A Mapping Function for Variable-Scale Maps in Small-Display Cartography

Lars HARRIE [1], L. Tiina SARJAKOSKI [2] and Lassi LEHTO [2]

[1] National Land Survey of Sweden, SE-801 82 Gävle, Sweden - lars.harrie@lantm.lth.se
[2] Finnish Geodetic Institute, P.O. Box 15, FIN-02431 Masala, Finland
tiina.sarjakoski@fgi.fi, - lassi.lehto@fgi.fi

Abstract:

The aim of this paper is to examine the variable-scale method of presenting geodata for personal navigation using small-display mobile devices. Ideally, the user should have a large-scale map of his immediate vicinity for choosing the right direction at an intersection, for example. At the same time, the user requires a small-scale overview map where he can see his destination. A solution that meets these requirements is a variable-scale map, which is constantly updated to keep the user's position in the large-scale area at the centre of the map. In this paper, a variable-scale mapping function is derived in accordance with some specific properties; then characteristics of the mapping function are visualised. Furthermore, real-time generalisation methods are used to adapt the original cartographic data to the small-scale areas of the variable-scale 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 prototype implementation of variable maps was tested in a case study. Finally, the potential and the limitations of variable-scale maps for personal navigation using mobile devices are discussed.

1 Introduction

In the near future an increasing number of maps will be displayed on portable computers and mobile telephones. These maps are often referred to as mobile maps. A major problem with mobile maps is their small displays, which put high demands on the selection of cartographic data to be shown. This becomes problematic when the user requires a considerable amount of cartographic information. In personal navigation, for example, users often need both a detailed map of the area surrounding the current position as well as an overview map. This means, in cartographic terms, that the user requires both large-scale and small-scale cartographic data. This paper concentrates on a method of giving the user both large-scale and small-scale map information simultaneously on a small portable display. The paper is based on the previous paper by the authors (Harrie, et al., 2002).

In principal, there are, three approaches to providing the user with both 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: Full view of both the small-scale and large-scale maps.
   Disadvantage: The user does not see the two maps simultaneously; and might therefore have difficulty connecting the information from 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 is shown in a key-map.
   Advantage: The two maps are visible simultaneously.
   Disadvantage: Even though the user sees both maps at the same time, identifying common objects in the maps is often problematic. In addition, the key-map hides data in the ordinary map window, and it is often difficult to have sufficient space for both maps at the same time on a small display.

Journal of Geospatial Engineering, Vol. 4, No. 2 (December 2002), pp.111-123.

3) Large-scale and small-scale cartographic data are presented in the same map: in the vicinity of the user’s position large-scale data is shown, and far from the user’s 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 types of representations.

This study is devoted to the third approach; that is, the paper concentrates on variable-scale maps. Even though many studies have been performed in this area (see Section 1.2) we believe the subject requires more attention. Technical advances have given the variable-scale approach new potential in at least three respects. First, due to the user’s position being known by cellular network or Global Positioning System (GPS), it is possible today to have a mobile device showing cartographic data where the user will always be in the centre of the map. Second, new methods for real-time data integration and real-time generalisation make it possible to tailor the map to specific user requirements (Lehto and Kilpeläinen, 2000; 2001a; 2001b). Third, the emerging vector-data standards will enhance the transfer of cartographic data to a mobile user. In principle, this means it is possible to create a variable-scale user-tailored map that is updated while the user is moving.

The terms *large-scale* and *small-scale* cartographic data are used only in a relative sense in this paper; that is, the small-scale data is less detailed than the large-scale data, but is not necessarily what most cartographers would regard as small-scale data in the absolute sense.

The body of the paper is organised as follows: It begins with a survey of previous studies of variable-scale maps; and the theoretical background of our approach is presented in the third section. Desirable properties of variable-scale maps are stated and then a mapping function is derived from these criteria. Furthermore, some characteristics of the new mapping function are computed and visualised. The fourth section is devoted to a prototype of variable-scale maps. It begins by describing the technical environment as well as some vector-data standards used. Real-time generalisation methods are then briefly described. These methods are necessary to make the level of detail suitable in all parts of the map. The section ends with a case study, and concludes with Discussion and Conclusions.

2 Previous studies of variable-scale maps

Variable-scale maps have two basic purposes. First, a variable-scale map is used when a constant-scale map is not sufficient for visualising all the required information. Second, 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). This paper deals with the first aim only. Furthermore, methods exist for showing images in variable scales (see e.g. Idelix, 2002); when these methods are applied to aerial images (in orthogonal projection) they give similar effects as map methods for variable-scale. However, this paper is devoted to maps stored as vector data; the issue of showing aerial images in variable scale is not discussed.

2.1 Background

A variable-scale map requires an appropriate mapping function. There are two main categories of these mapping functions. The variable-scale map coordinates (x_{vs}, y_{vs}) can be computed from the geographic coordinates latitude (φ) and longitude (λ):

$$(x_{vs}, y_{vs}) = f_{gc}(\varphi, \lambda)\,. \qquad (1)$$

In this case the mapping function (f_{gc}) is a type of map projection. The other category of mapping functions (f_{mp}) computes a variable-scale map from coordinates in a map projection plane (x_{mp}, y_{mp}):

$$(x_{vs}, y_{vs}) = f_{mp}(x_{mp}, y_{mp})\,. \tag{2}$$

For the latter category the original coordinates (on the ellipsoid) must have been projected on a plane in advance by a standard map projection.

This section contains descriptions of some variable-scale mapping functions from both categories above. Schematic maps are described in the last sub-section; these studies are of interest here, since schematic maps are a special kind of variable-scale map.

2.2 Studies using variable-scale maps computed from geographic coordinates

Much research has been devoted to developing map projections that have as little distortion as possible. In order to create a variable-scale map projection the aim is quite the opposite; the scale varies intentionally so that the map can visualise data with uneven distribution or focus on an area of interest. A number of map projections have been designed for this specific purpose. Snyder (1987) derived some azimuthal projections with a magnifying glass effect. These projections produce a map having a circular cap where the radial scale is constant outwards from the centre point (of the azimuthal projection); outside the circular cap the radial scale is smaller.

Several examples of applied use of variable-scale maps exist. Hägerstrand (1957) used a logarithmic azimuthal map projection to visualise migration patterns, finding that most people moved only within a region, and a few moved between regions. He realised that to visualise these migration patterns a constant-scale map was insufficient. The city maps by Falk-Verlag, Germany, are commercial examples of variable-scale maps are.

2.3 Studies using variable-scale maps from map projection coordinates

Fairbairn and Taylor (1995) proposed variable-scale maps for urban areas. They argued that the density of objects is greater in the city centre where the scale should therefore be larger. 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 recently presented by Guerra and Boutoura (2001). They proposed that a magnifying glass could be moved around a city map and that the area beneath the glass should be presented in another window where the data are magnified non-linearly.

2.4 Schematic maps

Special types of variable-scale maps are known as schematic maps (some authors use the term, see e.g. Kadmon, 1982). These maps have great geometrical distortions but are topologically correct; they are used mainly for presenting subway lines and other transportation networks. Recently, research has been devoted to establishing automatic methods of generating and querying schematic maps (Avelar and Müller, 2000; Avelar and Huber, 2001; Cabello and van Kreveld, 2002).

Agrawala and Stolte (2001) presented a study for personal navigation maps. They aimed to produce a navigation map resembling a hand-drawn sketch. Agrawala and Stolte argued that people are mainly interested in information about a route’s turning points and not the links between them. It is therefore better to shrink certain road elements (i.e., use a smaller scale locally) so that all required data concerning turning points may be presented. A beta version of their navigation map was made public on the web and received positive response.

3 Variable-scale mapping function

This section starts by describing the desired properties of a variable-scale map. Then a mapping function is derived according to these properties, which computes the variable-scale coordinates from coordinates stored in a map projection plane (cf. Equation 2).

Characteristics of the mapping function are described in sub-sections 3.2 - 3.4. It should be noted that the distortions and scale variations described in these sections only refer to the variable-scale mapping function (f_{mp}). Since the original data is stored in a map projection plane some distortions are inherent in the data, but these are not examined here.

The final sub-section provides a comparison between using a circular and quadratic area for uniform scale in a variable-scale map.

3.1 Basic properties

The aim of this study is to create a map for personal navigation using a small-display mobile device. The device communicates with a cartographic database by GSM. This implies that the map can be adapted to the current location of the user. A key idea of the variable-scale map, used in this study, is to show large-scale data for the circular cap around the user and small-scale data for areas beyond (see Fig. 1).

A variable-scale map requires the following properties (cf. Fig. 1):

a) The scale should be continuous over the whole map.
b) Within a circular cap with radius r_0 the map is shown in a uniform scale s_l (cf. Figure 1) 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) then decreases by a constant factor to equal 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.

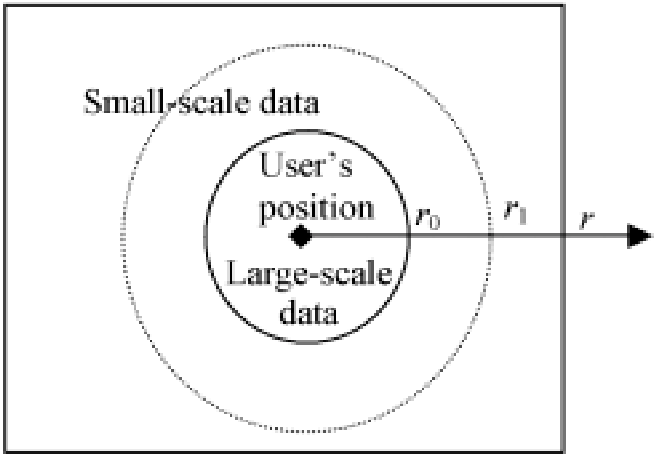


Figure 1. The figure illustrates the circular cap (with radius r_0) where large-scale data is shown and the area outside this cap where small-scale data is shown. Inside the small circular cap the scale is uniform (and equal to s_l) and beyond radius r_1.

3.2 Mapping function

In this sub-section we derive a variable-scale mapping function that gives a map having the properties listed in sub-section 3.1. The mapping function assumes that the original coordinates are stored in a map projection plane (cf. Equation 2). Since the mapping is symmetric, it can be constructed by applying the following three functions:

$$\begin{aligned} [r,\varphi] &= f_{\mathrm{I}}(x_{mp}, y_{mp}) \\ r_{new} &= f_{\mathrm{II}}(r) \\ [x_{mp}, y_{mp}] &= f_{\mathrm{III}}(r_{new}, \varphi) \end{aligned} \qquad (3)$$

where f_{I} and f_{III} are the ordinary transformation functions between Cartesian and polar coordinates and f_{II} is a radial displacement function where r_{new} (the new radial distance) is a function of r (the original radial distance) (see Equation 4).

The preferred presentation scale of the data set is here assumed to be equal to s_l. The given mapping function is actually one that maps the difference from a uniform scale of s_l. Considering this, and the desired properties in listed sub-section 3.1, we get the following radial displacement functions:

$$
\begin{aligned}
&r_{new}(r) = r\,,\ \ r <= r_0 \\
&r_{new}(r) = r_0 + \frac{1}{s_l}\int\limits_{u=r_0}^{r}\left(s_l + (s_s - s_l)\cdot\frac{u - r_0}{r_1 - r_0}\right)du = \\
&\quad = r + \frac{(r - r_0)^2\cdot(s_s - s_l)}{2\cdot s_l\cdot(r_1 - r_0)},\ \ r_0 < r <= r_1 \\
&r_{new}(r) = r_0 + \frac{1}{s_l}\int\limits_{u=r_0}^{r_1}\left(s_l + (s_s - s_l)\cdot\frac{u - r_0}{r_1 - r_0}\right)du + (r - r_1)\cdot\frac{s_s}{s_l} = \\
&\quad = r_1 + \frac{(r_1 - r_0)\cdot(s_s - s_l)}{2\cdot s_l} + (r - r_1)\cdot\frac{s_s}{s_l},\ \ r > r_1
\end{aligned} \tag{4}
$$

where r_0 and r_1 are defined according to Figure 1. Figure 2 shows an example of a radial displacement function.

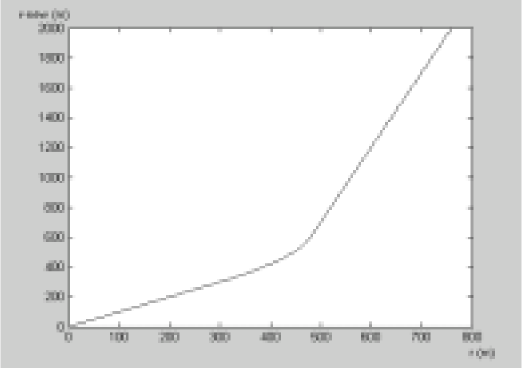


Figure 2. The radial displacement function for the input parameters: r_0=300 m, r1=600 m s_l=1:10 000 and s_s=1:50 000.

3.3 Scale variations

From the requirements used in deriving the mapping function we can directly determine that the scale in radial direction ($scale_r$) is equal to:

$$
\begin{aligned}
&scale_r(r) = 1,\ \ r <= r_0 \\
&scale_r(r) = 1 + \frac{(r - r_0)}{(r_1 - r_0)}\cdot\frac{(s_s - s_l)}{s_l},\ \ r_0 < r <= r_1 \\
&scale_r(r) = \frac{s_s}{s_l},\ \ r > r_1
\end{aligned} \tag{5}
$$

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

$$
scale_t(r) = \frac{r_{new}(r)}{r},\ \ \forall r \tag{6}
$$

As 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. Furthermore, Figure 4 shows two lines that were straight before the variable-scale mapping. The line that starts from the centre of the variable-scale mapping remains straight, while the other line becomes a curve. This property is important, and is described further in the next section.

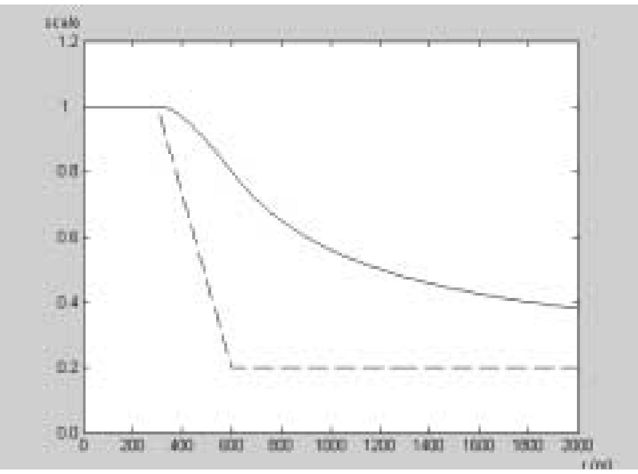
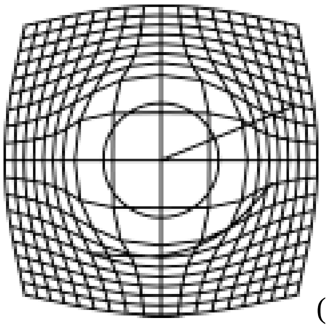
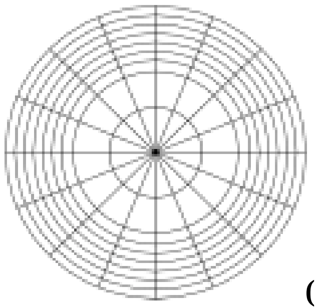


Figure 3. Plot showing the scale in radial (dashed line) and tangential (solid line) direction of the mapping function (as a function of the original radial distance (r)). The following input parameters were used: r_0=300 m, r_1=600 m, s_l =1:10 000 and s_s =1:50 000.



(Figure 4)



(Figure 5)

Figure 4. Distortions to a rectangular grid, with grid distance 250 m, 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. Fig. 1).

Figure 5. Distortions to a circular grid, with grid distance 250 m, 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.

3.4 Angular distortions

It is important to note that the mapping function given by Equations 3 and 4 is not conformal. In fact, no conformal mapping exists which gives a continuous magnifying glass effect of a circular area (this follows directly from the fact that a mapping between two annuli is conformal only if the ratio between the radii is constant, see e.g. Nehari, 1975).

To compute the maximum angular distortions we use Tissot's Indicatrix from map projection theory. Even though this theory is mainly used for mappings between a sphere and a plane, it is applicable in this particular case.

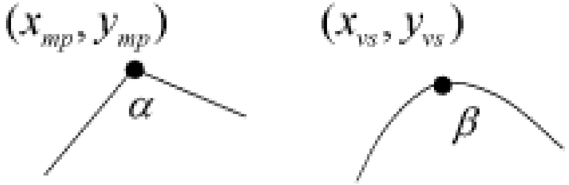
Using Tissot's Indicatrix we can compute the local scale factor of the mapping function in all directions from one point. The scale factor has a maximum and minimum value in two orthogonal directions. The scale factor in these two directions are the principal scale factors, normally denoted as a and b. The angular distortion varies at a point (ω; see Fig. 6) depending on the size of the original angle and the direction of the angle. However, the maximum angular distortion ($\omega_{\max}$) can be computed as a function of the principal scale factors (see derivations in Canters and Declair, 1989; Bugayevskiy and Snyder, 1995):

$$\omega_{\max} = 2 \cdot \arcsin\left(\frac{a-b}{a+b}\right) . \qquad (7)$$

In the mapping function given by Equations 3 and 4, the maximum and minimum scale factors are in the radial and tangential direction. Hence, we can substitute a and b for the scale factors in Equations 4 and 5 and obtain the following expression for the maximum angular distortion:

$$\omega_{\max}(r) = 2 \cdot \arcsin\left(\frac{scale_t(r) - scale_r(r)}{scale_t(r) + scale_r(r)}\right) \qquad (8)$$

As given by Equation 8 the maximum angular distortion is only a function of radial distance and not of the angle. In Figure 7 the size of the maximum angular distortion is plotted using the same input parameters as in Figures 2-5. The size of the distortion can be quite large, but it should be stressed that Equation 8 computes the largest distortion possible at a certain radial distance. If we compare the computed maximum angular distortion values in Figure 7 with the angular distortion of the grid in Figure 4, the latter distortions are smaller in size. But the angular distortions are similar in their general trend: no distortions within the cap (with radius r_0), then a fast increase of angular distortion to a distance of r_1, and finally a decrease of angular distortion.



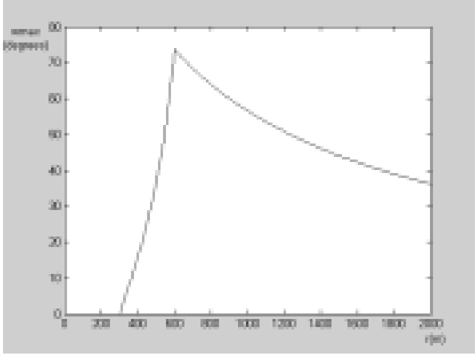


Figure 6 (left). Angle before (α) and after (β) applying a variable-scale mapping function. The angular distortion (ω) is given by $\omega=|\alpha-\beta|$.

Figure 7 (right). Plot showing the maximum angular distortion ($\omega_{\max}$) as a function of the 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 7 shows that the local maximum angular distortion is equal to zero within the cap of radius r_0. For the centre point of the mapping the “global” angles are also not distorted. This is because a straight line that starts from the centre point remains straight (cf. Figures 4 and 5). This property of the “global” angles is important in personal navigation; for a user (standing at the centre of variable-scale mapping), the angles on the map are correct from his position.

3.5 Circular or quadratic area with uniform scale

The variable-scale map presented above has used a circular area with a constant scale (cf. Fig. 1). In this sub-section we make a comparison between using a circular area and quadratic area for uniform scale (Fig. 8).

The variable-scale map for the quadratic case has properties analogous to the circular case in sub-section 3.1. Inside the square with side two times d_0 the scale is uniform and equal to s_{L}. Outside this region the scale in radial direction decreases linearly to be equal to s_s at the border of the outer square with side d_1 (cf. Fig. 8).

The mapping function for the quadratic case is also describable by a radial distance function. In fact, the only difference from Equation 3 and 4 is that the sizes of the quantities r_0 and r_1, in Equation 4, are dependent on the angle (φ, see Fig. 8):

$$
\begin{aligned}
r_0(d_0,\varphi) &= \frac{d_0}{\cos(\varphi)}, |\varphi| \le \frac{\pi}{4} \\
r_0(d_0,\varphi) &= \frac{d_0}{\cos\left(|\varphi| - \pi/2\right)}, \frac{\pi}{4} < |\varphi| \le \frac{3\pi}{4} \qquad (8) \\
r_0(d_0,\varphi) &= \frac{d_0}{\cos\left(|\varphi| - \pi\right)}, \frac{3\pi}{4} < |\varphi| \le \pi
\end{aligned}
$$

where $\varphi \in (-\pi,\pi]$, and r_1 is computed analogously.

That is, the mapping function for the quadratic case is as follows. r_0 and r_1 are computed by Equation 9 and then the new coordinates are

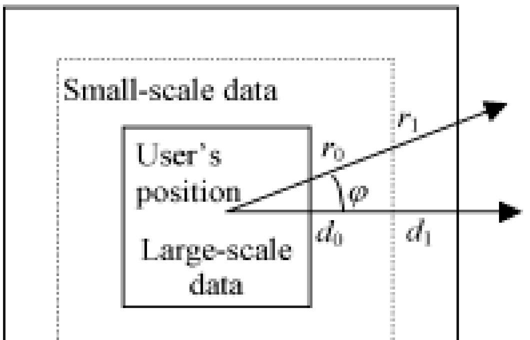


Figure 8. Illustration of a quadratic area (with side two times d_0) where large-scale data is shown and the area outside this square where small-scale data is shown. Inside the small square the scale is uniform (and equal to s_l) and outside the square with side two times d_1 the scale in radial direction is constant (and equal to s_s).

computed by Equations 3 and 4.

In order to compare a quadratic and circular variable-scale map we use the technique of familiar shape (Mulcahy and Clarke, 2001; Lichtner, 1979). Figure 9 shows maps of urban areas. The original map was transformed by a circular and a quadratic variable-scale mapping functions. Both types of mapping functions share angular distortion outside the circular cap or the square. However, the distortions are more symmetric in the circular case. Even though the street network is distorted by the circular variable-scale mapping function, it is fairly easy to get a feeling of the original street network (cf. Fig. 9b). In the quadratic case, the distortions along the diagonals make it difficult to understand the geometry of the original street network (cf. Fig. 9c). This is also shown in the distortions of a grid in Figure 10. In the left part of the grid one vertical grid line is enhanced. The grid line makes a knot when it crosses the diagonal, as shown. This type of angular distortion is problematic since it gives the user a wrong impressions for example, streets aligned in a street network.

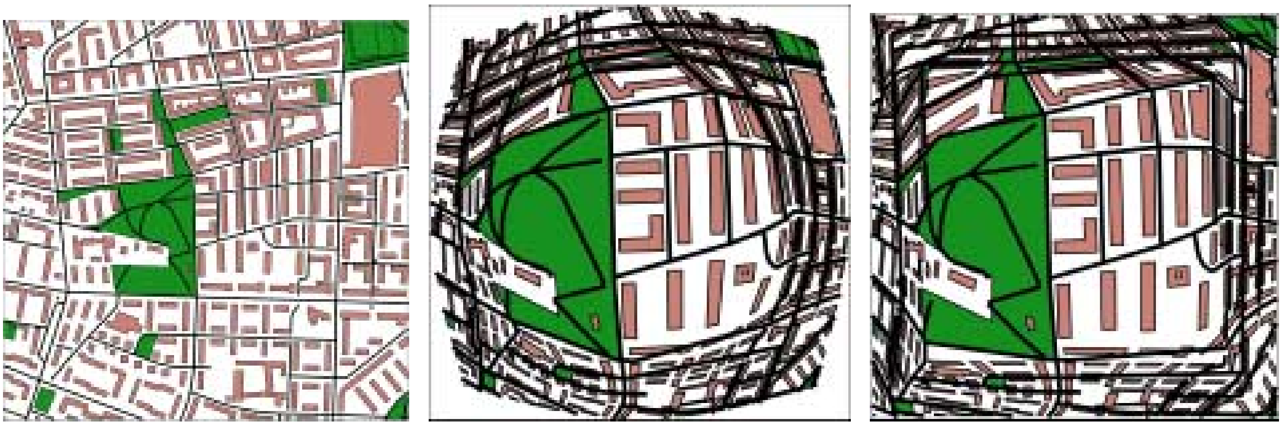
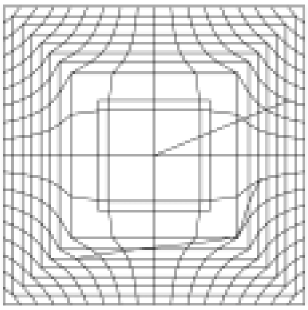
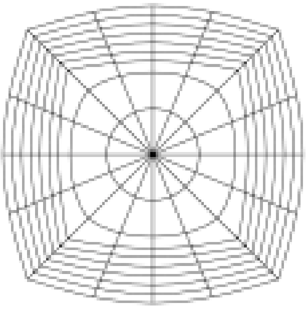


Figure 9. Mapping with variable scale: (left) original map, (middle) circular variable-scale map (r0=100 m, r1=200 m, sl=1:10 000 and ss=1:50 000), and (right) quadratic variable scale map (d0=100 m, d1=200 m, sl=1:10 000 and ss=1:50 000). The data are from the City of Malmö, Sweden. (Copyright of the local municipalities in Skåne and the National Land Survey of Sweden, 2002.)



(Figure 10)



(Figure 11)

Figure 10. Distortions to an initial grid, with grid distance 250 m, by quadratic variable-scale mapping. The following input parameters were used: d_0=300 m, d_1=600 m, s_l=1:10 000 and s_s=1:50 000. The square with side d_0 is shown in bold (cf. Fig. 7). Two lines that were straight before the variable-scale mapping are shown. The line that starts from the centre of the variable-scale mapping remains straight, while the other has a knot where it crosses the diagonal. One of the grid lines is enhanced to visualise the distortion effect.

Figure 11. Distortions to a circular grid, with grid distance 250 m, by quadratic 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.

Figure 11 illustrates how a circular grid is distorted by a quadratic variable-scale mapping function. Of special interest here is the fact that the radial lines remain straight. Considering this, and also that the scale is uniform in the inner square, it is apparent that the "global" angles are correct from the centre of the map in the quadratic case as well.

4 Prototype implementation

This study is part of the GiMoDig project (GiMoDig, 2002) and the variable-scale map has been implemented as one prototype within the project. This section begins with a brief description of the techniques used in the prototype.

To make a variable-scale map really useful, it is important that cartographic data's level of detail is in accordance with the presentation scale. Since the scale varies, the level of detail must be varied also. In the prototype system this is solved by applying real-time generalisation, described in sub-section 4.2.

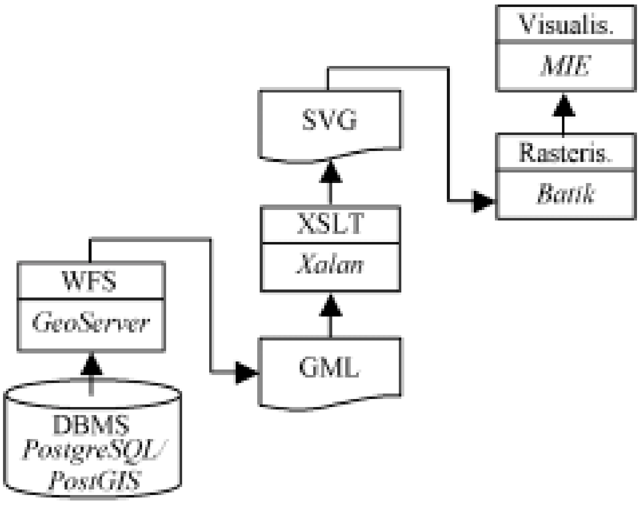


Figure 12. The most important components in the prototype system, and tools on which they are based.

4.1 Technical solution

In the implementation of the variable-scale map prototype system of, Extensible Markup Language (XML) techniques in data distribution and transformations were used (Fig. 12). First, a GML file (Geographic Markup Language, see OGC, 2002) was derived from the original cartographic data set stored in a PostGIS database (a spatial extension to the PostgreSQL database management system; see Refractions, 2002). This derivation was performed by the GeoServer (GeoServer, 2002) open source implementation of the Web Feature Service specification (WFS, see OGC, 2002).

The GML file was transformed by an XSLT transformation and an SVG file was created (Scalable Vector Graphics: a standard format for presenting vector data on the Internet, see W3C, 2002). Finally, the SVG images were viewed in a browser using an SVG plug-in. For mobile devices not supporting SVG display the image must be rasterised on the server. In the prototype system this step was carried out by the Batik SVG library from the Apache Development Group (Apache, 2002). The map resulting from the variable-scale process was visualised by the Mobile Internet Explorer (MIE) browser application on the mobile device.

The variable-scale mapping function was implemented in the XSLT process with Java-based XSLT extension functions; the same process also used for the real-time generalisation. For details of how an XSLT process can be applied to GML data see previous work by Lehto and Kilpeläinen (2000, 2001a, 2001b).

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 plug-in from Adobe (Adobe, 2002).

4.2 Generalisation methods

In the variable-scale map presented in this study the scale decreases outwards from the centre of the map. In regions of the map where the scale is small, the map might be difficult to interpret. For example, in Figures 9b and 9c buildings in the border areas are too detailed for the presentation scale. Methods are therefore required to simplify the representation and improve the readability of the small-scale parts of the map.

There are basically two approaches to increasing 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 within the cap and a small-scale data set outside the cap. A difficulty with this approach concerns the integration of the two data sets along the border of the cap. To enable such integration a multiple representation database (MRDB) is preferably used (an MRDB consists of different data sets connected by links between objects representing the same physical entities; see e.g. Buttenfield, 1993; Kilpeläinen, 1997; Timpf, 1997; Harrie and Hellström, 1999).

The second approach is to use a large-scale data set only. The data set is then generalised outside the cap. This means there is no need to integrate two different data sets; instead the approach requires suitable methods for real-time generalisation. Research in the field of real-time generalisation has taken place (see e.g. van Oosterom and Schenkelaars, 1995; Jones et al., 2000; Lehto and Kilpeläinen, 2000, Lehto and Kilpeläinen, 2001a, b), but problems in this area are still far from being solved.

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

Real-time generalisation is implemented in the XSLT transformation (for details, see Lehto and Kilpeläinen, 2000, Lehto and Kilpeläinen, 2001a, b). The XSLT transformation thus performs three different tasks: variable-scale mapping transformation, translating the data set into the correct XML vocabulary (SVG) and real-time generalisation.

5 Case study

This section describes a case study performed using the variable-scale prototype. The first part of the study was performed on a desktop computer and the second on a mobile device.

The study was performed on test data from the City of Helsinki and the National Land Survey of Finland. Only building and road data were used. The server-side processes were run on a two processor (AMD XP 1800+ 1.53GHz) Linux server with 1 GB of RAM and two 36 GB SCSI discs. A standard PC platform was the desktop client environment in the first part of the study. In the second part the mobile PocketPC-based PDA (StrongArm 206 MHz) was used. Wireless communication was carried out within a newly introduced GPRS network in Finland.

Figure 13 depicts how variable-scale maps are able to show in a single map, data of different levels of detail and of different scales. As is also shown, this is achieved at the expense of other qualities: the street network is no longer rectangular and the distribution of the buildings is somewhat less clear.

6 Discussion

A key issue of variable-scale mapping concerns user aspects. So far our work has not incorporated any usability studies. To compare the advantages and disadvantages of variable-scale maps user studies should concentrate on the following questions:

a) Will the user be able to make use of the integrated large-scale and small-scale data?

b) Since the mapping is not conformal it will destroy known geometries. What are the user reactions to distortions of rectangular street networks, for example?
c) Inherent to the variable-scale map is the problem of discrete jumps of representation occurring along the border of the cap (or square). For example, if at the border area the large-scale data represent buildings and the small-scale data represent built-up area objects, there will be a discrete jump between the two representations along the border. Each neighbourhood might have uniform representation, but different representations for some adjacent neighbourhoods would still remain. What will the user reactions be to these discrete jumps?
d) How good are variable-scale maps in comparison with other methods of presenting large-scale and small-scale data (e.g. methods described in 1.1)?

Other technical issues require further attention:

a) Time response with respect to transformation and distribution of data is crucial for mobile maps; this problem was not examined in our study.
b) More and better methods of real-time generalisation are required. The operators for real-time generalisation used in this case study consist of the operators simplification and selection. In practice, more generalisation operators are required (e.g. some building objects in Figure 13 need to be aggregated).

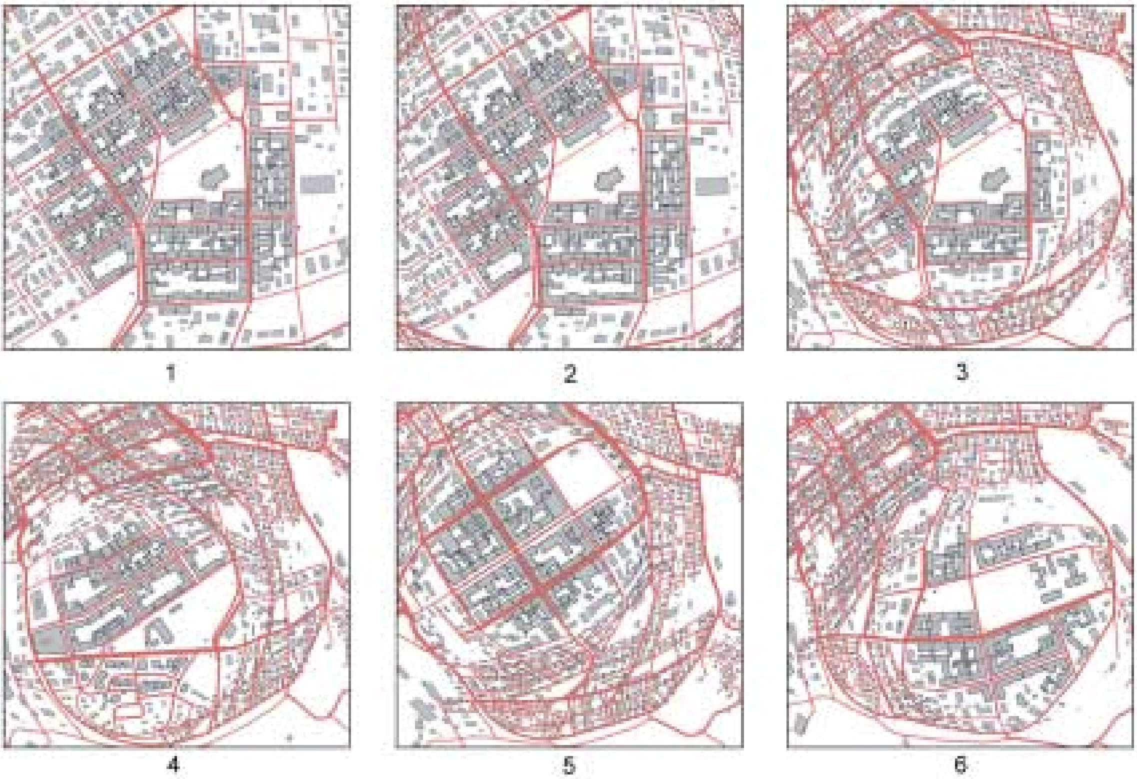


Figure 13. The above SVG image series illustrates the transformation variation depending on the changed parameters. Besides scale-variable, the small-scale map outside the circular cap r_0 has been generalised by selection and building simplification. The scales in the study were set to s_l = 1:1000 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

To conclude the technical issues above, we face a complicated computational problem that needs to be solved in real-time. It is questionable whether or not 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, studies are underway using a Java library

(Java Topology Suite; see Vivid Solutions, 2002) in an XML environment for real-time generalisation and integration of cartographic data (Harrie and Johansson, 2002).

7 Conclusions

The aim of this study was to create personal navigation maps for mobile devices having a small display. A variable-scale map approach was examined, in order to provide detailed as well as overview information to the user. In the study we derived a mapping function for a type of variable-scale map. This map has a circular cap where the scale is homogeneous and beyond which the radial scale constantly decreases to a threshold value. The mapping function is conformal in the centre of the map (which normally should be the user's location) but not in all of its parts.

Variable-scale map functionality was implemented in an XML environment; the transformations and required real-time generalisation of the geodata were performed as XSLT transformations. Our case study showed that variable-scale approach can be used to present an integrated view of large-scale and small-scale maps on a mobile, small-screen device, thus supporting personal navigation.

Acknowledgements

This research is part of the GiMoDig project, IST-2000-30090, funded by the European Union through the Information Society Technologies (IST) programme. We thank Professor Tapani Sarjakoski and Professor Monika Sester for their comments, Stefan Jakobsson for mathematical advice, Lars-Håkan Bengtsson for data transformation and Mikael Johansson for cooperation. Test data was provided by the City of Helsinki, the National Land Survey of Finland, and the City of Malmö, Sweden, to whom we are thankful.

References:

Agrawala, M. and Stolte, C., 2001. Rendering Effective Route Maps: Improving Usability Through Generalization. *Proceedings of SIGGRAPH01*, pp. 241-249.

Adobe, 2002. *The SVG Zone*. www.adobe.com/svg (accessed October 8, 2002).

Apache, 2002. *Web site of Apache XML Project*, xml.apache.org (accessed October 8, 2002).

Avelar, S. and Müller, M., 2000. Generating Topologically Correct Schematic Maps. In: *Proceedings of the 9th Spatial Data Handling Symposium*, Beijing, pp. 4a.28-4a.35.

Avelar, S. and Huber, R., 2001. Modelling a Public Transport Network for Generation of Schematic Maps and Location Queries. *Proceedings of the 20th International Cartographic Conference*, Beijing, China, pp. 1472-1480.

Bugayevskiy, L. M. and Snyder, J. P., 1995. *Map Projections – A Reference Manual*, Taylor and Francis, London, 328 p.

Buttenfield, B. P., 1993. *Research Initiative 3: Multiple Representations*, Closing report, National Center for Geographic Information and Analysis, NCGIA, Buffalo, 26pp.

Cabello, S. and van Kreveld, M., 2002. Schematic Networks: An Algorithms and its Implementation. *Proceedings of SDH'02*, Ottawa, Canada. (CD-rom).

Canters F. and Declair, H., 1989. *The World in Perspective – A Directory of World Map Projections*, John Wiley & Sons, New York, 181pp.

Fairbairn D. and Taylor, G., 1995. Developing a variable-scale map projection for urban areas. *Computers & Geosciences*, 21(9): 1053-1064.

GeoServer, 2002. *The GeoServer Project*. http://geoserver.sourceforge.net (accessed October 8, 2002).

GiMoDig, 2002. *Geospatial Info-mobility Service by Real-time Data-integration and Generalisation*. http://gimodig.fgi.fi/ (accessed October 8, 2002).

Guerra, F. and Boutoura, C., 2001. An Electronic Lens on Digital Tourist City-Maps. *Proceedings of the 20th International Cartographic Conference*, Beijing, China, p.1151.

Gusein-Zade, S. M, and Tikunov, V. S., 1993. A New Technique for Constructing Continuous Cartograms. *Cartography and Geographic Information Systems*, volume 20(3): 167-173.

Harrie, L. and Hellström, A.-K., 1999. A Prototype System for Propagating Updates between Cartographic Data Sets. *The Cartographic Journal*, 36(2):133-140.

Harrie L. and Johansson, M., 2002. Real-time Data Generalisation and Integration Using Java Topology Suite. *Geoforum Perspektiv*, to appear.

Harrie, L., Sarjakoski, L. T. and Lehto, L., 2002. A variable-scale Map for Small-display Cartography. *Proceedings of the Joint International Symposium on "GeoSpatial Theory, Processing and Applications*" (ISPRS/Commission IV, SDH2002), Ottawa, Canada, July 8–12, 2002, 6 p, CD-Rom.

Hägerstrand, T., 1957. Migration and Area: Migration in Sweden. *Lund Studies in Geography*, Series B, *Human Geography*, 13: 27-158.

Idelix, 2002. *Pliable Display Technology*. http://www.idelix (accessed October 8, 2002).

Jones, C. B., Abdelmoty, A. I., Lonergan, M. E., van der Poorten, P. and Zhou, S., 2000. Multi-Scale Spatial Database Design for Online Generalisation. *Proceedings of the 9th Spatial Data Handling Symposium*, Beijing, pp.7b.34-7b.44.

Kadmon, N., 1975. Data-bank Derived Hyperbolic-scale Equitemporal Town Maps. *International Yearbook of Cartography*, 15: 47-54.

Kadmon, N., 1982. Cartograms and Topology. *Cartographica*, 19(3-4): 1-17.

Kilpeläinen, T., 1997. Multiple Representation and Generalization of Geo-Databases for Topographic Maps. *Publications of the Finnish Geodetic Institute*, No. 124, Doctoral dissertation, 229pp.

Lehto, L. and Kilpeläinen, T., 2000. Real-Time Generalization of Geodata in the Web. *International Archives of Photogrammetry and Remote Sensing*, Volume XXXIII, Part B4: 559-566.

Lehto, L. and Kilpeläinen, T., 2001a. Real-time Generalisation of XML-encoded Spatial Data on the WEB. In: Kidner, D. B. and Higgs, G. (eds.), 2001. *Proceedings of the GIS Research UK*, April 18th – 20th, University of Glamorgan, Wales, pp. 182–184.

Lehto, L. and Kilpeläinen, T., 2001b. Generalizing XML-encoded Spatial Data on the Web. In: *Proceedings of 20th International Cartographic Conference*, August 6–10, 2001, Beijing, China, Volume 4: 2390–2396.

Lichtner, W., 1979. Kartennetztransformationen bei der Herstellung thematischer Karten. *Nachrichten aus dem Karten- und Vermessungswesen*, I(79): 109-119.

Mulcahy, K. A. and Clarke, K. C., 2001. Symbolization of Map Projection Distortion: A Review. *Cartography and Geographic Information Science*, 28(39: 167-181.

Nehari, Z., 1975. *Conformal mapping*, Dover Publications, Inc., New York.

OGC, 2002. *OpenGIS® Implementation Specifications*. http://www.opengis.org/techno/implementation.htm (accessed October 8, 2002).

Refrections, 2002. *PostGIS – Geographic Objects for PostgreSQL*. http://postgis.refractions.net/ (accessed October 8, 2002).

Snyder, J. P., 1987. "Magnifying-Glass" Azimuthal Map Projections. *The American Cartographer*, 14(1): 61-68.

Timpf, S., 1997. Cartographic Objects in a Multiscale Data Structure. In: Craglia, M., and H. Couclelis (eds.), *Geographic Information Research – Bridging the Atlantic*, Taylor & Francis, Location, pp. 224-234.

van Oosterom, P. and Schenkelaars, V., 1995. The Development of an Interactive Multi-Scale GIS. *International Journal of Geographical Information Systems*, 9(5): 489-507.

Vivid Solutions, 2002. *Java Topology Suite*. http://www.vividsolutions.com/projects/jts.html (accessed October 8, 2002).

W3C, 2002. *World Wide Web Consortium - Scalable Vector Graphics (SVG)*. http://www.w3.org/Graphics/SVG/ (accessed October 8, 2002).