Shortest-Paths Preserving Metro Maps

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A metro map, or subway map, is a schematic representation of a metro system of a city. The main goal of a metro map is to provide a traveler with information on which lines to take to get from station A to station B, and at which stations he needs to switch lines. It is often not beneficial to use the geographical embedding of the system, but rather a representation where the relevant information is presented as clearly as possible. There are several algorithms that aim to generate such maps [2].

One criterion that is not considered in these algorithms is whether or not the visually shortest route on the generated metro map still corresponds to the route with the shortest travel time. This could lead users to plan their travel along a route that results in a needlessly long travel time. To remedy this, we define the *theoretical planning error* (TPE) of a pair of stations to be the ratio between the travel time of the shortest route on the map and the shortest possible travel time of the metro system. This idea can be extended such that the TPE of the metro map is the maximum TPE over all pairs of stations. The theoretical planning error of a metro map can thus be defined mathematically as

$$\text{TPE} = \max_{u,v \in V} \frac{t(\operatorname{argmin}_{R \in \mathcal{R}(u,v)} \ell(R))}{\min_{R \in \mathcal{R}(u,v)} t(R)} \tag{1}$$

where V is the set of metro stations, $\mathcal{R}(u,v)$ is the set of routes from u to v, $\ell(R)$ is the perceived time it takes on the map to take route R and $t(R)$ is the actual time it takes.

Approach. We formulate the optimization of the TPE as a Mixed-Integer Program (MIP). One advantage of a MIP is that it is flexible and we can integrate our MIP with the one from Nöllenburg and Wolff [1]. The new objective function is a weighted combination of both approaches. The problem as defined in Equation 1 would result in an exponential number of constraints. The number of pairs of stations is already quadratic, but the number of possible routes between every pair can be exponential. We therefore use an iterative approach.

The process is started by generating a metro map without adding any TPE constraints. Then in each iteration the map that was generated in the previous iteration is analyzed offline, i.e. not in the MIP, to find the pair of stations that determines the TPE. For this pair, we generate a series of constraints for only two routes, the route that *appears* to have the shortest travel time, and the one that really has the shortest travel time. We add these constraints to the MIP

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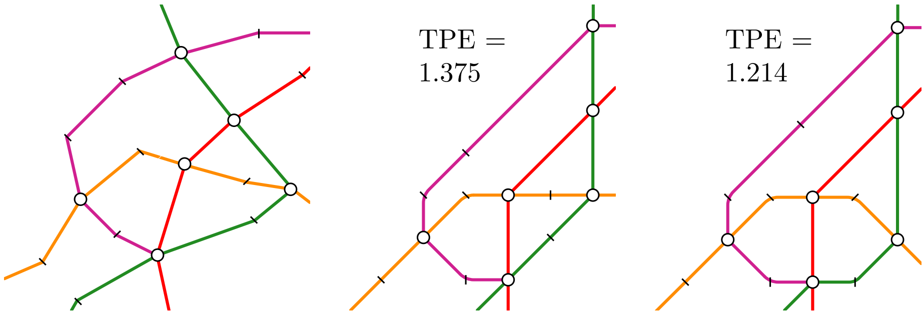

(a) Original embedding. (b) Map without TPE. (c) After 7 iterations.

Fig. 1. Results for part of the Vienna metro system

and solve it again. Since the TPE adds to the objective function, it is up to the linear program solver to see whether it can make the second route shorter (or more commonly whether it can make the first one larger) on the map while complying with the aesthetic requirements. The process terminates when the TPE of the metro map is 1 and therefore all shortest routes on the metro map correspond to the routes with the shortest travel time.

Results and Future Work. In Figure 1, a part of the results for the Vienna metro system can be seen. From Figures 1b and 1c it follows that small changes can in fact decrease the theoretical planning error (from 1.375 to 1.214). However, even though we have tried to limit the number of constraints in the program, the MIP solver CPLEX runs out of memory after 7 iterations. This cannot be solely attributed to the number of constraints as the original program has 2379 and iteration 7 contains 5816 constraints. We are currently looking into this issue.

We have verified that our approach indeed decreases the TPE. However, user studies are required to see whether or not this truly influences the planning capabilities of users. Additionally we consider allowing bends between adjacent stations to see if this increases the quality of the map.

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References

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