Set Visualization Using the Metro Map Metaphor

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Abstract

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1 Introduction

We consider a visualization style for hypergraphs that is inspired by schematic metro maps. Such maps are common for urban citizens, who all know that the stations traversed by the same colored curve belong to the same metro line. This intuitive understanding of grouping have been employed to visualize other abstract data forming hypergraphs. For example, Foo [3] turns personal memories into a metro map, Nesbitt [4] and Stott et al. [10] use the metro map metaphor to visualize relationships between PhD theses and items of a business plan, Sandvad et al. [7] for building Web-based guided tour systems, and Seskovec [8] uses it for visualizing historical events. One of the most popular applications is the visualization of the movies and movie genres by the creators of the website Vodkaster.

We formalize the problem of constructing such a visualization for given hypergraph as follows. Let $H = (V, \mathcal{E})$ be a hypergraph with vertex set V and edge set $\mathcal{E} \subseteq 2^V$. A *metro-map drawing* of H is a graphical representation where each node in V is depicted by a point in the plane and each hyperedge $e \in \mathcal{E}$ by an open continuous curve that passes through the points corresponding to the vertices in e. In case two hyperedges contain the same vertex, their curves both pass through the point representing this vertex and may either *touch* or *cross* at this point. We call the latter situation a *vertex crossing*, and we call a crossing of hyperedge

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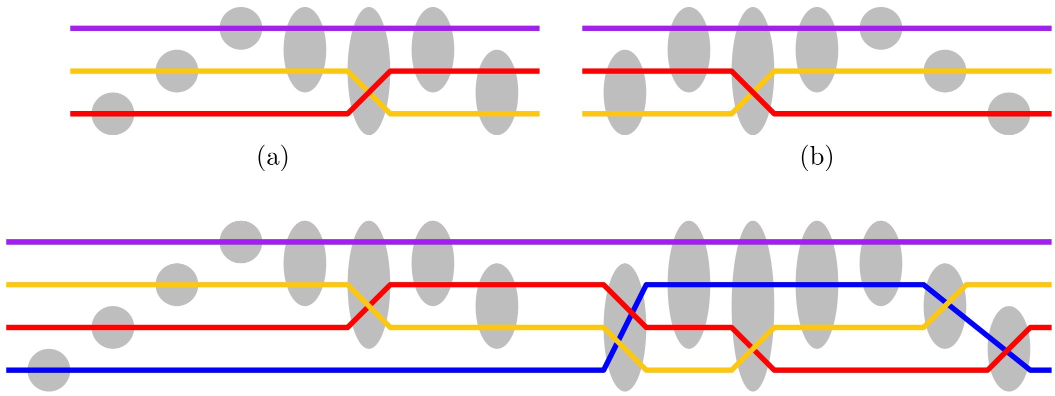

Figure 1 A metro-map drawing is a visualization of a hypergraph where the metro lines represent hyperedges and the stations represent hypervertices. (a) A metro-map drawing of a vertex-complete hypergraph with three hyperedges (violet, red, yellow), (b) a mirrored copy of (a), and (c) a metro-map drawing of a vertex-complete hypergraph with four hyperedges. The drawing is constructed recursively by routing the new (blue) hyperedge through a vertex that is only contained the new hyperedge and then through the concatenation of (a) and (b). The new hyperedge does not contain any vertex of (a), and it does contain every vertex of (b).

curves that is not a vertex crossing an *edge crossing*. A metro-map drawing of a hypergraph is called *monotone* if all hyperedge curves are monotone with respect to the x-axis.

2 Some Simple Observations

Since both vertex and edge crossing may impair the readability of the metro-map drawing of a hypergraph, we want to characterize the hypergraphs that can be represented without, or with a few, vertex and edge crossings. We observe that each hypergraph with at most four hyperedges can be represented without vertex and edge crossings. We call a hypergraph $H = (V, \mathcal{E})$ *k-vertex-complete* for some $k \leq |\mathcal{E}|$ if any subset $E \subset \mathcal{E}$ of at most k hyperedges has a distinct vertex in common, that is, there is an injective function $f\colon \mathcal{E} \to V$ such that $f(E) \in \bigcap_{e \in E} e \neq \emptyset$. We call $|\mathcal{E}|$-vertex-complete hypergraphs simply *vertex-complete*. We observe that a 2-vertex-complete hypergraph with five hyperedges does not have a metro-map drawing without vertex and edge crossings. This follows simply from the fact that K_5 is not planar. Next, we consider drawings with vertex crossings but without edge crossings. We can show that every vertex-complete hypergraph admits a metro-map drawing without edge crossing. The idea behind the proof is to exploit the vertices to realize the intersections among the hyperedge curves. For an example, see Figure 1.

3 A Heuristic

For practical applications, we propose a heuristic that constructs a metro-map drawing of a given hypergraph. The heuristic consists of four steps.

In the first step, we simplify the hypergraph, by ignoring all vertices that belong to a single hyperedge, and contracting all vertices that belong to the same set of hyperedges.

In the second step, we construct a so-called support graph. A *support* of a hypergraph $H = (V, \mathcal{E})$ is a graph $G = (V, E)$ with the property that, for each hyperedge e of H, the graph $G[e]$ induced by e is connected. A support is *path-based* if $G[e]$ is Hamiltonian. It is

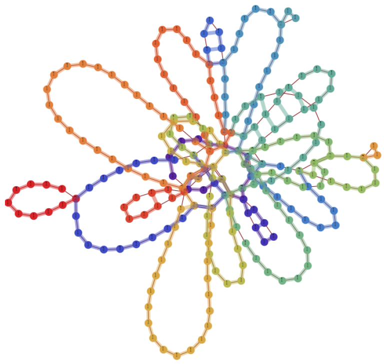

Figure 2 A preliminary drawing of the support graph of a dataset

NP-complete to compute a path-based support with the minimum number of edges [2]. We propose a heuristic algorithm for finding a path-based support for a given hypergraph.

In the third step, we lay out the support graph in the plane. In doing so, we try to ensure that all vertices belonging to the same hyperedges lie close by and that the paths representing the hyperedges have simple shapes. A preliminary drawing at this step is shown in Figure 2.

Finally in the fourth step, we feed the above drawing into a mixed-integer program (or some other existing algorithm) that generates a metro map layout [5].

The above steps can be implemented in many possible ways. The performance of our approach needs to be compared with existing similar approaches [1, 6, 9] experimentally.

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