Route Schematization With Polygonal Landmarks

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***Abstract*—GPS-based navigation devices use large-scale visualizations of the route, where the focus lies on turn instructions. Although efficient on the wayfinding task, this approach does not support survey knowledge acquisition, which is essential for the user to build up a cognitive map and obtain orientation. Another visualization option is the small-scale topographic overview of the route. However, due to the lack of detailed turn information, it is difficult for the user to interpret turn decisions, especially in small display devices. Current route schematization algorithms focus on improving interpretation of turns but ignore context information. Considering this limitation, we propose a schematization method that provides information about turns at decision points and, in the same layout, an overview of the route emphasizing spatial relationshisps with context regional features.**

***Index Terms*—route map, survey information, schematic map, geovisualization, wayfinding**

I. Introduction

Schematic visualizations of geographic information make use of abstract and symbolic representations to improve cognitive ergonomics of map interpretations. The most common schematic layout is the metro map, which emphasizes the sequence of stations and connections between metro lines. Route maps have a different function and therefore need different layout criteria. It aims to communicate essential route information and, because often the user is the driver, it needs to promote spatial awareness. For route maps, location is very relevant, so generalizations are more limited compared to transit maps designed for passengers. Moreover, context information, such as point-like or regional landmarks, has high relevance because it supports spatial chunking and orientation.

The layout criteria for schematic route maps need to emphasize turns at decision points, crossings, elements for spatial chunking [1], and the route's spatial relation with context information. Regional landmarks are context information that facilitate wayfinding as elements in spatial chunks [1]. Also they play an important role as global landmarks for survey knowledge acquisition and self-orientation [2], [3]. Information such as the "route goes around the city center" or "there is a right turn after going along the park" represents spatial relations between landmarks and a route. Schematic visualizations can be used for a cognitively adequate representation of such spatial relations [4]. Removing granularity and unnecessary shape complexity improves the focus on such information; however, this needs to be carefully balanced in order not to disturb the user's sense of distance and directions.

Related work on route schematization [5], [6] only consider the route geometry itself, i.e., they do not include context information. The focus+context method in [7] includes only transit lines as context for transit route maps. Our route schematization, in addition to highlighting essential route information, includes polygonal landmarks (parks, lakes, urban areas, etc.) highlighting their spatial relations with the route.

Formally speaking, our schematization method takes as its input the target route R as a geometrically embedded path and adjacent roads represented as stubs. Moreover, the spatial context of R is given as a set of polygonal landmarks. The goal is to compute a topologically correct schematic representation of the route R and its context, which satisfies a number of hard constraints and optimizes an aesthetic quality measure. We implement our approach as a combination of integer linear programming (ILP) for path schematization and local geometric transformations to place landmarks and context roads. Figure 1 illustrates the different steps of our method. In the following we describe the algorithm: Section II describes the route schematization and Section III the schematization of contextual polygonal landmarks.

II. Route Schematization

For the route schematization, we adapted and extended the original ILP model for metro map schematization by Nöllenburg and Wolff [8]. In addition to the route path R, we send to the schematization process the adjacent edges of the surrounding street network. The adjacent street edges are important elements to represent spatial chunks in route information (e.g., "after the park, turn in second right", "at the crossing, turn left").

A. Rescale

Before we send the route to the ILP process, we locally rescale the route to give more space to parts of the route with more concentration of decision points (DP). Let a DP be a node in the route where a turn is made at an intersection; we call a path connecting two DP a route section. The scale of the sections is reduced proportionally to their length using a common parameter that defines the level of distortion. This parameter tells how much the sections are reduced. In the minimal distortion, the sections keep their original length, and

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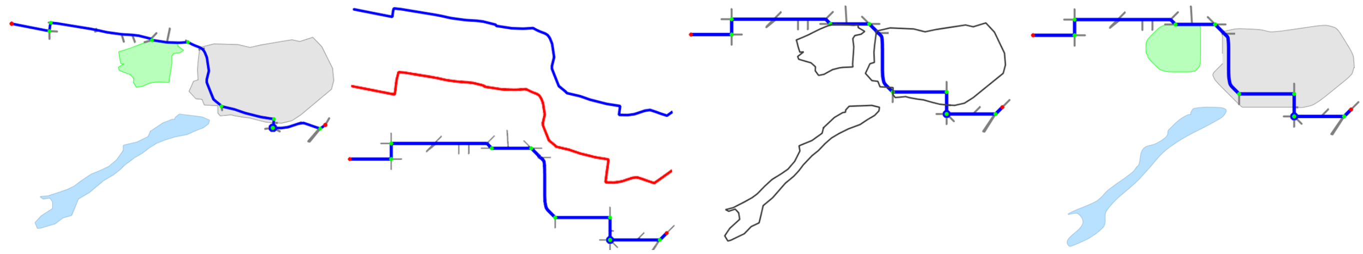


(a) (b) (c) (d)

Fig. 1: Schematization process flow. (a) As input, we get the route path, adjacent streets, and contextual polygonal landmarks. (b) Original route path in blue, rescaled route path in red, and ILP schematization of route path and with adjacent streets. (c) Affine transformation to transpose the polygonal landmarks into the schematic route. (d) The landmarks are schematized to highlight spatial relations and to fix topological inconsistencies.

in the maximal distortion, the resulting length is the shortest section length. The red path in Fig. 1(b) illustrates the effect of the rescaled compared to the original path (top). The distortion level was 60%. This rescaling improves the use of space, making short sections better visible on small displays.

B. ILP Model

Linear programming is an optimization technique used to find optimal values for real-valued variables that minimize (or maximize) a linear objective function and are subjected to restrictions that must be modeled into linear inequalities. There exist polynomial-time algorithms to solve linear programming problems. For map schematization, the desired variable values are, for example, point coordinates; the hard layout constraints are the restrictions; and soft layout constraints form the objective function to be minimized. Some of the constraints require extra variables to represent discrete information, like restricting edges orientation to a fixed set of angles, or to guarantee the correct topology, e.g., a test whether one point is to the left or right of another. Discrete information requires the use of integer variables, and linear programming with integer variables is NP-hard, but due to its high relevance in discrete optimization, several practically efficient solvers exist. To solve our ILP model we use IBM CPLEX®V12.7.1.

The original ILP can guarantee a topologically consistent schematization due to its circular order and edge spacing constraints [8]. We list here the other constraints that are relevant for our desired layout.

1) Hard Constraints:

- *Octilinearity of intersection edges*: for a discretized representation of intersections, all edges adjacent to the route must respect octilinearity. This makes intersection representations compatible for the 8-direction model of the wayfinding choreme theory [9].
- *Best turn representation at DPs:* route bends at DPs must respect a turn direction model, i.e., we force the orientation of the route edges adjacent to each DP to the orientation that best represents the original turn. It forces the turn's representations into the seven wayfinding choremes, adequate to a mental conceptualization [9].

2) Soft Constraints:

- *Bend minimization:* reduces the number of bends along the route. It diminishes unnecessary complexity along the route in oreder to facilitate path following.
- *Edge orientation:* reduces the difference of the orientation angle of edges to the original orientation. It improves the sense of direction along the route path.
- *Node position:* reduces the distance of the resulting node positions to the input positions (rescaled). It improves coherence in the relative position among all nodes.
- *Route sections proportion:* reduces the difference of proportion of the route sections in relation to the total route length compared to input path proportions (recaled proportion). Minimizes length distortions between DP.

III. Polygonal Landmarks

The schematization of the polygonal landmarks consists of the following steps: (i) classification of the landmarks into categories: *along the route*, *crossed*, *origin/destination*, and *global*. (ii) planarization of the polygons with the route path. (iii) creation of control edges to store relative positions of the polygons in respect to the route. (iv) adjustment of the length of the control edges in relation to the schematized route. (v) affine transformation to adjust the position of the polygons using the crossing nodes and the control edge vertices as control points. (vi) schematization of the polygons using ILP. Potential topological inconsistencies are fixed in this process.

A. Type of Landmarks and Control Edges

We select nodes from the polygons to be used as control nodes in an affine transformation. If the control node does not coincide with the route, we create an edge (control edge) to connect it to the route. The adequated selection of the control nodes depends on the class of the landmark.

1) Landmarks along the route: Landmarks not crossed by but within a certain distance to the route. We set for this case a pair of control edges. The control edge is defined by the control node (polygon node) and the closest point on the route, where an extra node is created. The control nodes are selected based on two values: the distance to the route (d_r); and the distance to the orthogonal line on the beginning (d_{l1}) and end (d_{l2}) of the linear referencing of the polygon against the route, one for each control edge . The values d_r and d_l are weighted in a linear function, and the nodes with minimum resulting value are selected. Figure 2 illustrates the pair of control edges and their respective d_r and d_l values.

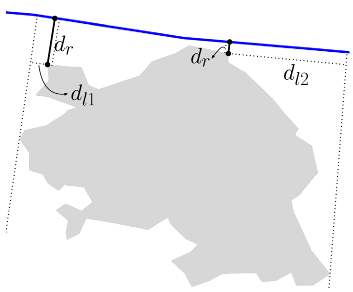


Fig. 2: Control edges (black solid line) for landmarks *along the route*.

2) Crossed landmarks: Polygons whose boundaries intersect with the route an even number of times. They do not need controls edges since the crossing nodes suffice as control nodes for a proper adjustment in the affine transformation.

3) Origin/Destination Landmarks: Polygons whose boundaries intersects with the route an odd number of times, and depending on whether the first or last node of the route is inside the polygon we classify it as origin or destination. In those cases, one of the crossings is one control node, and just a single control edge is created (Fig. 3). Again, we select the polygon node of the control edges based on two values: (1) the distance of the route (d_r), and (2) the value specifying how the node, together with the crossing control node, divide the polygon in two paths of a similar length. Let p be the perimeter of the polygon, and q the length of the path connecting the node to the crossing control node. The second argument of the evaluation function is calculated as $|q - p/2|$.

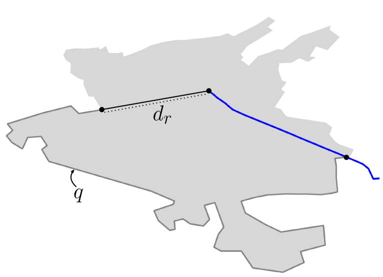
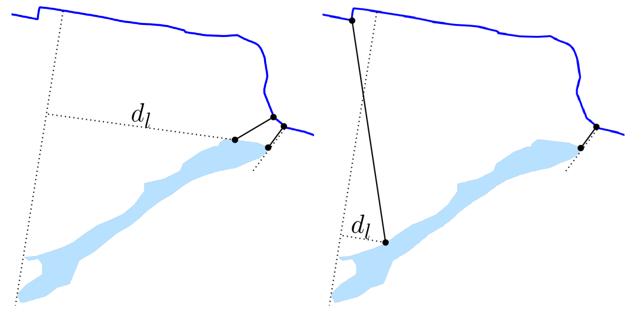


Fig. 3: Single control edge for *destination/origin* landmarks.

4) Global landmarks: Landmarks are classified as *global* if they are neither crossed by nor *along* the route. Landmarks containing the entire route are treated as *global* too. For global landmarks, we set a pair of control edges the same way we set it for landmarks along the route. The only difference is a bigger weight given to the d_l values in a evaluation function. Figure 4 demonstrates how the control edges are selected if the same landmark is treated as *along* (4a), or *global* (4b).



(a) Control edges for *along*. (b) Control edges for *global*.

Fig. 4: Difference between of control edges for landmarks *along* (a) and *global* (b). d_l for (b) got 5 times more weight.

B. Adjustment of Control Edges Lengths

The control edges are used to keep the relative positions of the polygons to the route. However, because we rescale the route shape, we need to rescale the control edges too. The scale of the route varies from section to section, so the scale factor cannot be the same for all control edges.

For a more coherent rescaling, the length of the control edges is defined by the length of the 20% closest route edges. Let e and e' represent the edges of the original and schematized route respectively. The ratio of the new length for each control edge is calculated as:

$$\sum \frac{l(e_i')}{d(e_i)} \Big/ \sum \frac{l(e_i)}{d(e_i)} \qquad (1)$$

where $l(e)$ is the length of the edge, and $d(e)$ is the normalized distance of e to the control edge. Because we weight each edge by the inverse of its distance, edges closer to the control edges will have a higher influence on the rescale factor.

C. Schematization of Landmarks

We model the ILP for landmarks with similar constraints as for the route (octilinearity of intersection edges, bend minimization, edge orientation, node position, edges proportion). The ILP is used to reduce shape complexity, to emphasize spatial relations (crossings and alongness), and to guarantee topology.

1) Fixing topological inconsistencies: Merely transposing the polygon using an affine transformation does not guarantee topological consistency. Crossings violating the original planarity like in Fig. 5(b) might occur. The ILP planarity (edge-spacing) constraint [8] guarantees planarity after the schematization. Every shape schematized in the ILP is bounded by an octilinear box. So, for better performance, we select only the edges overlaped by this box to be checked in the planarity constraint (Fig. 5(c)). That way the original planarity is guaranteed after the schematization.

2) Emphasizing crossings: Landmarks crossed by the route are used in spatial chunks (e.g., cross the lake and turn right). We discretize the crossings to the octilinear orientation by schematizing the adjacent edges together with the route ILP process (similar to the adjacent street edges).

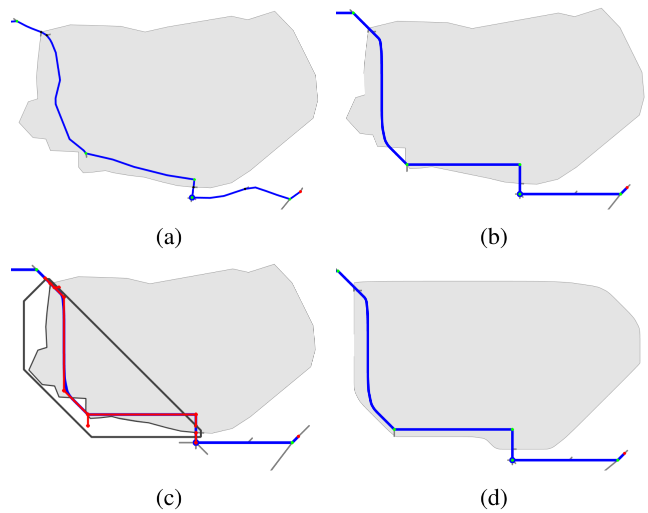


Fig. 5: ILP fixes topological inconsistencies. (a) Original route crosses polygon shape, (b) Transposed polygon into the schematized route contains extra edge crossings. (c) Octilinear bounding box, and detection of edges to avoid crossing (red). (d) Schematized polygon with correct topology

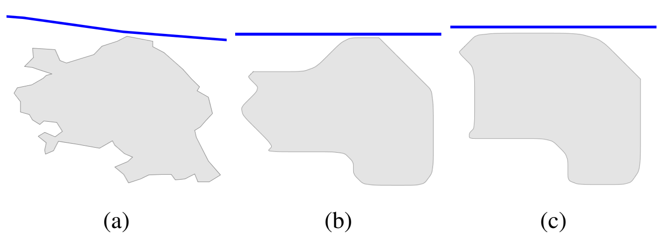


Fig. 6: Emphasizing alongness: (a) original shape, (b) regular polygon schematization, (c) tight polygon schematization.

3) Emphasizing alongness: Landmarks along the route can be used in spatial chunks (e.g., go along the park and turn left). We can increase alongness (ratio of the region boundary being parallel to a path) with the route by reducing the length of its pair of control edges before sending the polygon to the ILP process. Figure 6 illustrates the effect of this tighter adjustment.

4) Global: Global landmarks are useful as references for self-orientation and survey knowledge acquisition. So the relevant information for global landmarks is their relative position to the route. Using the control edges, we can transpose the global landmarks to an adequate position. To reduced shape complexity, we schematize them using ILP, but if the topology is not violated, an area-preserving simplification [10] could result in better design.

IV. Discussion

Figure 7 illustrates an input/output pair of our schematization method. Comparing the original with our layout in the same space extension, it can be seen that small route sections and landmarks are more evident in our layout due to the scale variation along the route. Important crossings and turns are more evident too, represented according to the wayfinding choremes [9]. With the contextual regional landmarks we could give an extra dimension to the one-dimensional route path, promoting survey-knowledge. Regarding their positioning, it respects some coherence, despite the scale distortion. Parallelism and crossings with the route are more evident too, that could facilitate their use on spatial chunks.

As limitations, the edge orientations are strictly octilinear, which might result in undesired deformation in some route paths and landmarks. Currently, our method cannot guarantee correct topology for polygons structured as subdivisions or polygons with a street network. This will be addressed in future work.

V. Conclusion

Route visualization is aimed to facilitate route and survey knowledge acquisition. Current route schematization methods do not include regional landmarks that are relevant as both, route and survey information. In this contribution, we presented a route schematization method that includes regional landmarks. Our method makes uses of ILP and geometric transformations to emphasize route information (crossings, turns at DP) and spatial relationship with local and global landmarks. For the future, we want to include street network structures. Also, to prove the layout concept, we want to test its usability in experiments with participants.

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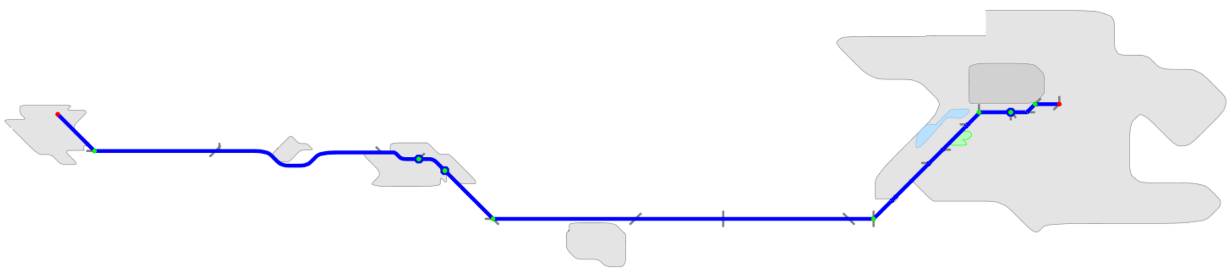
(a)



(b)

Fig. 7: Example of input (a) and output (b) of our method. The input instance is composed of 358 nodes, of which 137 are route and context street nodes. The total execution time was 11.28 seconds, of which 3.23s for the route and 8.05s for 8 landmarks. We run our application in 8GB RAM Intel Core i7 2.8 GHz Windows 10 Laptop and IBM CPLEX®V12.7.1 to solve the ILP model.