Aspect-Ratio-Preserved Labeling on Metro Maps

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***Abstract*—For better readability, metro lines are often aligned along the octilinear directions. Predefined layouts, however, limit the feasibility of placing station name labels. In this paper, we present a novel approach to automating the placement of station names around a schematic network while maximally respecting its original layout as the mental map. The idea behind the proposed approach is to progressively annotate stations from congested central downtown areas to sparse rural areas by introducing the sum of geodesic distances over the network to identify the proper order of stations to be annotated. Our approach elongates line segments of the network without changing their directions to spare labeling space around the station. Additional constraints are introduced to restrict the aspect ratios of the region confined by the metro network for better preservation of the mental map in the original schematic layout.**

***Index Terms*—Progressive Annotation, Geodesic Distances, Schematic Layouts, Mental Maps, Mixed-Integer Programming**

I. Introduction

Metro maps serve as the common media for travelers to explore the transportation networks of the metro lines available in major cities. Such maps are often transformed into schematic diagrams for better readability of the network topology. In particular, octilinear layouts are the most common form. The are obtained by aligning metro line segments to horizontal, vertical, and 45-degree slanting directions. This representation originates from the design criteria invented by Henry Beck [1].

Properly placing stations on schematic metro maps is also important, while this usually incurs additional technical challenges. This is primarily because the central downtown area of such a schematic map is usually congested with multiple metro lines around the interchange stations and thus it is difficult to find enough space for labeling station names, when compared with sparse rural areas around the terminals of the metro lines. This labeling problem becomes involved if the alignment of the name labels around the corresponding station is restricted to one of the octilinear directions. Nöllenburg and Wolff enable to automatically schematize geographical layouts of metro networks in a visually plausible fashion [3], while the technique still takes approximately 10 hours to compute optimal label placement [3] for a middle sized network such as Vienna metro network (Figure 1).

This paper presents a progressive approach for automatically annotating stations with their names while maximally respecting the original layout of the schematic metro map. This is accomplished by extending the authors' previous work [4] for placing station names as labels progressively from the crowded downtown area to sparse rural areas. Specifically, the new approach imposes additional constraints that restrict the variation in the aspect ratio of the regions confined by the metro network, which allows to maximally retain the mental map of the original schematic map.

II. Methodology

The proposed algorithm employs a mixed-integer programming (MIP) approach [3] to solve the constrained optimization problems for schematizing the metro networks by minimizing three different types of costs, which are *line bends*, *relative positions*, and *edge length*. Once the metro network has successfully been schematized, the next step is to place a station name label in the neighborhood of each station vertex.

A. Sorting station vertices for progressive annotation

The idea is to progressively place annotation labels one by one from the crowded downtown area to sparse rural areas around the boundary of the map domain. In this approach, this idea is implemented by sorting the station vertices according to the sum of geodesic (i.e., shortest topological) distances within the metro network. In most cases, the aforementioned approach can successfully place station names as annotation labels while maintaining the mental map of the original schematic layout. Nonetheless, the approach still fails to sufficiently retain the mental map through the progressive annotation (see Figure 1(b)) because no constraints are explicitly imposed to control the overall design of the metro map.

B. Extracting closed regions and preserving their aspect ratio

We found out that this problem is caused by the progressive annotation technique not adequately retaining the original aspect ratio of the specific features in the schematic metro map. This inspires us to focus on the regions surrounded by the metro network in the downtown area, because the downtown area is usually crowded with metro lines and interchange stations and thus is more likely to contain feature regions confined by the metro lines. If the proposed approach can limit the change in the aspect ratios of such feature regions,

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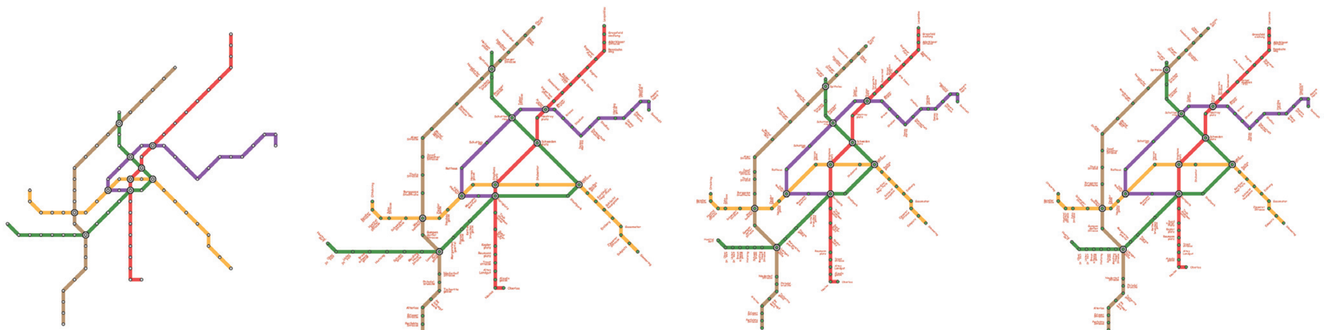

(a) (b) (c) (d)

Fig. 1. Annotating the Vienna metro network. (a) Original schematic map. (b) A progressively annotated map without any constraints on the entire shape. Progressively annotated maps while the aspect ratios of closed regions are constrained by the new constraints, where the tolerance error ratio E is set to be (c) $E = 0.5$ and (d) $E = 0.1$.

it can successfully mitigate the distortion of the user's mental map [2] of the metro map by constraining the changes of layout geometry.

Let us denote w and h the width and height of a rectangle respectively that tightly encloses the closed region. These variables can naturally be derived from the upper and lower limits of the closed region along the x- and y-axes as $w = x_{\max} - x_{\min}$ and $h = y_{\max} - y_{\min}$.

Assume that the constant values W and H represents the width and height of a rectangle defining the original closed region just after the network schematization, respectively. Since the aspect ratio of the closed region $\frac{w}{h}$ should be kept close to the original aspect ratio $\frac{W}{H}$, the following inequality conditions are introduced as new constraints: $\frac{W}{(1+E)H} \leq \frac{w}{h} \leq \frac{(1+E)W}{H}$, where E is a constant that represents the error tolerance ratio. These conditions can be rewritten as $Wh \leq (1+E)Hw$ and $Hw \leq (1+E)Wh$. It is clear that the aspect ratio of the closed region $\frac{w}{h}$ changes more significantly if the corresponding error tolerance ratio E increases. Thus, our new formulation allows us to control the degree of distortion in the progressive annotation process by adjusting the error tolerance ratio E.

III. Results

Our system has been implemented on a laptop PC with 3.1 GHz 6-Core Intel Core i5 CPU and 16GB RAM. Figure 1 presents the Vienna metro map, in which the network layout in the central downtown area is strongly distorted. This undesirable deformation can be controlled with the help of the constraints that preserves the aspect ratios of the closed regions confined by the network. The running time of each image is depicted in Table I.

TABLE I
Computation times of Figure 1 (in seconds).

City	Figure 1(a)	Figure 1(b)	Figure 1(c)	Figure 1(d)
Vienna	2.08	140.8	164.3	235.5

We also recruited 10 undergraduate and graduate students to evaluate our approach. They were requested to compare the original schematic layout of the synthesized metro map with the three annotated versions and to select the best match for preserving the mental map of the original schematic layout. In these cases in which the simple progressive annotation can successfully annotate stations of the schematic map without excessively distorting the original layout, the participants were likely to answer randomly, and the votes are uniformly distributed over the three layouts. The participants did not discriminate between the constrained version with different error tolerance ratios for the metro maps in Lisbon and Vienna. This is probably because the difference between the two versions is small and the severe constraints sometimes enlarge the closed regions a little excessively to meet the given conditions.

IV. Conclusion and Future Research Direction

This paper refines an approach to progressively annotating stations in schematic metro maps. The algorithm extracts all closed faces confined by the network and imposes the proposed constraints on them to limit the variation in their aspect ratio. More careful selection of such feature regions may further improve the capability to maintain the underlying mental map embedded in the original schematic layout.

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