

A VARIABLE-SCALE MAP FOR SMALL-DISPLAY CARTOGRAPHY

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ABSTRACT:

The aim of this paper is to develop methods for presenting geodata for personal navigation in real-time to a mobile user. Ideally, the user should have an overview map in the vicinity of his position; required for e.g. choosing the right road in a crossing. At the same time the user requires a small-scale map where he can see the final target of his route. A solution to obtain these user requirements is to create a variable-scale map that is constantly changing to make the user position always be in the large-scale part of the map. In the paper a formula for a variable-scale map is derived and its properties are demonstrated. Furthermore, real-time generalisation methods are described, these methods are used to adapt the original cartographic data to the small-scale areas of the map. A prototype system of a variable-scale approach was created using the emerging XML-based vector-data standards (GML and SVG), where the generalisation and scale-variations were performed in an XSLT transformation. The paper describes a minor case study which shows that variable-scale maps have a potential for personal navigation.

1. INTRODUCTION

1.1 Background

In the near future an increasing number of maps will be displayed in portable computers and mobile telephones. These maps are often denoted mobile maps. One major problem with mobile maps is the small displays, which put high demands on the selection of the cartographic data to be shown. This is problematic when the user requires much cartographic information. In personal navigation, for example, the user often requires both a detailed map around the current user position as well as an overview map. That is, in cartographic terms, the user requires both large-scale and small-scale cartographic data. This paper concentrates on a method for giving the user both large-scale and small-scale map information simultaneously on a small portable display.

There are, principally, three different approaches to provide the user both with large-scale and small-scale maps on a single display:

1) The user switches between a small-scale map and a large-scale map.

Advantage: The user gets full view of both the small-scale and the large-scale map.

Disadvantage: The user does not see the two maps simultaneously; therefore, the user might have difficulties in connecting the information of the two maps. Furthermore, switching between maps is necessary.

2) The large-scale map is shown in the ordinary map window and the small-scale map in a key-map.

Advantage: The user sees the two maps simultaneously.

Disadvantage: Even though that the user sees the two maps at the same time it is often problematic to identify common objects in the maps. In addition, the key map hides data in the ordinary map window or it is often difficult to get sufficient space for both the maps at the same time in a small display.

3) Large-scale and small-scale cartographic data are presented in the same map. In the vicinity of the user large-scale data is shown and far from the users position small-scale data is shown.

Advantage: The large-scale data and small-scale data are integrated.

Disadvantage: The map has a variable scale as well as discrete jumps between different representations.

This study is devoted to the third approach; that is, the paper is concentrated on variable-scale maps. Even though many studies have been performed using variable-scale maps (see Section 1.2) we think that the subject requires more attention. The technical development has given to the variable-scale approach new possibilities in at least three aspects. Firstly, today it is possible to have a mobile device showing cartographic data where the user always will be in the centre of the map (possible since the user position is known e.g. by cellular network or Global Positioning System (GPS)). Secondly, new methods for real-time integration and real-time generalisation make it possible for tailoring the map for specific user requirements. Thirdly, the emerging vector-data standards will enhance the possibility to transfer cartographic data to a mobile user. That is, in principle, it will be possible to create a variable-scale user-tailored map, that is updated while the user is moving.

This paper starts with a survey of some previous studies of variable-scale maps. In the second section theory of our variable-scale maps is given. In our approach a map in the map projection plane is required as input data, and the mapping introduced here is a distortion to this original map. The third section focuses on the technical environment as well as on vector-data standards used in the study. The type of variable-scale map presented here requires that some data be generalised in real-time. This is further described in Section 4. The fifth section contains case studies. The paper concludes with discussion and conclusions.

1.2 Previous studies of variable-scale maps

There are basically two aims of variable-scale maps. Firstly, a variable-scale map is used when a constant-scale map is not sufficient for visualising all the required data. Secondly, a variable-scale map is used to make the density of a variable uniform; such maps are normally called cartograms (see e.g. Gusein-Zade and Tikunov, 1993). In this paper we are only interested in the first aim of a variable-scale map.

Much research has been devoted to develop map projections that give as little distortions as possible. To create a variable-scale map the aim is quite the opposite; the scale is intentionally varying so that the map can visualise data with uneven distribution or with the aim of focusing on an area of interest. A few map projections have been designed for this specific purpose. Snyder (1987) derived some azimuthal projections with a magnifying glass effect. These projections give a map with circular cap where the radial scale is constant out from the centre point (of the azimuthal projection); outside the circular cap the radial scale is smaller. As mentioned above, however, the mapping used in this paper uses coordinates in a map projection plane as input coordinates and not geographic coordinates (as in map projections).

There are a few examples of applied use of variable-scale maps. Hägerstrand (1957) used a logarithmic azimuthal map projection to visualise migration patterns. He found that most people only moved within a region, but a few moved between regions; to visualise this migration patterns he realised that a constant-scale map was insufficient. Commercial examples of variable-scale maps are the city maps by Falk-Verlag, Germany.

Fairbairn and Taylor (1994) proposed variable-scale maps for urban areas. They argued that the density of objects is larger in the city centre and therefore the scale should be larger there. In their study they implemented a variable-scale map where the scale decreases linearly from the centre of the map towards the edges (formulas for similar scale variations were also derived by Kadmon, 1975). Furthermore, Lichtner (1979) used a transformation that magnified several parts of urban thematic maps. Similar ideas were presented by Guerra and Boutoura (2001). They proposed that a magnifying glass could be moved around in a city map and that the area of the glass should be presented at another window where the data are magnified non-linearly. It should be noted that all these studies used coordinates in the map projection plane as input coordinates to the scale variation transformation.

Special types of variable-scale maps are the schematic maps (some authors use the term cartograms for this kind of maps, see e.g. Kadmon, 1982). These maps have great geometrical distortions, but are topologically correct; they are mainly used for presenting subway lines and other transportation networks. Recently, research has been devoted to establish automatic methods to generate and query schematic maps (Avelar and Müller, 2000; Avelar and Huber, 2001).

Agrawala and Stolte (2001) presented a study for maps in personal navigation. They aimed at producing a navigation map that resembles a hand drawn map sketch. Agrawala and Stolte argued that humans are mainly interested in information about turning points of the routes and not the links between the turning points. Therefore, it is better to

shrink some road elements (i.e., use a smaller scale locally) to be able to give all the required data about the turning points. The study presented in this paper is based on the same basic philosophy as the study in Agrawala and Stolte (2001); the main difference lies in that while the user in their study was given a single map the user in our study will receive an updated map while moving along the route (when a complete prototype exist).

2. VARIABLE-SCALE MAPS

2.1 Basic properties

The aim in this study is to create a map for a mobile user. This user communicates with a cartographic database. This implies that the map can be tailored for the current location of the user. A main idea of the variable-scale map, used in this study, is to show large-scale data for a circular cap around the user and small-scale data outside this circular cap (see Figure 1).

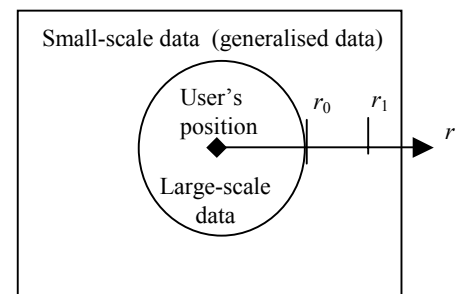


Figure 1. The figure illustrates the circular cap (with radius r_0) where large-scale data is shown and the area outside this cap where small-scale data is shown. Inside the circular cap the scale is uniform (and equal to s_l) and outside radius r_1 the radial scale is constant (and equal to s_s).

2.2 Mapping function

A characteristic of a variable-scale map is that is not using a uniform scale in the whole map; in our application only the data within the circular cap is shown in a uniform scale s_l (Figure 1). This scale is equal to the preferred presentation scale of the original data set. Outside the cap the scale is decreasing according to the following rules:

- The scale should be continuous over the whole map.
- The scale (in radial direction) should be equal to s_l at the radial distance r_0 from the user position. The scale (in radial direction) is then decreasing by a constant factor to be equal to s_s at a radial distance of r_1 . For distances longer than r_1 the scale (in radial direction) should also be equal to s_s .

These rules can be satisfied by a mapping from the original data (stored at a scale of s_l) to the new data to be displayed. This mapping can be constructed by a radial displacement function where r_{new} (the new radial distance) is a function of r (the original radial distance). It should be noted that the angle is not changed in the mapping. By applying the rules above we get the following radial displacement functions:

$$r_{new}(r) = r, \quad r \leq r_0$$

$$r_{new}(r) = r_0 + \frac{1}{s_l} \int_{u=r_0}^r \left(s_l + (s_s - s_l) \cdot \frac{u-r_0}{r_1-r_0} \right) du =$$

$$= r + \frac{(r-r_0)^2 \cdot (s_s - s_l)}{2 \cdot s_l \cdot (r_1 - r_0)}, \quad r_0 < r \leq r_1 \quad (1)$$

$$r_{new}(r) = r_0 + \frac{1}{s_l} \int_{u=r_0}^{r_1} \left(s_l + (s_s - s_l) \cdot \frac{u-r_0}{r_1-r_0} \right) du + (r-r_1) \cdot \frac{s_s}{s_l} =$$

$$= r_1 + \frac{(r_1-r_0) \cdot (s_s - s_l)}{2 \cdot s_l} + (r-r_1) \cdot \frac{s_s}{s_l}, \quad r > r_1$$

where r_0 and r_1 are defined according to Figure 1. In Figure 2 a radial displacement function is shown.

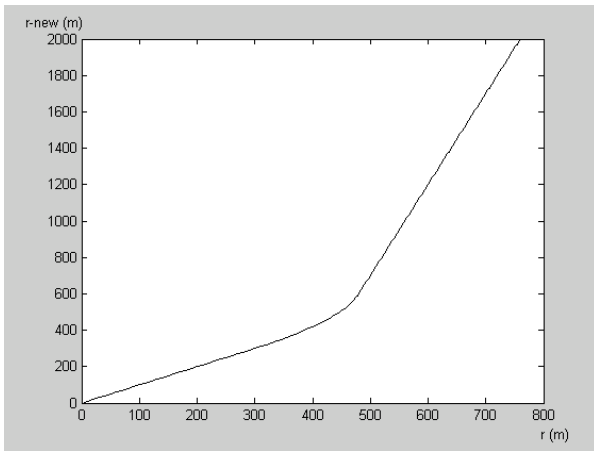


Figure 2. The radial displacement function for the input parameters: $r_0=300$ m, $r_1=600$ m, $s_l=1:10\ 000$ and $s_s=1:50\ 000$

2.3 Scale variations

It is important to note that the mapping function above is not conformal. In fact, there exists no conformal mapping that satisfy our requirements of the scale variations in radial direction (unless the uninteresting case when $s_s=s_l$; this follows from that a mapping between two annulus is conform only if the ratio between the radius are constant, see e.g. Nehari, 1975).

From the requirements used in deriving the mapping function we can directly determine that the scale in radial direction ($scale_r$) is equal to (this formulas are also given by the partial derivatives $\partial r_{new} / \partial r$):

$$scale_r(r) = 1, \quad r \geq r_0$$

$$scale_r(r) = 1 + \frac{(r-r_0)}{(r_1-r_0)} \cdot \frac{(s_s - s_l)}{s_l}, \quad r_0 < r \leq r_1 \quad (2)$$

$$scale_r(r) = \frac{s_s}{s_l}, \quad r > r_1$$

The scale in tangential direction ($scale_t$) is simply given by:

$$scale_t(r) = \frac{r_{new}(r)}{r}, \quad \forall r \quad (3)$$

As is shown in Figure 3 the scale in tangential direction is larger than the scale in radial direction outside the cap. This is also seen in Figure 4, where the original grid has a hyperbolic form (cf. figures in Lichtner, 1979). This property is unavoidable if we want the central part of the map in larger scale. Figure 5 gives an example on how this transformation change a topographic map.

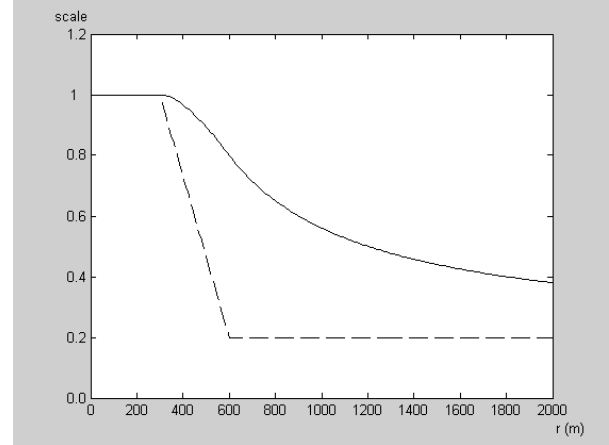


Figure 3. Plot showing the scale in radial (dashed) and tangential (solid) direction of the mapping function (as a function of the original radial distance (r)). The following input parameters were used: $r_0=300$ m, $r_1=600$ m, $s_l=1:10\ 000$ and $s_s=1:50\ 000$.

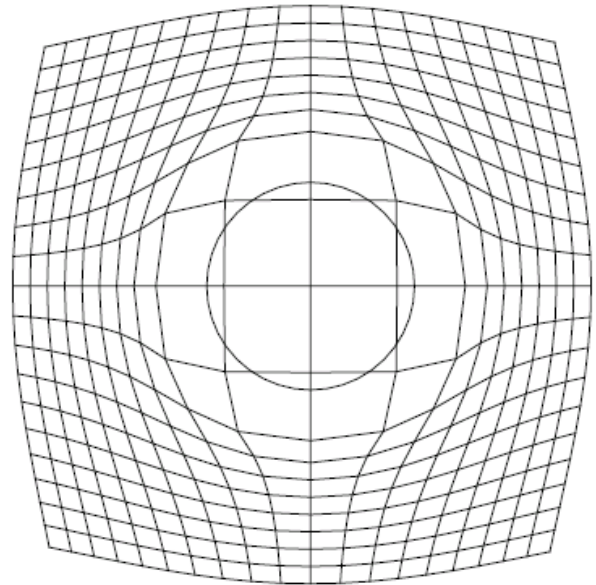


Figure 4. Distortions to an initial grid by variable-scale mapping. The following input parameters were used: $r_0=300$ m, $r_1=600$ m, $s_l=1:10\ 000$ and $s_s=1:50\ 000$. The circle represents the circular cap with radius r_0 (cf. Figure 1).

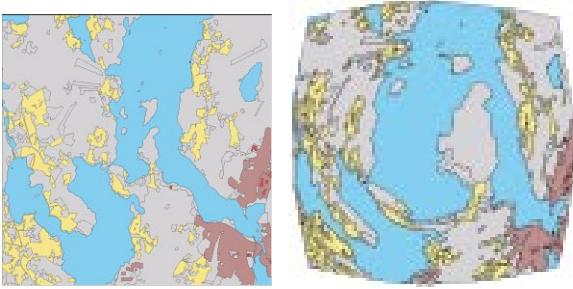


Figure 5. Distortions to a topographic map (same input parameters as in Figure 4). From Terrain map, © National Land Survey of Sweden, Gävle 2002. Printed by permission M2002/2770.

3. TECHNICAL SOLUTION

In the implementation of the prototype system of variable-scale maps, the Extensible Markup Language (XML) techniques in data distribution and transformations are used. The input data files are encoded according to Open GIS Consortium's GML specification (OGC, 2002).

The geometric transformation of the variable-scale map is computed as an XSLT process with Java-based XSLT extension functions; the same process that is used to translate the GML file into an SVG image (a standard format for presenting vector data on the Internet, see World Wide Web Consortium, 2002). For details of how an XSLT process can be applied for GML data see previous work by Lehto and Kilpeläinen (2000, 2001a,b).

The free-of-charge XML software components applied in the prototype system include an XML parser (Xerces), an XSLT processor (Xalan) from Apache community (Apache, 2002) and the SVG Viewer plugin from Adobe (Adobe, 2002).

4. GENERALISATION METHODS

During the XSLT transformation the source dataset can be manipulated. So, in addition to carrying out the geometric variable-scale transformation and translating the dataset into the correct XML vocabulary (SVG), an XSLT process can also be applied to change the map content. In the context of the variable-scale map, manipulations can be used to make the small-scale part of the map easier to read (which is often required, see e.g. Figure 5).

There are basically two different approaches to increase the readability of the small-scale part of the map. The first approach is to use two different data sets: a large-scale data set in the cap and a small-scale data set outside the cap. A difficulty with this approach is to integrate the two data sets along the border of the cap. To enable such integration a multiple representation database (MRDB) is preferably used (an MRDB consist of different data sets that are connected by links between objects that represent the same physical entities; see e.g. Buttenfield, 1993; Kilpeläinen, 1997; Timpf, 1997; Harrie and Hellström, 1999).

The second approach is to use only a large-scale data set. This data set is then generalised outside the cap. This implies that there is no need to integrate two different data sets; instead this approach requires suitable methods for real-time generalisation. Even though there has been research in the field of real-time generalisation (see e.g. van Oosterom and

Schenkelaars, 1995; Jones et al., 2000; Lehto and Kilpeläinen, 2000, Lehto and Kilpeläinen, 2001a, b) the task of real-time generalisation is still far from being solved.

In this study we chose the second approach (i.e., only using one single data set). The implemented generalisation operators in this study include building simplification and selection. In the implemented selection function individual spatial objects can be selected or rejected for inclusion in the result dataset based on their feature type. Decisions are also based on properties derived during the transformation. Building simplification is based on an algorithm that constructs the minimum enclosing rectangle of the building and orients a scaled version of it along the longest side of the building.

5. CASE STUDY

A case study was performed on data from City of Helsinki. Only building and road data were used in these studies.

5.1 Method

The case study was performed as follows. Firstly, a GML file was derived from the original cartographic database. This was performed by an in-house implementation (at the Finnish Geodetic institute) of Web Feature Service (WFS, see OGC, 2002). The GML files were transformed by an XSLT transformation and SVG images were created. Finally, the SVG images were viewed in a browser using an SVG plugin. That is, these studies were only performed on desktop computers.

5.2 Result

As is shown in Figure 6 the variable-scale maps are able to show data of different level of details and of different scales within a single map. As is also shown, this is done at the expense of other properties of the map: the rectangular street network is no longer rectangular and the feeling of the distribution of the buildings is somewhat deteriorated.

6. DISCUSSION

This paper describes an ongoing project; there are several issues that require more studies. Some technical issues are:

- So far we have only tested variable-scale maps in a desktop environment. To really evaluate the method, it should be tested using mobile devices. This study is a part of a larger project GiMoDig (GiMoDig, 2002); our aim is to evaluate the variable-scale maps displayed in mobile devices later within the frame of this project.
- The issue of time for transformation and distribution of data are crucial for mobile maps, but the time respond problem has not been treated in this study.
- More and better methods for real-time generalisation are required. The methods for real-time generalisation in this case study consist of the operators simplification and selection. Although the mobile maps use to show a very simplified picture of the reality, in a real usage situation these simple routines are not sufficient. Besides the aggregation operator, earlier demonstrated as an XSLT transformation by Lehto and Kilpeläinen (2001a,b), also other operators are needed.

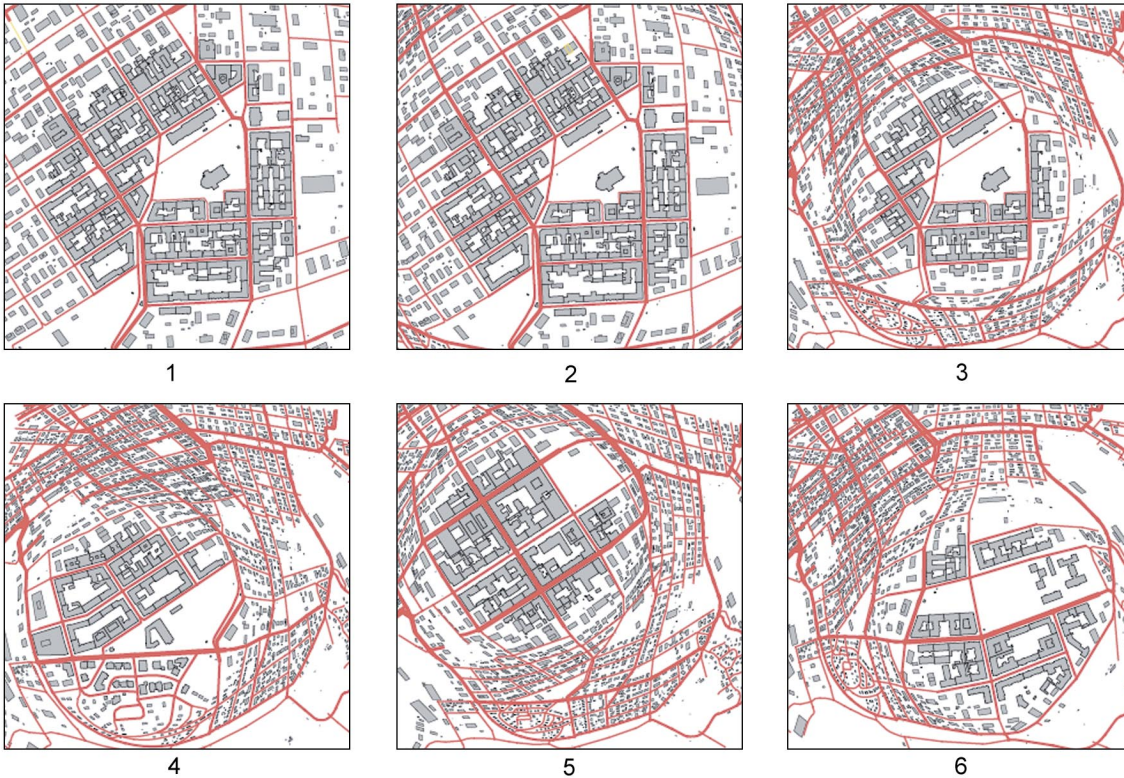


Figure 6. The SVG image series above illustrates the transformation variation depending on the changed parameters. Besides scale-variable, the small-scale map outside the circular cap r_0 has been generalised by selection and building simplification. In the study the scales were set to $s_l = 1:1000$ and $s_s = 1:4000$. The remaining parameters were set as follows:

- | | |
|---|--|
| 1: $r_0 = 300$ m, $r_1 = 1000$ m, user position in the middle | 4: $r_0 = 200$ m, $r_1 = 400$ m, user position in the lower left corner |
| 2: $r_0 = 300$ m, $r_1 = 600$ m, user position in the middle | 5: $r_0 = 200$ m, $r_1 = 400$ m, user position in the upper left corner |
| 3: $r_0 = 200$ m, $r_1 = 400$ m, user position in the middle | 6: $r_0 = 200$ m, $r_1 = 400$ m, user position in the lower right corner |

- So far all our studies have been based on only one dataset. Whether one or several datasets should be used for variable-scale maps is a manifold question. Using only one dataset would imply that we avoid the problems of inconsistency between the datasets. Using two datasets, in turn, suffers from a data integration problem.

To conclude the last two technical issues above, we face a complicated problem whether we use one or several data sets. It is questionable if an XSLT transformation is sufficient for solving these problems (without extensive own coding). A possible solution might be to use a geometrical and topological Java library. Parallel to this project, studies are performed of using such a Java library (Java Topology Suite; see Vivid Solutions, 2000) in an XML environment. We intend to test this library for real-time generalisation and integration of geodata in future studies.

Besides the technical aspects, the user aspects are of course important. So far our studies have not incorporated any user studies. To compare the advantages and disadvantages of variable-scale maps the user studies should concentrate on questions such as:

- Will the user be able to make use of the integrated large-scale and small-scale data?
- Since the mapping is not conformal the mapping will destroy known geometries. What are the user reactions to distortions of e.g. rectangular street networks?
- A problem of the variable-scale map is the discrete jumps of representation along the border of the cap. For example, if the large-scale data represent buildings at

the border area as building objects and the small-scale data the same area as built-up area objects there will be a discrete jump between the two representations along the border. What will the user reactions be to these discrete jumps?

7. CONCLUSIONS

The aim of this study was to create maps for mobile devices with small displays. To be able to give both detailed as well as overview information to the user a variable-scale approach was used. In the study we derived formulas for a type of variable-scale maps. These maps have a circular cap where the scale is homogeneous and outside this cap the radial scale is constantly decreasing to a threshold value. The map is not conformal; the distortions are visualised in figures in the paper.

The variable-scale approach was implemented in an XML environment; the transformations, as well as real-time generalisation of the geodata outside the cap, were performed as XSLT transformations.

A case study shows that variable-scale maps are able to present integrated large-scale and small-scale data. We think the result is promising and will continue to work with technical improvements and user studies.

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