\mathbf{P}\,\mathbf{v} \tag{3}$$

where

P	is the weighting matrix, and
$\mathbf{v}^T$	is the residual vector transposed.

The least-squares solution of the unknown point movements (stored in vector **x**) is given by:

$$(\mathbf{A}^T\mathbf{P}\mathbf{A})\cdot\mathbf{x} = \mathbf{A}^T\mathbf{P}\,\mathbf{l}\ . \tag{4}$$

Finally, the map is generalised by adding the computed point movements to the original coordinates.

The whole process of simultaneous graphic generalisation can be viewed as follows. In the initial state, some constraints are severely violated (e.g. displacement and simplification) while other constraints are not violated at all (e.g. movement and stiffness). The generalisation process then distributes the violations more evenly over all the constraints; the degree to which the violations are spread is dependent on the weights stored in matrix **P**. A thorough discussion about these weights is given in Harrie (2003).

2.1 Computational aspects of simultaneous graphic generalisation

There are two main tasks that are computationally demanding in simultaneous graphic generalization: solving the Equation system 4 and create the spatial relationships. Sarjakoski and Kilpeläinen (1999) proposed the use of conjugate gradient method to solve the Equation system 4. Conjugate gradient method is an iterative method that is storage and computationally efficient for sparse equation system (as is the case for Equation system 4). The spatial relationships are derived from constrained Delaunay triangulation (similar methods are also used by Ruas and Plazanet, 1996; Ware and Jones, 1998; Højholt, 2000; Sester, 2000). Delaunay triangles can be computed in O(n log n) expected time, where n is the number of points (cf. de Berg et al., 1997).

Practical performance tests in Harrie and Sarjakoski (2002) indicated an expected computational complexity of O(n log n) time of simultaneous graphic generalization. However, this value is much dependent on implementation solutions, type of cartographic data and parameter setting.

3 A system architecture for real-time maps

In theory, generalization routines could be implemented in the client. However, this would require that the client have access to cartographic data (and not only a graphic representation of the data) and high process / programming capabilities. Currently, an implementation of complex generalization routines in a client is not a realistic alternative. Therefore, these routines are required to be implemented in a service that could be reached by the client; hence, a kind of system architecture for real-time map applications is required. This system architecture could be based on Open GIS consortium (OGC) specification for cartographic web services as e.g. Web Map Service (WMS, 2004) and Web Feature Service (WFS, 2004).

The study described in this paper is part of the EC project GiMoDig (Geospatial info-mobility service by real-time data integration and generalization; GiMoDig, 2004); which is a project that aims at establishing methods for distributing cartographic data from core databases at national mapping agencies to mobile devices (mainly following the OGC standards). Figure 1 is a simplified overview of the GiMoDig system architecture (see Lehto, 2003 or Sarjakoski and Lehto, 2003 for details). The

client makes a WMS request for a map. The request is transformed in the layers below and is finally formulated as a WFS request to the data layer. The response to this request is cartographic data in the GML format. The cartographic data are sent to the data processing layer. In this layer generalization of the cartographic data is performed. The data processing layer then sends the generalized cartographic data to the portal layer. Finally, in the portal layer, the GML data is translated into, for example, an SVG or JPEG image for display at the client.

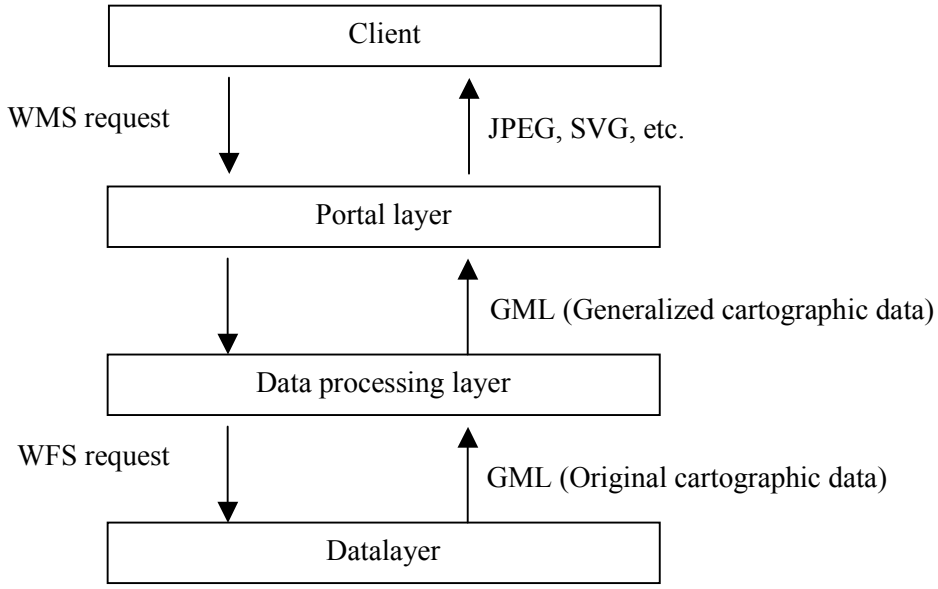

Figure 1. A simplified version of the GiMoDig system architecture.

Generalization routines should be implemented in the data processing layer. Figure 2 shows the workflow for this layer (which is implemented by Tommi Koivula and Lassi Lehto, Finnish Geodetic Institute). There are two programming environments for the generalisation: XSLT and Java/JTS (JTS is an open source Java package from Vivid Solutions, 2003, that conforms to the *Simple Features Specification for SQL,* by OGC, and contains robust implementations of the most fundamental spatial algorithms in 2D). XSLT could be used for fast generalisation that does not require relationship between objects (see Lehto and Kilpeläinen, 2000, 2001a, 2001b). JTS is not that computationally fast; on the other hand the JTS environment provides tools for handling complex relationships between objects in the generalisation process (see Harrie and Johansson, 2003; Hampe et al., 2004; Harrie et al., 2004; Zhang and Harrie, 2004; Stigmar, 2004).

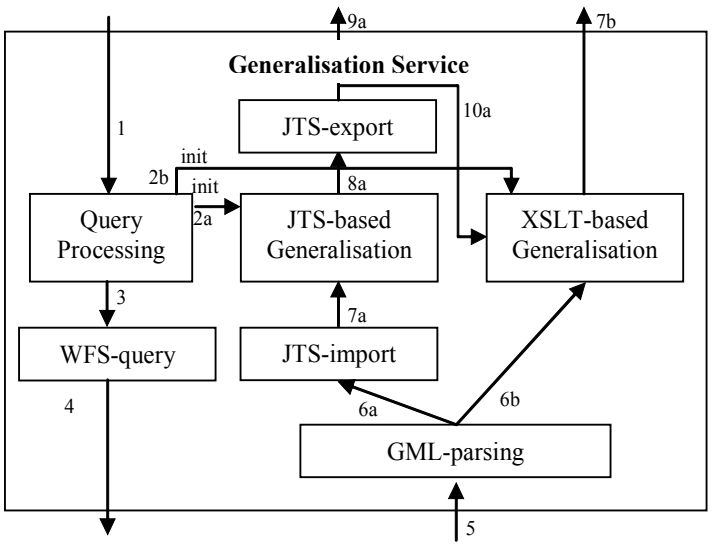

Figure 2. Generalisation Service in GiMoDig, internal workflow (Lehto, 2003).

4 Prototype system

Sections 2 and 3 describes an optimisation routine for cartographic generalisation (simultaneous graphic generalisation) respective a system architecture for real-time maps (developed in the GiMoDig project). This section describes how the implementation of simultaneous graphic generalisation (as described in Harrie and Sarjakoski, 2002) could be adjusted and extended to fit into GiMoDig system architecture. It should be noted that a complete integration into the GiMoDig system is not yet performed but the prototype is written according to the Java interfaces developed for the general workflow of the processing layer (cf. Figures 1 and 2). This implies (hopefully) that it would not be too much work to perform a complete integration.

4.1 Prototype structure

The implementation of simultaneous graphic generalisation in Harrie and Sarjakoski (2002) was written in c and c++. The program utilises two c/c++ packages:

- Delaunay Triangulation (written by Shewchuk, 1996), and
- Conjugate gradient method (written by Tapani Sarjakoski, Finnish Geodetic Institute).

Furthermore, the program communicates with the object-oriented map production system LAMPS2 (Laser-Scan, 2004) via ASCII files. The program requires that the cartographic data is stored in a link-node structure in the LAMPS2 environment and the topological relationships are exported to the c/c++ program.

The data processing layer in the GiMoDig system architecture (Figure 2) is in a Java environment. To utilise the c/c++ program in the this environment Java native interface (Gordon, 1998) was used. The division of the tasks between the Java and c/c++ parts of the prototype follows Figure 3. The reason for this division of the tasks was the wish to use as much of the original implementation of simultaneous graphic generalisation (written in c/c++) and a judgement that it would be easier to find the topological relationships in Java (see 4.2 below).

With reference to Figure 3 the prototype works as follows:

1) Data is requested from a WFS-server.
2) GML data is parsed into Java objects. The parsing is performed by a package from JUMP (2004) extended by Tommi Koivula.
3) The data is structured into a link-node data-structure. A call is performed to the c-program for simultaneous graphic generalisation using Java native interface. The function call passes data about the objects and how they should be treated in the generalisation process.

4) Simultaneous graphic generalisation is performed. The result from this process (the point movements in vector **x** in Equation 2) are returned to the Java environment.
5) The current objects are generalised by adding the point movements to their coordinate values.
6) The result is visualised in the JUMP graphical user interface.

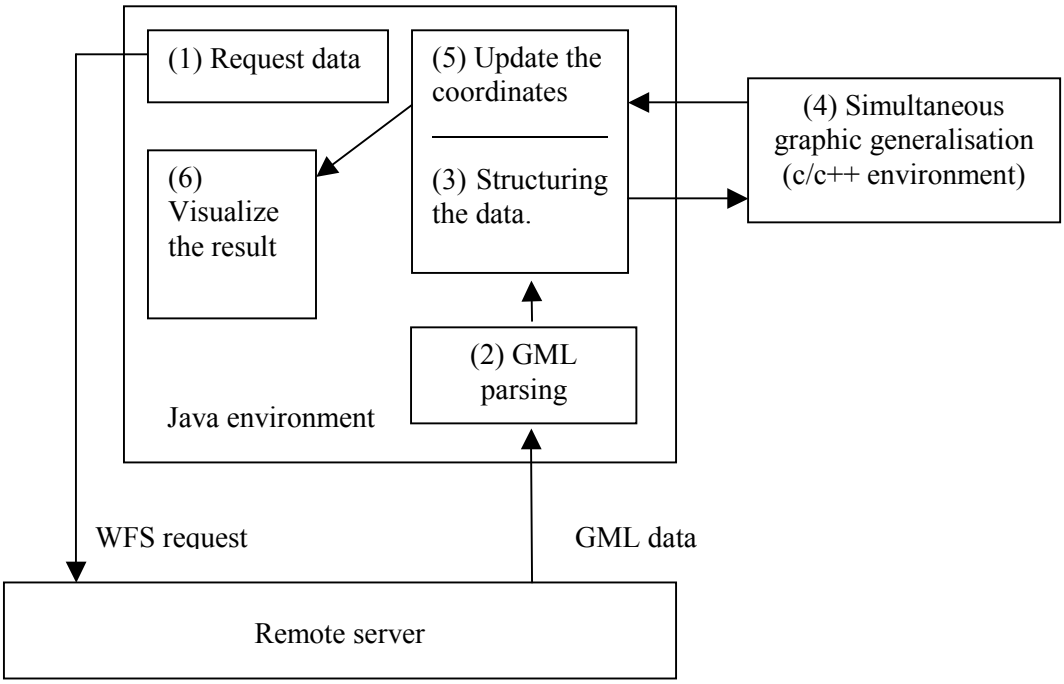

Figure 3. The structure of the prototype

4.2 Topological relationships for the input data

To properly define the constraints in a generalisation simultaneous graphic generalisation (and probably also in all other approaches for continuous optimisation) the cartographic data is required to be in a link-node structure (or other data structures that explicit store the topological relationships). The reason is that the routine must be able to distinguish between spatial conflicts between objects (their symbols interfere with each other) and objects that are connected or intersect (for these objects there are no spatial conflict even though the symbols may overlap). Furthermore, a link-node data structure is required to check that the graphic generalisation routine does not introduce any topological errors in the data.

In the prototype we used JTS to structure the data in real-time. In short, the routine works as follows:

1) Convert all polygon objects into closed line objects.
2) Put all point and line objects in a list.
3) Check if two first geometries in the list *intersect* and/or *meet*.
    a) If two objects *meet* then this information must be stored (this information is later used in the generalisation process to guarantee that the topological relationships are not lost).
    b) If two objects *intersect*. Divide the objects so that they follow the rules for a link-node data structure. Remove the original objects from the list and append the new objects to the list.
4) Go back to point three until all objects are checked.

In practice there are several problems regarding this structuring process. The main problem is perhaps the use of real-number (or more correctly rational numbers with high precision) when forming the topological relationships (even though JTS provide “robust” algorithms). To perform this it would perhaps be preferable to use a discrete two-dimensional space.

5 Feasibility study

The feasibility study shown here is the very first test of the program. The cartographic generalisation problem and the generalisation result is not the best. However, the main issue here is the performance of the program, and specially the relationship between the processing time of the different parts of the generalisation process.

5.1 Cartographic result

The feasibility study was performed using a web feature service at the Finnish Geodetic Institute (see Lehto, 2003). Only ten objects were used (cf. Figures 4 and 5):

- 2 minor road objects (the data is not perfect; this single link was actually divided into two separate links),
- 3 major road objects (one for each link), and
- 5 building objects.

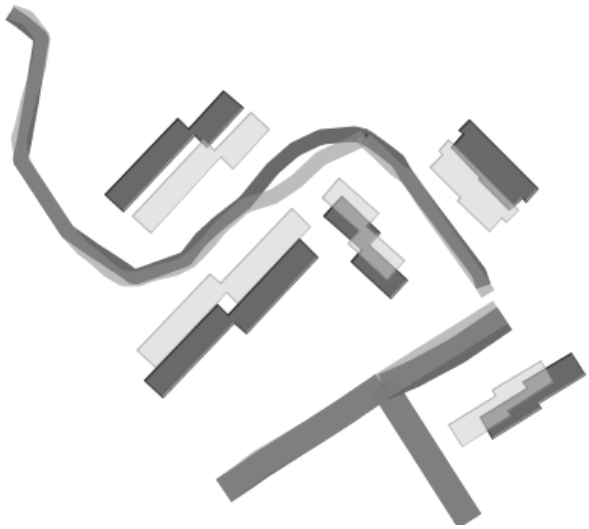

Figure 4. Result of the generalisation process. Original map in grey and generalised map in black. Cartographic data from National Land Survey of Finland

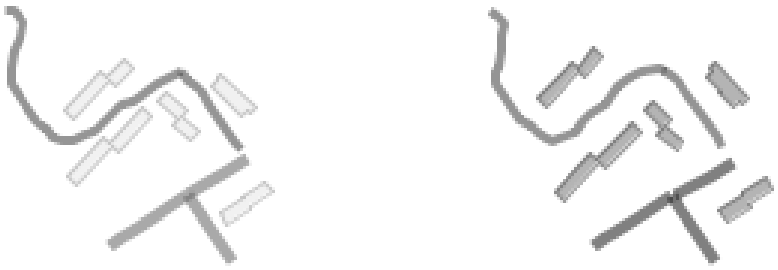

Figure 5. (a) The original map; (b) The generalised map. Cartographic data from National Land Survey of Finland

5.2 Performance result

The performance result is given in Table 1. The performance is divided into three different phases:

- retrieving data (steps 1 and 2 in section 4.1),
- structuring data (step 3 in section 4.1), and
- generalisaing data (steps 4 and 5 in section 4.1).

The same data as in Figures 4 and 5 were used and the computations were performed in a PC with a Pentium III processor.

Table 1: CPU-time for different phases in the prototype.

	Retrieving data (ms)	Structuring data (ms)	Generalising data (ms)
Test 1	1182	331	881
Test 2	1272	330	891

The data used in the test was comparatively easy to structure. A couple of objects *meet*, but no object *intersect*. Tests with fictitious data indicates that it take longer times if some of the objects *intersect* (which is quite naturally).

6 Discussion

The main aim of this study was to evaluate the use of the optimisation routine simultaneous graphic generalisation in a real-time environment. There are two main issues that were of special interest:

- developing a method for creating a link-node data structure in real-time, and
- computational performance of simultaneous graphic generalisation.

The cartographic aspects were not really studied so far. More studies are here required.

The feasibility study shown that it is, from a computational point of view, possible to use a generalisation method of this type in real-time if the amount of data is small. The computation time was a bit to long, but on the other hand there are much faster computers available than the one used in the feasibility study. Concerning the generalisation of the data, there are most likely methods to improve the efficiency (but the author is not aware of any such method). For structuring the data there are certainly other methods to use that could enhance the performance as discussed below.

6.1 Structuring the data

With reference to Figure 1 there are three alternatives to have access to topological relationships in the generalisation process:

1) Perform generalisation in the data layer.
2) Transport the topological relationships from the data layer to the data processing layer.
3) Compute the topological relationships in the data processing layer in real-time.

In our prototype we used the third approach. The reason for this choice is stated below.

We would like to integrate the prototype into a system architecture similar to the one in Figure 1; then alternative 1 is not really a choice. But, principally, another system architecture could be used where the data layer and the data processing layer would be one single unit. The advantage then would be the access to topological relationships for e.g. generalisation processes. However, such a solution would not allow that the data layer consist of a cascading WFS solution (i.e., there are several WFS servers that provides data to a single output WFS server) (this solution is e.g. implemented in the GiMoDig project, see Lehto, 2003).

There is a lack of good tools for alternative 2. Most WFS servers provide GML2 data; this format does not support topological relationships. The new GML3 format gives such support (OGC, 2004). But there are few (if any available?) WFS servers that actually supports GML3 and few (if any available?) parsers that could code this into topological data in e.g. a geometrical Java library.

To conclude, we found that alternative 3 was the best one for our prototype. The next issue was to implement the routines for structuring the data. Since we were using Java/JTS for other computation in the data processing layer we chose this environment also for the structuring. JTS provides a number of (efficient) routines for computing topological relationships between objects. It is possible to make more computationally efficient implementations than in the prototype (see e.g. the use of plane sweep algorithm in de Berg et al., 1997, pp. 20-28). However, this would imply much more time for coding than we could spend on this study.

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