

Browsing large graphs with MSAGLJS, a graph draph drawing tool in JavaScript

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Msagljs github home page: <https://github.com/microsoft/msagljs>

1 **Abstract.** There has been progress in visualization of large graphs re-
2 cently. Tools appeared that can render a huge graph in seconds. However,
3 if we request that the node labels are rendered, and the edges are routed
4 around the nodes, then the problem is still standing. Interacting with a
5 large graph in an Internet browser with the same ease as browsing an
6 online map, inspecting the high level structure and zooming in to the
7 high level detail, is still a challenging task.
8 In this paper we describe novel approaches to several aspects of this
9 problem.
10 We give a new efficient algorithm for edge routing, where the edges are
11 routed around the nodes. The algorithm produces edge paths which are
12 visually appealing and optimal in their homotopy class.
13 To facilitate graph visualization with DeckGL, or any other viewer sup-
14 porting tiles, we propose a new simple and fast tiling method. The
15 method guarantees that in every view, except of the highest layer, the
16 number of visible nodes per tile is not larger than a predefined bound.
17 Our method provides a high level overview of the graph, with the grad-
18 ual increase of the detail level. We make the node labels of the most
19 important nodes for the current view visible.
 The edge routing algorithm mentioned above is reused at the tiling stage
 to simplify the paths on the lower levels. In addition, we bundle edges
 per-tile as an optimization heuristic

20 Introduction

21 We target our approach to large but not huge graphs. The maximum number of
22 vertices of the graphs we looked at was 28k, and the maximum number of the
23 edges was 237k. There are quite a few algorithms that calculate node positions
24 for such graphs, and work very fast [1, 2]. We look at the node layout as a solved
25 problem.

26 In the first part of the paper we address edge routing where an edge does
27 not intersects the nodes it is not adjacent to. Our approach works for any node
28 layout, as long as it produces a layout whithout overlap. We build on the edge
29 routing from [3] and improve it. There has been progress in visualization of

30 large graphs recently. Tools appeared that can render a huge graph in seconds.
31 However, the situation changes if we request that the node labels are rendered,
32 and the edges overlap only the nodes they are adjacent to. Interacting with a
33 large graph in an Internet browser with the same ease as browsing an online
34 map, inspecting the high level structure and zooming in to the high level detail,
35 is still an unsolved problem. In this paper we describe novel approaches to several
36 aspects of this problem.

37 We propose a novel and efficient algorithm for edge routing, where each edge
38 can only intersect its source or target. The algorithm produces edge paths which
39 are visually appealing and even optimal in their homotopy class.

40 To facilitate graph visualization with DeckGL, we propose a new simple and
41 fast tiling method. The method guarantees that in every view, except of the
42 views of the Shighest layer, the number of visible entities is not larger than a
43 predefined bound. The method can be used in other viewers that support tiling.

44 Our method provides a high level overview of the graph.

45 The edge routing algorithm mentioned above is reused at the tiling stage to
46 simplify the paths on the lower levels. In addition, we bundle edges per-tile as
47 an optimization heuristic.

48 Related work

49 A popular graph drawing tool Graphviz [4] applies Scalable Force-Directed Place-
50 ment [5] for large graphs, with no support for tiling. Its edge routing for this case
51 builds the whole visibility graph. This can be very slow because the visibility
52 graph can have $O(n^2)$ edges, where n is the number of the nodes in the graph.
53 Interestingly, the funnel algorithm [6, 7], the last step of our approach, is used
54 in Graphviz for the edge routing in the Sugiyama layout. We are not aware of
55 any tool that integrates Graphviz and uses tiling as well.

56 yWorks [8] has method "Organic edge routing" that produces edge routes
57 around the nodes. We could find only a very general description of the method:
58 "The algorithm is based on a force directed layout paradigm. Nodes act as re-
59 pulsive forces on edges in order to guarantee a certain minimal distance between
60 nodes and edges. Edges tend to contract themselves. Using simulated annealing,
61 this finally leads to edge layouts that are calculated for each edge separately".
62 It seems the algorithm runs in $O(n + m)\log(n + m)$ time, where n is the number
63 of the nodes and m is the number of the edges.

64 ReGraph [9] uses WebGL as the viewing platform. It can render a large graph
65 using straight lines for the edges. The tool does not support tiling, but instead
66 the user interactively opens the node that is a cluster of nodes.

67 "graph-tool.skewed" [10] does not implement its own layout algorithms or
68 edge routing algorithms, but instead provides a nice wrapper around the algo-
69 rithms from other layout tools.

70 Circos [11] visualizes large graphs in a circular layout. It does not support
71 tiles.

72 Cosmograph [12] uses a GPU to calculate the layout of a graph and can
 73 handle a graph with a million nodes. It renders edges as straight lines. It does
 74 not support tiling.

75 Edge routing in MSAGLJS

86 The edge routing starts, as in [3], by building a spanner graph, an approximation
 87 of the full visibility graph, and then finding shortest paths on the spanner. The
 88 spanner, see Fig 2, is built on a variation of a Yao graph, which was introduced
 89 independently by Flinchbaugh and Jones [13] and Yao [14]. This kind of graph
 90 is defined by the set of cones with the apices at the vertices. The cones have the
 91 same angle, usually in the form of $\frac{2\pi}{n}$, where n is a natural number. The family
 92 of cones with the apex at a specific vertex partition the plane as illustrated in
 93 Fig. 1. For each cone at most one edge is created connecting the cone apex with
 94 a vertex inside of the cone, so the graph has $O(n)$ edges where n is the number
 95 of vertices.

96
 100 The approach of [3] applies local optimizations to shorten an edge path.
 101 Namely, it tries to shortcut one vertex at a time from the path, as illustrated in
 102 Fig 3. To smoothen a path, it fits Bezier segments into the polyline corners by
 103 using a binary search to find a larger fitting segment, see Fig 4. While analyzing
 104 performance of the edge routing in MSAGLJS, we noticed, that for a graph with
 105 more than 1k nodes these heuristics sometime create a performance bottleneck,
 106 in spite of using R-Trees[15].

107 In addition, when the naive shortcutting of polyline corners fails, the resulting
 108 path might remain not visually appealing, as shown in Fig. 3.

109 We replace these heuristics with a more precise and efficient optimization
 110 described below.

111 Path optimization

112 We finalize edge routes by the “funnel” algorithm [6, 7], routing a path inside a
 113 simple polygon, that is a polygon without holes.

114 An application of the ‘path in a simple polygon’ optimization to edge routing
 115 is not a new idea: the novelty of our work is in how we find the polygon and
 116 how we use it. The authors of Graphvis used the ‘funnel’ algorithm [16], but
 117 only for hierarchical layouts, where a simple polygon, \mathcal{P} , containing the path is
 118 available. They write: “If \mathcal{P} does not contain holes ... we can apply a standard
 119 “funnel” algorithm ... for finding Euclidean shortest paths in a simple polygon”.
 120 In general case, for a non-layered layout, they build the visibility graph which is
 121 very expensive for a large graph.

122 Here we find the polygon \mathcal{P} for any layout. We drop the requirement that
 123 \mathcal{P} is simple. Indeed, to run the “funnel” algorithm one only needs a “sleeve”: a
 124 sequence of triangles leading from the start to the end of the path, where each



Fig. 1. Yao graph



Fig. 2. Spanner graph is built using the idea of Yao graphs. The dashed curves are the original node boundaries. Each original curve is surrounded by a polygon with some offset to allow the polyline paths smoothing without intersecting the former. The edge marked by the circles is created because the top vertex is inside of the cone and it is the closest among such vertices to the cone apex. The apex of the cone is the lower vertex of the edge. MSAGLJS uses cone angle $\frac{\pi}{6}$, so the edges of the spanner can deviate from the optimal direction by this angle. Therefore, the shortest paths on the spanner have length that is at most the optimal shortest length multiplied by $\frac{1}{\cos(\frac{\pi}{6})} \simeq 1.155$.

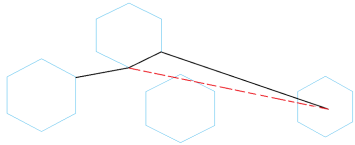


Fig. 3. Unsuccessful shortcut

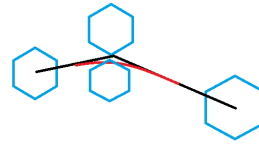
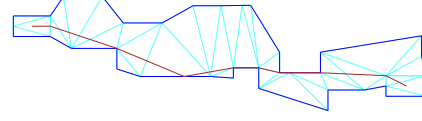


Fig. 4. Fitting a Bezier segment into a polyline corner



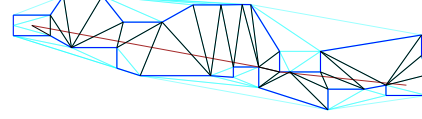
131 **Fig. 5.** Path \mathcal{L} with \mathcal{T} , a fragment.



132 **Fig. 6.** Polygon \mathcal{P} containing \mathcal{L} .



133 **Fig. 7.** New triangulation of \mathcal{P} .



134 **Fig. 8.** The optimized path together
135 with the sleeve diagonals.

125 triangle shares a side with its successor. Let us show how to build polygon \mathcal{P} ,
126 create a sleeve, and produce an optimized path.

127 We call obstacles, \mathcal{O} , the set of polygons covering the original nodes, see
128 Fig. 2. Before routing edges, we calculate a Constrained Delaunay Triangulation
129 [17] on \mathcal{O} . Let us call this triangulation \mathcal{T} .

130 For each edge of the graph we proceed with the following steps.

138 We route a path, called \mathcal{L} , on the spanner, as illustrated by Fig. 5. Let \mathcal{S} and
139 \mathcal{E} be the obstacles containing correspondingly \mathcal{L} 's start and end point. To obtain
140 \mathcal{P} , let us consider \mathcal{U} , the set of all triangles $t \in \mathcal{T}$ such that either $t \subset \mathcal{S} \cup \mathcal{E}$, or t
141 intersects \mathcal{L} and is not inside of any obstacle in $\mathcal{O} \setminus \{\mathcal{S}, \mathcal{E}\}$. The union of \mathcal{U} gives
142 us \mathcal{P} . The boundary of \mathcal{P} comprizes all sides e of the triangles from \mathcal{U} such that
143 e belongs to exactly one triangle from \mathcal{U} , see Fig. 6.

144 To create the sleeve [6, 7], we need to have a triangulation of \mathcal{P} such that every
145 edge of the triangulation is either a boundary edge of \mathcal{P} , or a diagonal of \mathcal{P} .
146 Because \mathcal{U} might not have this property, as in Fig. 6, we create a new Constrained
147 Delaunay Triangulation of \mathcal{P} , where the set of constrained edges is the boundary
148 of \mathcal{P} , see Fig. 7.

149 We trace path \mathcal{L} through the new triangulation and obtain the sleeve. Finally,
150 we apply the funnel algorithm on the sleeve and obtain the path which is the
151 shortest in the homotopy class of \mathcal{L} , as illustrated in Fig. 8.

152 The discussion [18] of the algorithm helped us in the implementation.

153 Polygon \mathcal{P} is not necessarily simple, as shown in Fig. 9. In this example the
154 path that we calculate with the funnel algorithm is not the shortest path inside
155 of \mathcal{P} .

156 Performance and quality comparison

160 In Fig. 10 we compare the paths generated by the old and the new method. We
161 can see that the paths produced by the new method have no kinks. We also

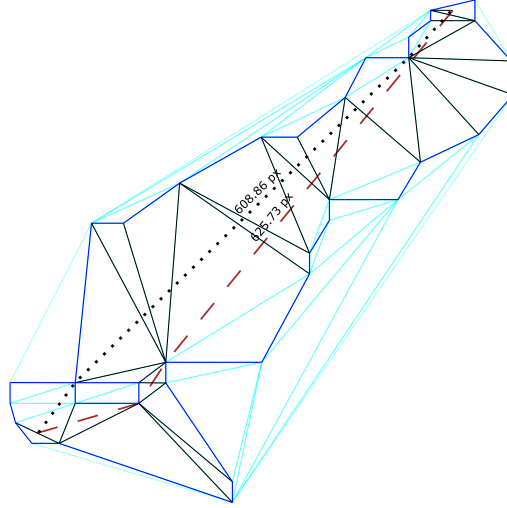


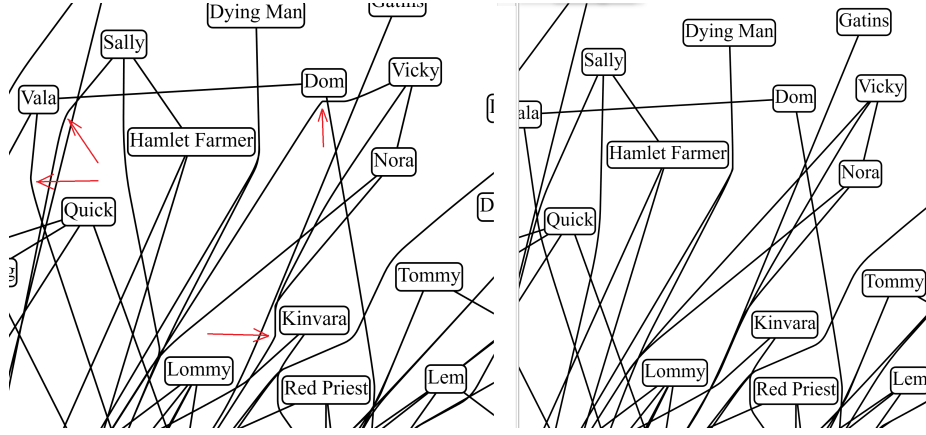
Fig. 9. \mathcal{P} is not simple. The dotted path is shorter than the dashed one that was found by the routing.

know that these paths are the shortest in their 'channels'. Arguably, the new method produces better paths.

Our performance experiments are summarized in Table. 1. We see that the older approach outperforms the new one on the smaller graphs; those with the number of nodes under 2000. The new method is faster on the rest of the graphs. We still prefer to use the new method independently of the graph size since the slowdown is insignificant, under half of a second in our experiments, but the quality of the paths is better. On the larger graphs the new method runs faster and produces better paths, so it is an obvious choice.

graph	nodes	edges	old method's time	new time
social network [19]	407	2639	1.0	1.4
b103 [20]	944	2438	1.6	2.0
b100 [21]	1463	5806	5.6	5.785
composers [22]	3405	13832	510.5	17.5
p2p-Gnutella04 [23]	10876	39994	375.4	293.8
facebook_combined [24]	4039	88234	132.2	119.1
lastfm_asia_edges [25]	7626	27807	43.3	41.4
deezer-europe_edges [25]	28283	92753	1596.9	1209.3
ca-HepPh [26]	12008	237010	521.2	495.0

Table 1. Performance comparison with time in seconds.



157 **Fig. 10.** The difference in the paths between the old, on the left, and the new,
 158 on the right, paths. The arrows on the left fragment point to the kinks that were
 159 removed by the new method.

181 1 Tiling

182 The algorithm works in three phases. The first phase builds the levels starting
 183 from the lowest level and proceeding to higher and more detailed levels, with
 184 smaller tiles, until no more tile subdivision is required.

185 The second phase processes the levels in the reverse order, by filtering the
 186 entities out to satisfy the capacity quota.

187 Finally, the third phase simplifies the edge routes to utilize the space freed
 188 by the filtered out entities.

189 A tile, in our settings, is a pair $(rect, tiledata)$, where $rect$ is the rectangle
 190 of the tile and $tiledata$ is a set of elements visible in $rect$. An element could
 191 be a node, an edge label, an edge arrowhead, or a *edge clip*. An edge clip is a
 192 pair (e, p) , where e is an edge and p is a continuous piece of the edge curve c_e .
 193 Sometimes we need several edge clips to trace an edge through a tile.

194 The initial tile, the only tile on level 0, is represented by pair $(0, 0)$. For
 195 $z = 1$, there are four tiles: $(0, 0)$, $(0, 1)$, $(1, 0)$, and $(1, 1)$. Each tile (i, j) can be
 196 subdivided into four subtiles for level $z + 1$: $(2i, 2j)$, $(2i, 2j + 1)$, $(2i + 1, 2j)$, and
 197 $(2i + 1, 2j + 1)$.

198 Each z -level is represented by a map L_z , so $L_z(i, j)$ gives us a specific tile.
 199 Empty tiles correspond to undefined $L_z(i, j)$.

200 Edge clips are used to represent the edge intersections with the tiles and
 201 provide the renderer with the minimal geometry that is sufficient to render a
 202 tile. To ensure this we require property \mathcal{F} :

- 203 a) For each tile t , for each curve clip $(e, p) \in t.tiledata$, $p \subset t.rect$ and p might
- 204 cross the boundary of the $t.rect$ only at endpoints of p .
- 205 b) For each edge e , the union of all p for all $(e, p) \in t.tiledata$ is equal to
- 206 $c_e \cap t.rect$.

207 First phase of tiling

208 The first phase starts with $L_0 = \{(0, 0) \rightarrow (rect, tiledata)\}$: and $tiledata$ comprising curve clips (e, c_e) , for all edges e of the graph, all graph nodes, all edge labels, and all edge arrowheads. We ensure property \mathcal{F} by setting $rect$ to a padded bounding box of the graph, so each edge curve does not intersect the boundary of $rect$.

213 Let us assume that L_z is already constructed and \mathcal{F} holds for its tiles. To build level L_{z+1} we divide each tile $t = L_z(i, j)$ into four subtiles of equal size. For each node, arrowhead, or edge label of $t.tiledata$, if the bounding box of the element intersects the subtile's rectangle then we add the element to the subtile $tiledata$.

218 The edge clip treatment is more involved. Let (e, p) be a curve clip belonging to tile t . We find all intersections of curve p with the horizontal midline and the vertical midline of $t.rect$. Each intersection can be represented as $p[t_j]$. We sort sequence $u = [start, \dots, t_j, \dots, end]$, where $[start, end]$ is the parameter domain of p , in ascending order, and remove the duplicates.

223 Next we create curve clips $(e, l_k) = (e, trim(p, u_k, u_{k+1}))$, as shown in Fig 11. We assign each curve clip (e, l_k) to the subtile with the rectangle containing the bounding box of l_k .

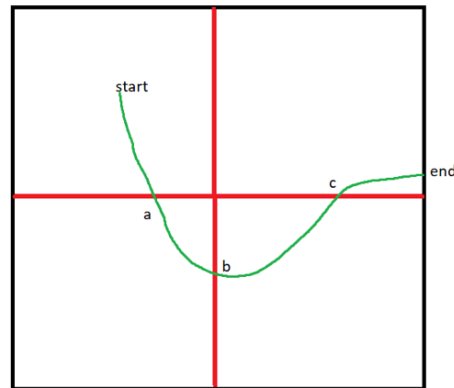
229 Because, by the induction assumption property \mathcal{F} is true on L_z , and by construction, each new curve clip can cross the boundary of the subtile only at the clip endpoints. We also cover all the intersections of p with the subtiles with the new edge clips, so the property \mathcal{F} holds for L_{z+1} .

233 Two parameters control the algorithm: tile capacity, \mathcal{C} , and the minimal size of a tile: $(\mathcal{W}, \mathcal{H})$. If for each (i, j) the number of elements in $L_z(i, j).tiledata$ is not greater than \mathcal{C} , or, if $w \leq \mathcal{W}$ and $h \leq \mathcal{H}$, where w (h) is the current tile width (correspondingly, height), then the second phase starts.

237 In our setting $\mathcal{C} = 500$, and $(\mathcal{W}, \mathcal{H}) = 3(w, h)$, where w is the average width and h is the average height of the nodes of the graph.

239 **Edge bundling** In our settings each edge clip is uniquely defined, module direction, by its start and end point. We can use this property to bundle the edges. In each tile we keep a map from unordered pairs of points to the set of edge clips that have these points as start and end points. Each such pair defines an edge bundle. For all edge clips in a bundle we create only one curve segment, avoiding the expensive trimming. We also count a bundle as one element in the tile capacity quota, as in most of the cases the drawing attributes of the edges in the bundle are the same.

247 In our experiments, the number of edge bundles is about 50% of the number of edge clips, so the edge bundling is a significant optimization.



226 **Fig. 11.** Intersect curve $[start, end]$ with the midlines. Sort the intersections pa-
 227 rameters together with start, and end into array $u = [start, a, b, c, end]$. Split the
 228 curve to sub-curves $[start, a]$, $[a, b]$, $[b, c]$, $[c, end]$.

249 Second phase of tiling

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