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Forced-Directed Edge Bundling
Scientific Visualization
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Introduction

Graphs are a major tool used in expressing data in a manner that can be informative to an individual. Graphs allow for easy representation of data while providing the user the ability to understand the relationship between data points. Most graphs that are currently used are in the form of a node-link diagram. This method depicts nodes as dots joined by lines or curves for the edges. Node-link diagrams provide an intuitive way to represent graphs, however visual clutter can quickly become a problem when graphs are comprised of a large number of nodes and edges are visualized. However, there are methods to approach this issue of visual clutter.

The node-link diagrams can be manipulated to reduce the visual clutter. One can focus on changing the nodes, edges, or both within the graph. This project was focused on the flight route dataset which suffers greatly from visual clutter. The visual clutter in this dataset is a result from most of the edge connections between the nodes. The nodes here represent airports and the edges represent the flight routes between those airports. Since this dataset is more concerned with the flight locations and not the actual method of flying, this implementation will take advantage of being able to manipulate the edges. Manipulating the nodes would alter the visual information that is needed to be portrayed, thus we focus only on the edges.

Forced-Directed Edge Bundling

The implementation used here was that of a self-organizing, force-directed approach. This implementation model uses a physics core in order to provide an easy method of bundling edges. In order to manipulate edges of the graph, the edges need to be broken down into segments to allow for a curvature to occur. This method of edge segmentation can be seen in Figure 1. The edges P and Q are subdivided with four separate points per edge. The outer points (P0 P1 Q0 Q1) will remain fixed during the curvature of the edges. This ensures that the nodes do not change during edge bundling. The force Fs is a linear spring acting force that is exerted between each subdivision point on an edge. A global constant K is used for the spring force to determine the the stiffness of the edges. Since the edges are of different lengths and are subdivided into segments a local spring constant is applied to each segment of the edge ($k_P = K/|P|$(number of segments), where $|P|$ is the initial length of edge P).

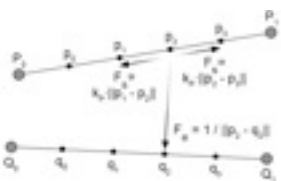


Figure 1: Edge Interactions of P and Q.

Another force that is applied to the edges is the attracting electrostatic force (Fe). This forced is used between each pair of interacting edges and the number of electrostatic forces applied is the based upon the number of subdivisions of the

$$\mathbf{F}_{P_i} = k_P \cdot (\|P_{i-1} - P_i\| + \|P_i - P_{i+1}\|) + \sum_{Q \in E} \frac{1}{\|P_i - Q_i\|}$$

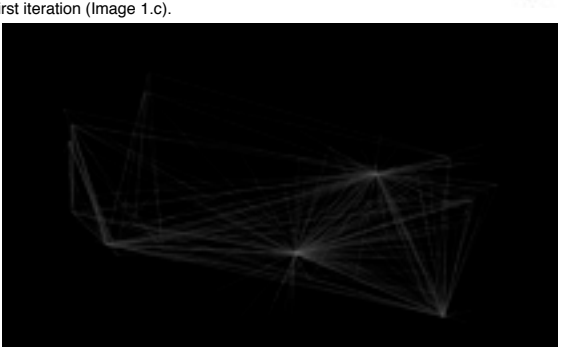
Image 1: a) non-edge bundling; b) non-compatibility measure bundling; c) compatibility measure bundling

edges. During each iteration step the combined force exerted on each subdivision point of each of the edges is calculated.The position of each subdivision point is updated by moving it a small distance in the direction of the combined force that is exerted on it.

The model then generates an edge-bundled graph, but the amount of bundling that occurred is often too high (Image 1.b). This can be changed by K, but this would affect the regions in which high bundling is desired, thus a set of edge compatibility measures are applied to control the amount of interaction between edges.

The first compatibility measure to be applied is the angle compatibility. The angle compatibility is based on the fact that almost perpendicular edges should not be bundled together (Figure 2.a). The second compatibility is based on the length of the edges in which considerably different lengths of edges should not be bundled together: scale compatibility (Figure 2.b). The third compatibility is that edges that are far apart from one another should not be bundled together: position compatibility(Figure 2.c). The last compatibility measure is the visibility compatibility. This is used when the edges are parallel to one another, similar in length, and close together but should remain independent of each other (Figure 2.d). The total compatibility measure is just the simple sum of these compatibility measures which results in the edge bundling graph that is not as bundled as the first iteration (Image 1.c).

$$\mathbf{F}_{p_i} = k_p \cdot (\|p_{i-1} - p_i\| + \|p_i - p_{i+1}\|) + \sum_{Q \in E} \frac{C_e(P,Q)}{\|p_i - q_i\|}$$



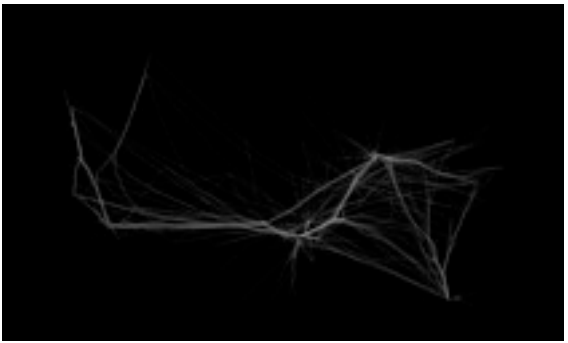
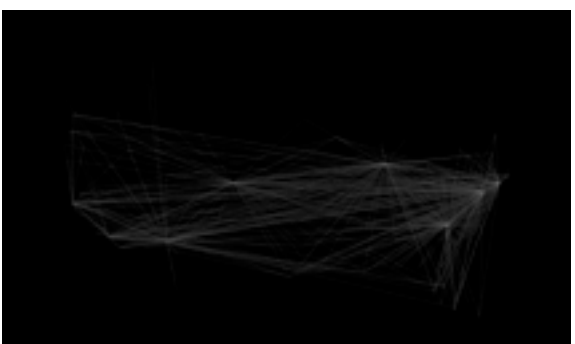


Image 2: American Airlines route map with and with out forced-directed edge bundling.



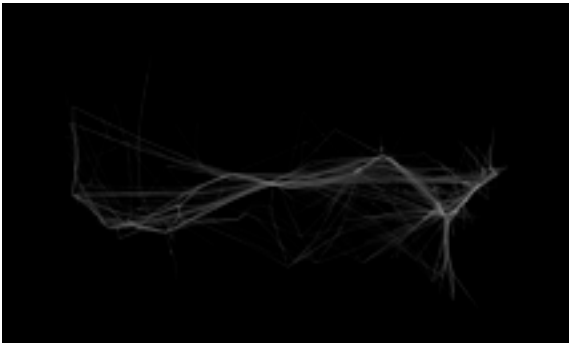


Image 3: US airlines route map with and without forced-directed edge bundling.

Results

The results above are the graphs for both the straight edge and forced-directional edge bundling of two different data sets. The first data set is the flight routes for the American Airlines industry (Image 2). The second data set is the flight routes for all US. airlines (Image 3). The method was only applied to flights that were within the bounding longitudinal and latitudinal coordinates of the United States. This is due to the computational time require for this implementation. In just the full US. airline route data there are over 7,000 edges that have to be represented on the map. Each edge has a preset value of 10 segments which forms over 70,000 data points to calculate spring forces and electrostatic forces against, this results in an enormous amount of computational time. Considering the straight edge graph (Image 4) of the entire world, this graph alone produces 61,199 edges. If this implementation was applied to this amount of the data the computational time would take days for completion and would be unrealistic for multiple alterations of the constant K or the number of segments for each edge.

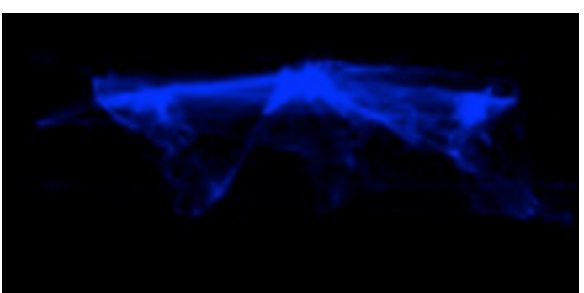


Image 4: Straight Edge Graph of entire world flight routes.

Future Work