Visibility through Inaccuracy:
Geometric Distortions to Reduce the Cluttering in Route Maps

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Abstract

We present the concept of the FOCUS LINE, a new geometric distortion method designed to solve the problem of symbol cluttering in maps. FOCUS LINE's utilise significant differences in the symbol density across the original map and distorts the layout to create the presentation area required. When focussed on dense areas, the distortion guarantees a continuous and smooth integration of the enlarged area in the map as a whole. Unlike related approaches, the FOCUS LINE distortion considers the properties of the street network as found in city maps.

The Focus Line polyfocal distortion is characterised by a new shape of distortion reducing unnecessary distortions to the overall layout. The distortion is designed such that the amount is easily adjustable by parameters that have a geometric correspondence. Applying this method to tactile route maps, we discuss the results of an automatic approach and present interactive tools based on the FOCUS LINE distortion. These tools have been included in a prototypical implementation of a map editor for a systematical modification of the map layout.

Keywords: geometric distortions, focus lines, detail and context display, generalisation, information visualisation, interactive graphics, computer cartography

1 Introduction

When placing symbols on maps, the limited space poses severe problems for the layout. When space runs out, two obvious solutions exist: (a) to enlarge the map scale and the map accordingly or (b) to reduce the amount of information displayed. However, the first approach will find its physical limits and the latter will be far from the desired. Traditional cartography uses *generalisation* to tackle the problem. This includes procedures like simplifying the shape, as well as displacing and aggregating symbols. However, generalisation is a very sophisticated task requiring much experience and thus is largely manually performed.

Due to the new availability of digital map data, the problem of processing maps algorithmically (rather than manually) is currently gaining significantly in importance. While such data is still expensive to buy, the digital representations can, in principle, be manipulated by users to obtain *customised* maps. In this paper we concentrate on a specific example of customisation: Given digital map data and a defined route, produce a map of a fixed, pre-defined size which describes the route in detail while excluding superfluous information off the route.

Being able to including a significant amount of information on the route implies that the map must be distorted so as to widen the route to make room for the information to be presented.

Rather than dealing with this problem in its full generality, we concentrate in this paper on methods for distorting maps so that they are suitable for tactile route maps for blind people. This is an extreme example, tactile maps must be even less cluttered than normal maps for sighted people since they must be read by the haptic sense of a reader's fingers.

In this paper an approach for computer-supported uncluttering of tactile route maps is described. The algorithm makes use of a new method of FOCUS LINES, which are introduced in this paper. This method is characterised by

- a new centre of distortion resulting in a new shape of distortion,
- a specific formula to calculate the amount of distortion and
- a specific way to simultaneously handle several centres of distortion.

The paper is organised as follows. Chapter 2 motivates the problem of producing customised route maps and characterises the computer graphics problem to be solved. Techniques for deliberate distortion are surveyed in Chapter 3. In Chapter 4 the new distortion method is introduced. Giving an example of the results achieved by the new technique, the benefits and shortcomings are discussed. User interaction to distort maps based on the new method is introduced in Chapter 5. Concluding remarks are made in Chapter 6.

2 Motivation

Tactile route maps are of particular importance to blind pedestrians. While hardware exists for producing tactile output, the real problem is deciding which information to present. It is vital that only such information is presented as will actually be needed, because on the one hand tactile maps tend to be rather bulky, so that no space should be wasted, and on the other hand they are time-consuming to read (touch). A route specified by the user[1] should thus be presented with more detail at the expense of detail and precision in areas off the route.

A symbol for a route segment on a tactile map must be about 1-2 cm wide, so that additional symbols may be added inside to describe the path. This additional information includes such items as crosswalks, traffic lights and bus stops. Using a double line as street symbol, the reduced resolution requires in particular that the width of the street symbol has to be increased substantially, occupying space for symbols in the vicinity. Simply allocating the required presentation area on a true-scale map leads to cluttering; Figure 1 demonstrates the consequences of enlarging the street symbols to the extent that is

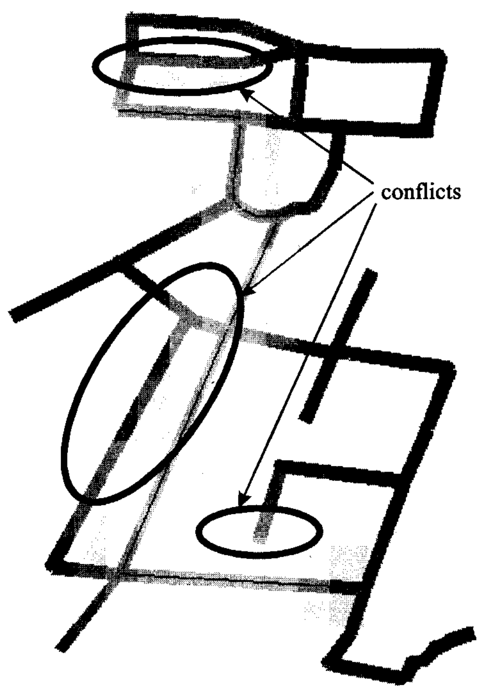

Figure 1: True-scale map with indication for the required space to enlarge the route symbols (shaded grey), conflicts are marked

[1] Alternatively, a user might specify the starting- and endpoint of a route and let a program calculate the best route. However, who defines the route is not an issue for the purposes this paper.

necessary to display all required route information. This leads apparently to overlapping and fusion of the surrounding symbols.

In the course of this paper we shall show that slight distortions to the map layout can help to solve this problem of symbol cluttering. However, the distortion method has to be designed specifically for this purpose. The distortion has to create a sufficiently large presentation area displacing the surrounding symbols accordingly. On the other hand, the overall shape of the map should be preserved to avoid disorienting the reader. This means the relative positions of the features to each other have to be maintained to the extent possible, including distances and/or angles among the segments. To avoid disruptive discontinuities, a smooth integration of the enlarged route in the context of the whole street network is required.

Furthermore, the distortion method should perform automatically given a pre-defined route. However, in case manual editing is required, a simple and intuitive interaction possibility has to be provided based on the applied distortion method. This is the goal pursued in the present paper.

3 Deliberate Distortions

Distortions to the map layout have already been used in the cartography although not on a larger scale. These approaches base on locally varying scales. The resulting so-called *cartograms* have been applied for a number of reasons, e.g. improvements in map legibility and alternative designs of thematic maps. One of the first attempts to create maps with varying scale was a photo-mechanical method developed in the 50's by the publishing company Falk in Hamburg (Germany)[6]. It has been used to present a city centre with a high symbol density at a larger scale than the outer city areas. The hyperbolic projection implemented by Kadmon can be considered as a computer-based replica of this method [3]. Further approaches to computer-based map distortions are described in [13] (logarithmic-azimuthal projection), [12] (magnifying lens projection) and [9] (polynomial projection[2]).

All of the above-mentioned distortion methods have in common that they make use of exactly one centre of distortion. From this Focus Point (FP), the scale continuously decreases radially and non-linearly towards the map border. However, this is not sufficient for all applications, e.g. maps of villages with several settlements. Kadmon *et al.* [4] thus introduced the polyfocal projection which is characterised by the simultaneous use of several FP's (see also [5]).

A more specific approach to the symbol displacement as necessary when assigning street symbols that are broader than the actual streets is documented in [8]. While this approach has been designed to solve the problem for the widening of street symbols that form meshes it is not directly applicable to the problem of route maps because a route does not in general correspond to a mesh.

Several approaches have been developed to improve the visualisation of large information spaces based on the generalised fisheye view [7]. These procedures have been designed mainly to display (partly hierarchical) graphs. The visualisations are characterised by emphasising (e.g. through enlargement) the nodes that are of special interest to a viewer. Since a map of a city cannot be looked at as a graph with nodes as main information carrier, these techniques cannot directly be applied to this kind of cartographic presentations. However, distortion methods have been used in some of these techniques ([10], [11]).

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[2] Rase did not name his projection. We will refer to it as polynomial projection because of its properties and following the conventions for the other projection names.

In contrast to the cartographic-oriented methods that utilize variations in map scale an alternative approach based on image morphing using vector pairs is described in [10]. However, the placement of the vector pairs in city maps is not straightforward, making this method difficult to apply algorithmically to the problem of uncluttering route maps.

The above mentioned distortion methods were investigated but they did not seem to be suitable for reasons described in the next chapter. As a consequence a new distortion method will be developed.

4 The Focus Line Distortion

We shall now develop a specific distortion method that creates space along the route. A distortion modifies the map layout in a way that the scale changes from the distortion centre P_{focus} towards the map perimeter. Thus, almost every point P in the original map is repositioned. This can be described by a function that changes the vector p, the vector from P_{focus} to a point P in the original map, to the equivalent vector p' in the distorted map:

$$p' = p \cdot D\left(\frac{r}{r_{\max}}\right) \cdot \frac{r_{\max}}{r} \qquad (1)$$

where r is the length of p, r_{max} the radial distance from P_{focus} to the map border via P (see Figure 2). The distortion function $D(s)$ is normalised such that it maps from the range [0, 1] to [0, 1]. The distortion function has to be a non-linear function to be different from simply rescaling the map. To fulfil the requirements imposed by the purpose of uncluttering maps as stated in Chapter 2, the distortion has to be designed very carefully. In the following two subchapters, these requirements will be applied to both shape and amount of distortion.

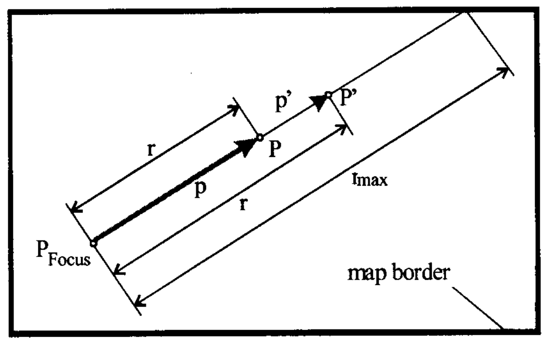

Figure 2: General distortion, P is mapped to P'.

4.1 Shape of Distortion

A route consists of several linear segments. Presentation area is required along them to both sides. Previous distortion methods (recall Chapter 3) use one or more point-shaped centres of distortion that induce radial distortion. Placing several foci along the route leads to significant changes to the angles between segments in the surrounding area. Hence, FP approaches do not preserve the overall shape as required.

Our new method is based on the concept of FOCUS LINE's (FL). A FL defines a distortion centre that runs along a segment. Distortions are induced symmetrical and perpendicular to the segment (cf. Figure 3). The area determined by perpendicular lines through the end points of the FL will be called *area of influence*. The length of a FL is thus decisive for the area of influence. In case, the FL is limited by the map border, an unnecessarily large distortion is caused. We refer to this impact as a *corridor effect* which is character-

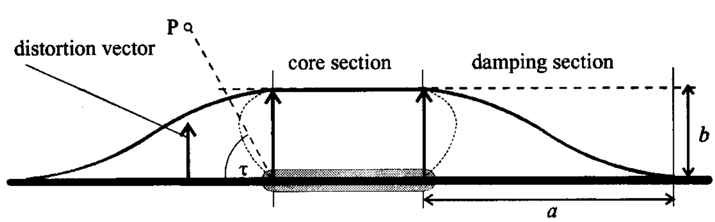

Figure 3: Scheme of the FL distortion method. The thick line is the FL that causes distortion to both sides (only one is depicted). The grey area around the FL presents a segment. The drawn vector indicates the resulting distortion applied to P.

ised by a band across the map to both sides of the FL. Along the band everything is enlarged by the same amount. By contrast, in case the FL has the length of a segment, a sudden change at the segment borders is visible that contradicts the call for continuity in the layout (recall Chapter 2).

Splitting up the FL into a CORE SECTION and a DAMPING SECTION solves this problem (cf. Figure 3). The distortion is fully applied to every map point in the core section whereas the distortion continuously runs to zero in the damping section preserving the layout to a great extent. This can be achieved by introducing two damping functions $DMP_d(t)$ and $DMP_a(\tau)$. $DMP_d(t)$ defines a weakening of the distortion function $D(s)$ with increasing distance t to the core section. The damping function $DMP_a(\tau)$ ensures minimal distortions to the angles of the bordering segments.

The introduction of the damping functions changes equation (1) as follows:

$$p' = \begin{cases} p \cdot D\left(\frac{r}{r_{\max}}\right) \cdot \frac{r_{\max}}{r} & \text{if } P \text{ within the influence area of the core section} \\ p \cdot D\left(\frac{r}{r_{\max}}\right) \cdot \frac{r_{\max}}{r} \cdot DMP_d(t) \cdot DMP_a(\tau) & \text{if } P \text{ within the influence area of the damp section} \\ p & \text{otherwise} \end{cases} \quad (2)$$

The damping function $DMP_d(t)$ should result in a continuous weakening of the distortion within the damping section of length a from the maximum in the core section to zero depending on the distance t of P_{focus} to the core section. This can be achieved by using a cubic function that has been determined through cubic spline interpolation demanding C^1 continuity in the border points (cf. Figure 3):

$$DMP_d(t) = \frac{2}{a^3}t^3 - \frac{3}{a^2}t^2 + 1 \quad (3)$$

Preserving the angles in the influence area of the damping section requires maintaining the angles between the FL segment and the connected segments. Nearly straight continuations of the FL segment, i.e. the angle to the other end point of a connected segment τ is close to 0°, have to be preserved. Whereas significant turns ($\tau \approx 90°$) should be subject to the distortion with nearly the same amount as in the core section to avoid an interrupted presentation and to improve legibility. To achieve a continuous distortion, the same has to be applied to all points in the influence area of the damping section depending on their angle to the core section τ. The following equation proved to be appropriate with respect to particularly emphasising larger angles:

$$DMP_a(\tau) = |\sin\tau| \quad (4)$$

4.2 Amount of Distortion

The previous section introduced a new centre of distortion resulting in a new shape of distortion exceeding the previously used FP for the purpose of uncluttering route maps. This section will now specify the function which calculates the amount of distortion that is induced by this centre – the DISTORTION FUNCTION $D(s)$ (cf. equations (1) and (6)). This function has to be designed according to the requirements as specified in Chapter 2.

To compare the previously used distortion functions (cf. Chaper 3), Equation (1) is generalised to consider the different parameters for each function:

$$p' = p \cdot D\left(d_1, \ldots, d_n, \frac{r}{r_{\max}}\right) \cdot \frac{r_{\max}}{r} \qquad (5)$$

The width of the old segment symbol and the width required are both known. To perform efficiently, i.e. to distort exactly to the extent as required, the distortion function should be adjustable to the old width s_0 and the new width s'_0:

Requirement 1: There exists a tuple of distortion parameters $(d_1, \ldots, d_n)$ such that $D(d_1, \ldots, d_n, s_0) = s'_0$ $(0 \leq s_0 \leq s'_0 \leq 1)$.

Since the overall available space remains constant, the necessary magnification close to the route implies a demagnification in the route context (cf. Figure 4). To avoid an unnecessarily strong demagnification in the outer areas, the border between magnification and demagnification has to be adjustable. This border s_1 is characterised by an ascent of 1.

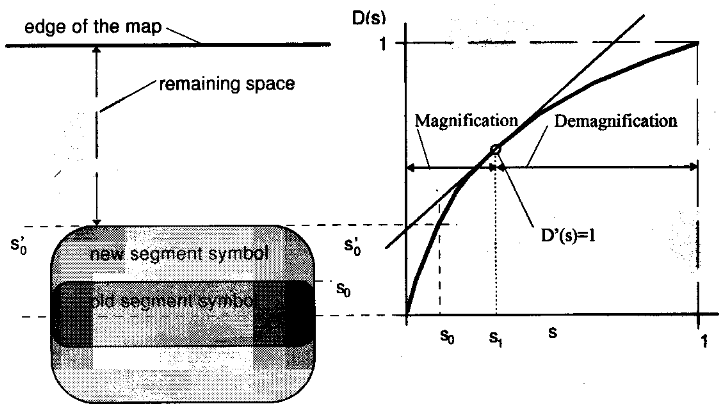

Figure 4: Space requirements and the distortion function

Requirement 2: There exists a tuple of distortion parameters $(d_1, \ldots, d_n)$ such that $\frac{d}{ds}D(s_1) = 1$.

Since a magnification is defined by enlarging the old width from s_0 to s'_0 this point also determines the border of magnification. Everything outside has to be displaced and thus to be shrinked. Hence, both requirements have to be met for the same s:

Requirement 3: There exists a tuple of distortion parameters $(d_1, \ldots d_n)$ such that $D(s_0) = s'_0$ and $\frac{d}{ds}D(s_0) = 1$.

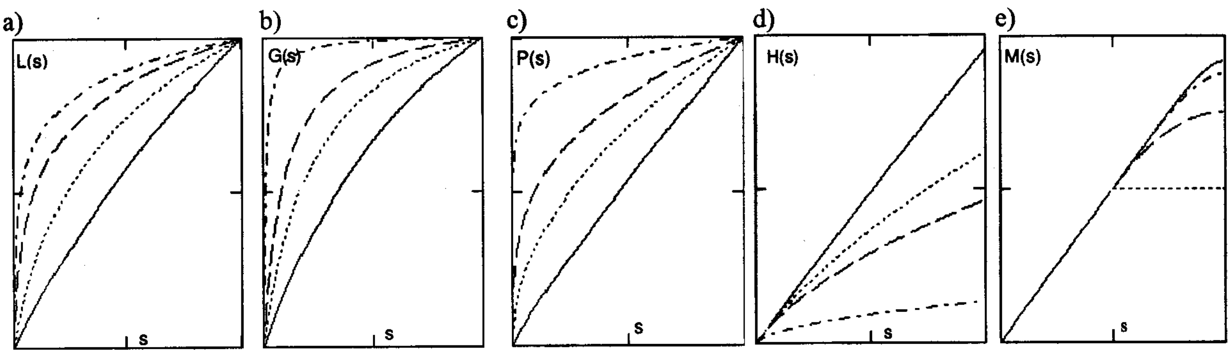

Figure 5: Several distortion functions in comparison. The x-axis represents the original position, the y-axis depicts the possible new postions after applying the distortion. To illustrate the parameterisation of the functions, several curves are shown for each distortion function.
The depicted curves show: a) logarithmic-azimuthal function L(s)[6], b) Fisheye-function G(s) [11], c) polynomial function P(s)[9], d) hyperbolic function H(s)[3], e) Magnifying Lens approach M(s)[12].

The distortion functions of the previous approaches as described in Chapter 3 (see Figure 5) have been analysed in [2] to determine their appropriateness with respect to the three requirements defined above. It was established that while most of them can fulfil the Requirements 1 and 2 independently, none of them is able to meet Requirement 3. The latter imposes two restrictions for the same value s which requires an increased flexibility that the functions depicted in Figure 5a) to c) are insufficient due to only one parameter. Both the hyperbolic function (Figure 5d) and the Magnifying Lens approach (Figure 5e) do not preserve the map size. While rescaling the distorted map could restore the map size, neither function meets Requirement 3.

Since no previously defined function meets Requirement 3, we introduce a new distortion function:

$$D(s_0, s_0', s) = \begin{cases} es^2 + fs, & \text{for } s \le s_0 \\ \frac{1}{2g}\left[h - \sqrt{h^2 + 4g(1-s)}\right] + 1, & \text{for } s > s_0 \end{cases}, \qquad (6)$$

where e, f, g and h are auxiliary variables defined as follows:

$$e = \frac{s_0 - s_0'}{s_0^2},\ f = \frac{2s_0'}{s_0} - 1,\ g = \frac{s_0 - s_0'}{(1 - s_0')^2} \text{ and } h = \frac{2 \cdot (1 - s_0)}{1 - s_0'} - 1.$$

This function is continuously differentiable in the range [0, 1] allowing a smooth integration of the enlarged route in the whole street network. Figure 6 demonstrates the flexibility of this new function.

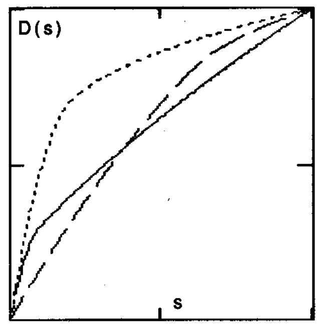

Figure 6: Newly developed distortion function depicted for three parameter sets.

4.3 The Polyfocal Focus Line Distortion

Since a route is usually described by more than one segment, the effect of defining several FL's simultaneously has to be considered. The distortion method has to make sure that the individual distortions of each FL do not sum up to an extreme distortion[3], i.e. the amount of distortion applied to a point P must not increase with every additional FL.

The distortion induced by each FL $F_i\,(i=1,\ldots,n)$ is scaled down by a weight c_i $\left(0 \le c_i \le 1;\ \sum_i c_i = 1\right)$. Using this weight, points are mapped as follows:

$$P' = P + \sum_i c_i (p_i' - p_i) \qquad (7)$$

where p_i, p'_i are the vectors from $P_{focus,\,i}$ on F_i to P and P'_i respectively, the latter being the point mapped by the distortion induced by F_i $(i = 1, \ldots, n)$.

The weight c_i has to be defined such that FL's close to P have more influence than distant FL's. Thus, c_i diminishes with the square of the distance to the FL:

$$c_i = \frac{r_i^{-2}}{\sum_j r_j^{-2}} \qquad j = 1, \ldots, n \qquad (8)$$

[3] Similar problems were solved with similar methods in the polyfocal approaches in [4] and [10].

4.4 Results

The Polyfocal FL Distortion was developed to unclutter route maps automatically. This automatic approach estimates the required presentation area along the route on the basis of the requested map content. The route is regarded as the focus of the map, i.e. all segments belonging to the route are used as FL. They are parameterised with the old width s_0 and the new width s'_0 according to (6). A polyfocal distortion using these pre-defined FL's will lead to an automatically created route map.

This automatic approach already leads to good results. Figure 7a) shows a map of a part of the city of Magdeburg drawn to scale, while Figure 7b) depicts the basic layout for a route map created automatically. It is obvious that all the conflicts as demonstrated in Figure 1 could be succesfully removed. All symbols surrounding the route have been displaced such that any overlapping or fusion is prevented. The overall shape could be preserved even such that the distortion is not easily recognisable. The map is usable as it is.

However, in some cases the results may not satisfy the map reader completely, e.g. the roundabout in the upper area of Figure 7a) has lost its characteristic round shape. Another shortcoming of the default behaviour is that since route segments are not themselves moved about, route segments running parallel to one another run into one another when widened and may no longer be distinguishable. This particular problem is not easily solved using the current approach due to the characteristic of the polyfocal approach to weight the influence of each FL depending on the distance.

Since the FL approach does not analyse the map to an extent enabling the detection of such problems, manual intervention by a map designer is still required in some cases. The following chapter will therefore show the implementation of a map editor and introduce interaction possibilities developed on the basis of the FL distortion.

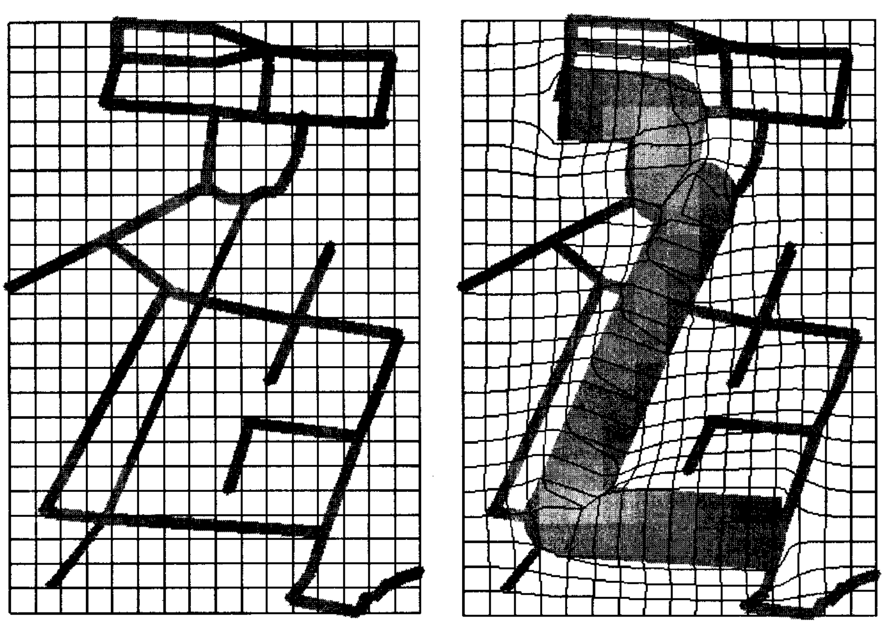

Figure 7: Example for the creation of a route map using the FL distortion. A grid has been overlayed to indicate the distortion applied to the layout.
a) original part of the Magdeburg street network,
b) route map of the same part with enlarged presentation area for the route

5 Interaction

The FL distortion method has been integrated in a map editor for the creation of tactile route maps. The editor creates a map layout without considering the route. Since the required space along the route corresponds to widening the segment symbols, the destination width is indicated by grey shadows around the original symbols (cf. Figure 8a). Given these requirements a map designer can now intervene in the distortion process and:

- select route segments to serve as FL's,
- modify the parameters of the FL's or
- place and define FP's and FL's independent from the segment symbols.

The independent FP and FL have been developed on the basis of the distortion function (Equation (6)) that fulfils the Requirement 3 as defined in Chapter 4.2. This allows an intuitive interaction since the parameters s_0 and s'_0 have a geometric correspondence, in contrast to the parameters for many of the approaches mentioned above.

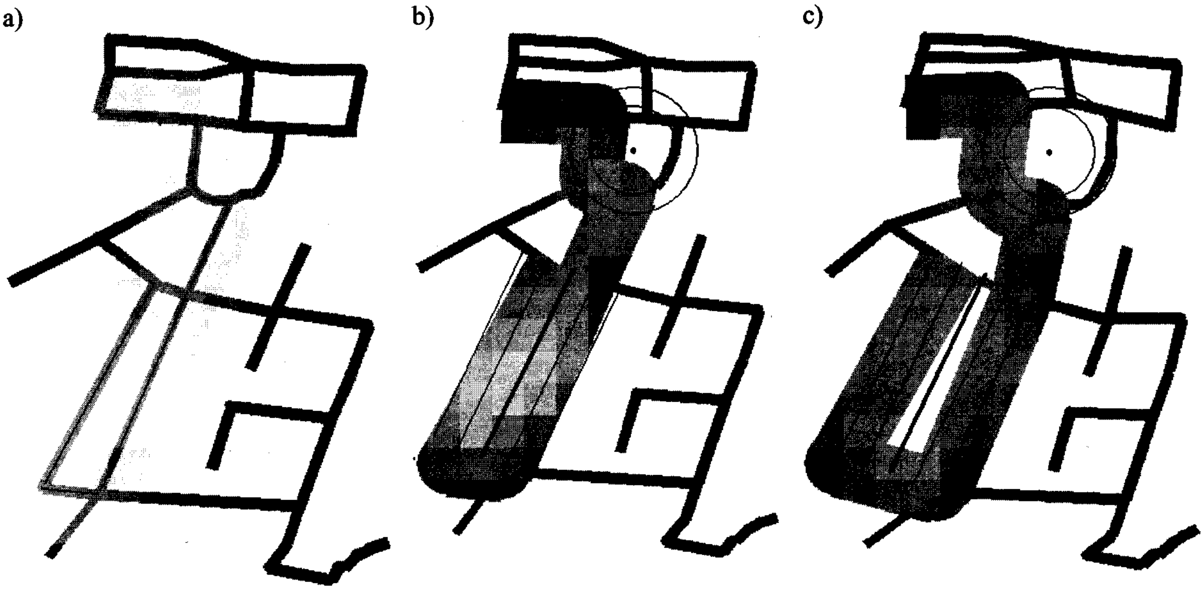

Figure 8: Demonstration of the FL based interaction. a) depicts a route with a U-turn; b) shows the same route after automatic distortion, an independent FP has been placed at the round about and a FL at the U-turn; c) after applying the FP and the FL the resulting map is conflict-free

Figure 8 demonstrates the application of both the independent FP and the independent FL. Figure 8b) depicts the result of the automatic distortion and enlargement applied to the original map that is drawn to scale as shown in Figure 8a). Note that the roundabout near the top end of the route is no longer easily recognisable, and also that the two parallel legs in the bottom part of the route are no longer distinguishable.

The user now sets out to manipulate Figure 8b) to solve these problems and improve the map. By drawing the two concentric circles he defines the position of a FP as well as the distortion parameters. The inner circle determines s_0 and is used to define the original part of the map to be enlarged, while the outer circle for s'_0 defines the destination size. Applied to the roundabout in Figure 8b) this means that after placing the inner circle on the roundabout, a map designer can determine its new size with the outer circle. In the resulting picture (Figure 8c) the segments now run along the outer circle. Note that there are only small distortions in the area around the affected region.

Similarly to the FP, an independent FL is defined by drawing two sets of parallel lines (Figure 8b): the inner set defines the region to be enlarged, the outer set defines its new size (the actual FL is the thick line in the between the others). This operation has been applied to the parallel segments of the route (Figure 8b). Figure 8c) demonstrates that the simultaneous application of both the FP and FL has solved the problems mentioned above while only marginally affecting the regions around the route.

6 Conclusions and future work

The FOCUS LINE approach introduced in this paper has been designed specifically to solve the symbol cluttering in route maps. The distortion applied is subtile and preserves the overall shape though effective with respect to the results. Used to automatically distort the map layout appropriately it performs sufficiently for most of the cases. In special cases requiring manual intervention, high-level tools have been provided that allow intuitive interaction. Solving these cases automatically requires a comprehensive analysis of the map layout that is a feature which would be very good to have in the system.

Although the FOCUS LINE approach has been developed for route maps, it is not restricted to this area. In many maps, a significant difference in symbol density occurs that is solved by standard generalisation methods. It has to be investigated to what extent the Focus Line approach can be part of the usual generalisation process.

It should be investigated how far the interaction technique based on the FOCUS LINE distortion as described in Chapter 5 can be extended to other similar problems. We surmise for example that it can, in particular, provide better distortion control for the fisheye techniques [7].

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References

[1] G. Hake, D. Grünreich: *Kartographie.* de Gruyter; Berlin, New York, 1994.

[2] J. Hamel: *Adaptive Symboländerungen bei der Erzeugung taktiler Routenkarten.* Master Thesis at the Department of Simulation and Graphics, Otto-von-Guericke University of Magdeburg, 1995.

[3] N. Kadmon: "Data-bank derived hyperbolic-scale equitemporal town maps". *Internationales Jahrbuch für Kartographie* (15), 1975, pp. 47-54.

[4] N. Kadmon, E. Shlomi: "A polyfocal projection for statistical surfaces". *The Cartographic Journal: Journal of the British Cartographic Society.* Edinburgh (15), 1978, pp. 36-41.

[5] W. Lichtner: "Computer-unterstützte Verzerrung von Kartenbildern bei der Herstellung thematischer Karten". *Internationales Jahrbuch für Kartographie* (23), 1983, pp. 83-96.

[6] D. H. Maling: *Coordinate systems and map projections.* Pergamon Press; Oxford *et al.* 1993.

[7] E. G. Noik: "A space of presentation emphasis techniques for visualizing graphs". *Proceedings of Graphics Interface*, 1994, pp. 225-234.

[8] B. M. Powitz: "Zur Automatisierung der kartographischen Generalisierung topographischer Daten in Geo-Informationssystemen". Dissertation at the Department of Cartography, University of Hannover, 1993.

[9] W.-D. Rase: Kartographische Anamorphosen. *Kartographische Nachrichten* (42), 1992, pp. 99-105.

[10] M. Sarkar, S. S. Snibbe, O. J. Tversky, S. P. Reiss: Stretching the rubber sheet: a metaphor for viewing large layouts on small screens. *Proc. of the ACM Symposium on User Interface Software and Technology*, 1993, pp. 81-92.

[11] M. Sarkar, M. H. Brown: "Graphical fisheye views". *Comm. of the ACM* (12), 1994, pp. 73-83.

[12] J. P. Snyder: "'Magnifying glass' azimuthal map projections". *American Cartographer* (1), 1987, pp. 61-68.

[13] W. R. Tobler: "Geographic area and map projections". *Geographical Review* (53), 1963, pp. 59-78.