3D Graph Drawings: Good Viewing for an Occluded Edges

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Abstract
The growing studies show that the human brain can comprehend increasingly complex structures if they are displayed as objects in three dimensional spaces. In addition to that, recent trends of information technology advances have led to the yielding of a lot of data, and consequently have led to many large and complex models of 3D graph drawings in many domains. 3D graph drawing and presentation techniques are combined available at interactive speed. Even large graphs with hundreds of vertices can be meaningfully displayed by enhancing the presentation with additional attributes of graph drawings and the possibility of interactive user navigation.

Good Drawing (Visualization) resolves the problems of the occluded structures of the graph drawings and amplifies human understanding, thus leading to new insights of information visualization.

The aim of this paper is to describe our work, which usesa force-directed algorithm as a framework to address problem edge-edge occlusions. The yielding three dimensional graph drawings conform to various standard criteria layout aesthetics of good viewing graphs. The implementation of the work is done by Gephi package, which has built-in force directed layout algorithms, specifically Fruchterman and Reingold approach. We interactively visualize many 3D graphs of different size and complexity to support our method. The result shows that our work is capable of producing good viewpoints for 3D graph drawing,by usingFruchterman and Reingold algorithm.

Keywords – 3D Graph Drawings, 3D Graph Visualization, Edge-edge Occlusion, force-directed layout, Good Viewpoint, Gephi**.**

1. Introduction

The field of graph drawing is a basic visualization tool of relational information of a graph in space. For graphs with large size of vertices and edges, there are many effective techniques available. Traditionally, graph drawing research has concentrated on creating two-dimensional drawings. However, in this decade, researchers have begun to explore and analyzes the possibilities offered by three dimensional data are often made by means of dimension reduction techniques, since experiments suggest that people can fully comprehend information more efficiently when it is presented in three dimensional representations because it convey information, provide a meaningful mapping of data in such low dimensional spaces [18], [10].

Unfortunately, the past ten years of 3D graph drawing research has had very little impact on the graph drawing industry. Even though these 3D algorithms are theoretically significant, none of them have been adopted by the commercial graph drawing software providers. However, achieving good 3D visualization is, in fact, quite a challenging problems due to the occlusion and navigation problems involved, these problems often dissolve the effectiveness of the three dimensional graph drawings [14].

We focus on the problem of drawing an undirected graph with straight-line edges. By using force-directed methods. These methods generate drawings of graph in the plane so that each edge is represented by a straight line connecting its two adjacent vertices. The computation of the drawings is based on associating graph with a physical model. Then, the algorithms iteratively try to find the placements of the vertices so that the total energy of the physical system is minimal. Several forcedirected methods can visualize large graphs containingmany thousands of vertices in reasonable time [12].

In this paper, we address the problem of edge-edge occlusions for 3D graph drawings. The drawing of a graph to produce good viewing conforms to the following aesthetic criteria[19]: nonzero angular resolution, maximization of (average) angular resolution, symmetry, and uniform edge length. In addition, the efficiency of the drawing algorithm is also factored into our design. Note that our initial input drawing is a random drawing.

The resulting final layout of the force-directed approach brings the system to equilibrium, where the total force on each vertex is zero, or equivalently, the potential energy is locally minimal with respect to the vertex positions. Regarding the drawing standard, force-directed methods draw the edges as straight-line segments, so the whole issue reduces to the problem of positioning the vertices. For some known algorithms are those of [8],[9],[7]. Major advantages of force-directed methods are their relatively simple implementation and their flexibility (heuristic improvements are easily added)[13].

In this paper, we propose model that is based upon*Fruchterman and Reingold*algorithm [9], that is, a force directed layout algorithm, for obtaining good viewpoints of three dimensional graph drawings. The model aims to draw a 3D graph a good viewpoints on three dimensional plane placing vertices and edges of the graph on the screen by calculating forces on vertices, in order to produce a pleasant arrangement that allows simplifying the understanding of the graph.

Our method draws graphs without edge-edge occlusions that means there is no zero angular resolution between incident edges. In the model, the repulsive forces applied to a graph are caused by adjacent vertices and the attractive forces of edges (springs) push out the occluded edges.

The experimental results of applying our method on sets of 3D graphs,provideevidence that our method is capable of producing 3D drawing that have good viewingwithout edge-edge occlusions,and also preventing zero angular resolution, havinglarger average angular resolution.

The rest of this paper is organized as follows. Section 2 gives some related works.

In Section 3, our method is introduced in depth. Section 4 gives a variety of experimental results. Finally, a conclusion is given in Section 5.

2. Related Work

In this section, we outline the published work on force-directed graph drawing.

There are several graph drawing methods that use force-directed approaches for examples, Chernobelskiy et al [5] described two algorithms that use force-directed, spring-embedding approach algorithms to create Lombardi drawings that have edge better angular resolution and nice aesthetic placement for both vertices and edges.

Kamada and Kawai [17] model the forces slightly differently, with springs following Hooke's law, between every pair of vertices. These forces are a potential forces to replace the force formula, and the optimization procedure tries to minimize the total energy of the system. A preprocessing step sets the strength of each spring proportional to the graph theoretic distance between its end vertices. From this they derive an objective function for optimal placement of a vertex based on the combined springs from all the other vertex. They solve for each vertices in turn using a Newton-Raphson method and move the node to the optimal position found. Of course moving a vertex changes the forces affecting vertices already considered, so this algorithm must also be run iteratively until the layout converges to a stable state.

Sugiyama et al[22]used force directed method that based on magnetic forces. The method replaces the edges of a graph by magnetized springs, and gives a global magnetic field that acts on the springs. It gives three basic types of magnetic fields (parallel, radial, concentric) to control the orientation of the edges, and hence can generate drawings with different good viewing.

The resulting drawing of the force directed methods can reduce visual complexity and occlusion, and ease navigation. For examples: Ware[25] designs 2.5D uses depth selectively and pays special attention to 2D layout may provide the best match with the limited 3D capabilities of the human visual system. The model examined by the PolyPlane methods, the resulting drawing can reduce visual complexity and occlusion, and ease navigation. Poorna [20] proposed a method to detect edge by using a computation method called Modulation Transfer Function (MTF), her method showed how to automatically explore edge profiling for large graphs' datasets.

3. Force-Directed Approach to Edge- edge occlusion

In this section, we present a force-directed graph layout method for edge-edge occlusions. Graph layout methods, such as the Fruchterman and Reingold algorithm [9], are used to place the vertices and edges of the graph on three dimensional space, in order to minimize the number of edges occlusion, thereby achieving an aesthetically pleasing layout and got good viewing of 3D graph drawings.

3.1 Force-Directed Approaches

Force-directed graphdrawing methods consist of two components: A force model that consists of physical objects (e.g., repelling particles, springs), seeFigure 1, which are related with the givengraph G = (V,E) and an algorithm that tries to compute a placement of the vertices in theplane so that the total energy of the related physical system has a local minimum value.The underlying assumption is that the energyminimum states of suitable defined physicalsystems will correspond to good drawings.

The quality criteria for graph drawing widely used for graph drawings to be good viewing and have aesthetic pleasing are the following[3]:

- All vertices should be clearly separated,
- Vertices connected by an edge should be placed nearby each other to
  Prevent edges that are too long,
- Edge crossings should be minimized, and
- The available space should be used in an optimal way.

Graphs that are drawn by force directed layout approaches with few edge-edge occlusions appear as a two dimensional projection of a three dimensional view, these properties motivate us to use force directed layout approaches to construct 3D graph drawings, that had aesthetic layouts of general undirected graphs and their presentation with interactive speed.

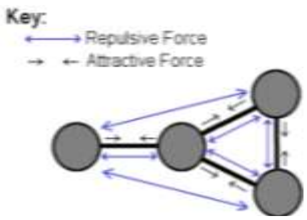


Figure 1: shows repulsive and attractive forces between vertices

3.2 Force-directed layout Applications

There are a lot of applications on force-directed methods [19], e.g.:

- The visualization of distributed mobile object environments.
- Online dynamic graph drawing.
- Drawings of metro maps.
- Drawings of time-varying graphs.

3.3 Fruchterman and Reingold algorithm

The algorithm represents each vertex as an electrically charged element and each edge as a spring linking two vertices. In this system, vertices with the same charge repel each other, while opposites attract due to the springs. This algorithm iteratively computes a displacement for each vertex determined by the forces until convergence to equilibrium is obtained [9], [2].

The repulsive force exists between any two vertices is inversely proportional to the distance between them. On the other hand, the attractive force exists only between neighboring vertices and is proportional to the square of the distance [16].

Let d_{uv} denote the Euclidean distance between two vertices v and u. Then the attractive force, $\mathbf{f_a}$, and the repulsive force, $\mathbf{f_r}$, are calculated as follows:

$$f_a = \frac{-k^2}{d_{uv}} \qquad \text{Equation (1)}$$

$$f_r = \frac{d_{uv}}{k} \qquad \text{Equation (2)}$$

$$k = C\sqrt{\frac{area}{number\ of\ vertices}} \qquad \text{Equation (3)}$$

Where k is a constant proportional to the square root of the ratio of the area where the graph is laid out to the number of vertices, C is an experimented constant. The Fruchterman and Reingold algorithm is applied for several iterations; during each iteration, the vertices are moved in proportion to the calculated attractive and repulsive forces until the desired drawings is obtained. Many implementations of $\mathbf{f_r}$ use a temperature component that limits the maximum displacement of a vertex. As the iterations progress, the temperature becomes lower, in effect allowing finer adjustments to the positions of the vertices [9].

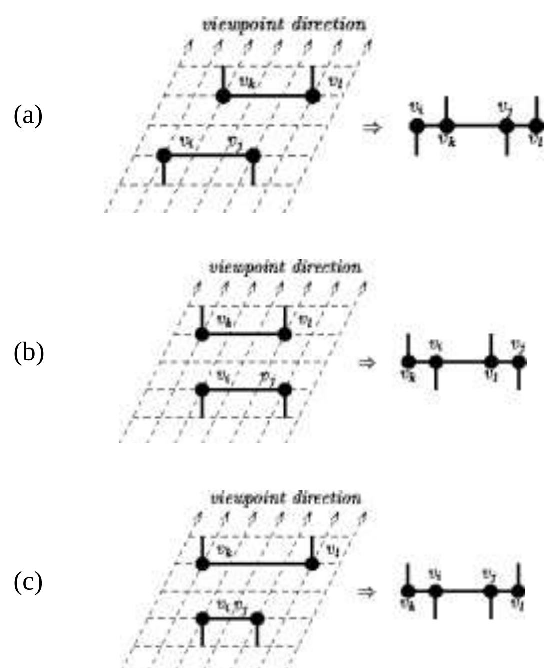
3.4 Good Viewpoints

Good viewpoints are those for which the abstract graph of the three-dimensional graph drawing, and the apparent abstract graph of the resulting two-dimensional image, are the same; without edge-edge occlusions. In application of three dimensional graph drawings, the drawings are intended to convey information to the user. This information is encoded in the graph drawing by a set of primitive relationships, between vertices and edges. A user recognizes these relationships by applying cognitive procedures that query the representations of the graph drawing, and constructa semantic interpretation (a mental map) [15].

3.5 Edge-Edge Occlusions:

There are two typesof edge-edge occlusions. The first one occurs when a pair of edges from the three-dimensional graph drawing map to a pair of edges that cross at a single internal point in the twodimensional drawing. This type, edge-edge occlusions, are called crossing occlusions, or simply edge crossings [15], [8].

The second type of edge-edge occlusions, called *significant edge-edge occlusions*, occur when two edges of the three-dimensional graph drawing map to a pair of edges that share a line segment in twodimensional drawing. Our study focuses on the second one, significant edge-edge occlusions, for shortcut, we point to this occlusions only edge-edge occlusions (see Figure 2).



(d)

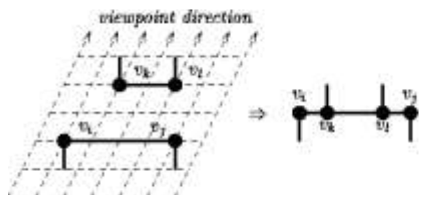


Figure 2: Four general variants of significant edge-edge occlusions (these figures are taken from[15], [8]).

Our method to address the problem of edge-edge occlusions, based onFruchterman and Reingold algorithm, the algorithm is included in Gephi software [11], the approach visualizes graph drawings with a separation of vertices and edges of the graph drawings in a way helps readability of graph, which makes the layout of the drawing much clear.To get a good 3D drawing, good viewing, that has no edge-edge occlusions, Gephi, Fruchterman and Reingold algorithm, assigns a force to each vertex and aims to minimize the overall energy of the system. The repulsive forces affect adjacent vertices positions and automatically taking away the occluded edges that connected the adjacent vertices, this process is done automatically by Gephi making uniformly edges and makes the angle between adjacent edges wider; throughout the drawing area. On the other hand attractive force pulls vertices connected by edges closer together.Finally, a drawing without edge-edge occlusion is generated when the operation is reaching a converged point(threshold), equilibrium state, between repulsive and attractive forces.The provided user interface of Gephi enables the usersto explore the layout of graph by available transformation operations (Rotation, Translation and scaling). In addition, a vertices and edges of graph drawing may be changed theirs attributes by the submenus of Gephi,these lead to complete perception of a 3Dgraphfrom a 2D graph drawing.

The graphs' data set are taken from [25] and processed by Gephi,Fruchterman and Reingold algorthim.

4. Results and Discussions

4.1 Implementation

We implemented Fruchterman and Reingold algorithm using the visualization capabilities of the Gephi application [11]. Our experiments on a windows system with an Intel Core i5 (3.20 GHz) processor and 4 GB RAM. The models of 3D graphs processed in this paper are different types of graphs.

The Gephi software package[11] written in Java on the NetBeans platform[1], The Gephi Consortium is a French non-profit corporation which supports development of future releases of Gephi. Gephi is members includeSciencesPo, Linkfluence, WebAtlas, and Quid [6]. Gephi is an interactive visualization platform for all kinds of graphs, networks, and complex systems, dynamic and hierarchical graphs.

There are controls for the graph drawing speed, gravity and iteration that aid three dimensional perception. Gephi application enables us to change graph drawing attributes like size and colors of the vertices and edges.

Several 3D graph drawings produced by Gephi, fruchterman and Reigold approach are included in 4.2 section for some sets of 3D graphs.

Table 1: lists the data of 3D graphs that have been taken from [25], the graphs have edge-edge occlusions. We use Gephi application to check the graphs and got the graph properties that are shown in Table 1, these properties reflect number of vertices, edges, the connected components, shorted paths, graph density and average degree of graphs.

Graph	Graph Type	No.of Vertices	No.of edges	Connected Components	Number of shortest paths	Graph Density	Average Degree
celegansneural	Undirected	297	2148	296	87912	0.049	14.465
cond-mat	Undirected	16726	47594	1188	192121892	0.000	5.691
lesmis	Undirected	77	254	76	5852	0.087	6.597
netscience	Undirected	1589	2742	1193	152274	0.002	3.451
Polbooks	Undirected	105	441	104	10920	0.081	8.400
power	Undirected	4941	6594	4940	24408540	0.001	2.669

Table 1: Statistics taken by Gephi application (Description of test problems)

4.2 Discussions

Experiment results show that the efficiency and effectiveness Fruchterman and Reingold algorithm in addressing edge-edge occlusions of 3D graph drawings for that graphs that are shown in Table 1. Thus, the algorithm is good at separating edges (angular resolution>0) as much as possible in the drawing space. In Figure 3(a), (c), (e), (g), (i), and (k), intuitively, 3D graph drawings which haveedge-edge occlusions, whereas Figure 3(b), (d), (f), (h), (j), and (l), the graph drawingshave no edge-edge occlusions, (approximately, edges do not occlude each other in general).

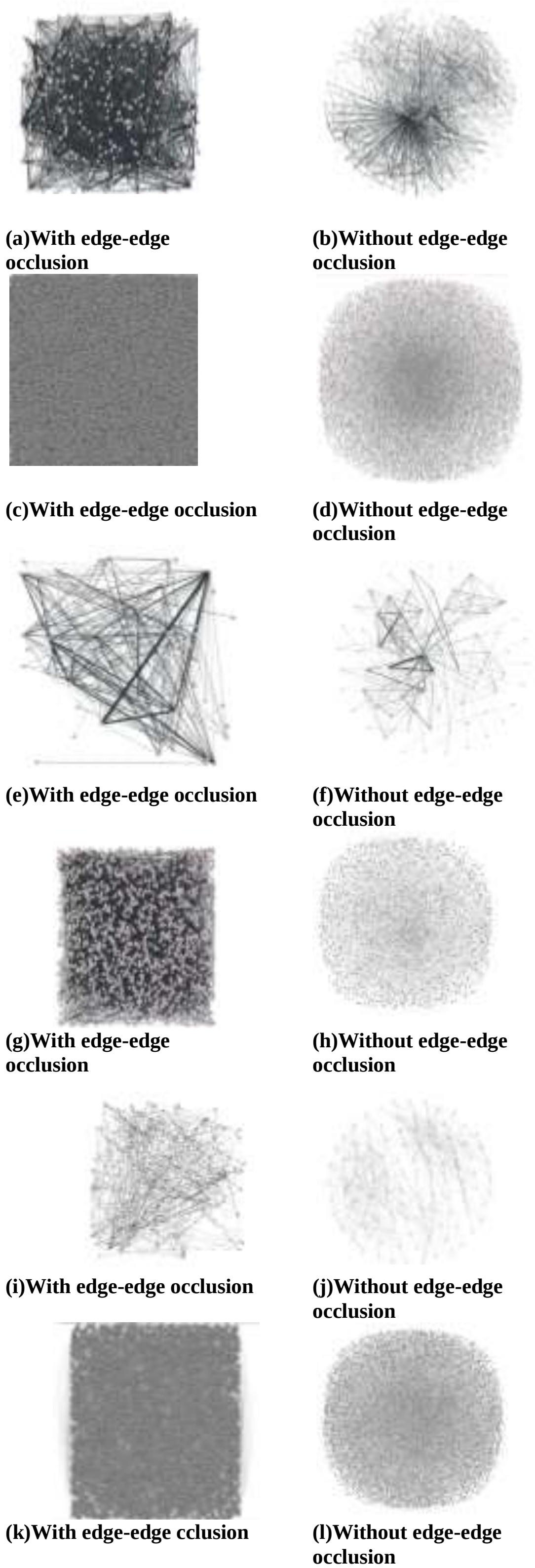


Figure 3: Snapshots of the 3D graph drawings

It is worthy to point out that if the drawing of each iteration of Fruchterman and Reingold method is rendered, the exploring process allows the user to interact the drawing, which meets the requirements in graphdrawing.

5. Conclusions

In this paper, we propose a method to address the problem of edge-edge occlusions for three dimensional graphs, the method uses Fruchterman Reingold algorithm for drawing three dimensional graphs for sets of 3D graphs that had been taken from [24]. We also have discussed the other various graph drawings techniques, specifically forced directed layout approaches which could draw good viewpoints of three dimensional graph drawings. Since good viewing of graph drawings brings a lot of advantages in understanding and readability of the graph drawing that conforms to criteria of aesthetics for graph drawing.

We applied Gephi to real-world graphs data. The results show that the algorithm draws 3D drawings by providing the viewer with good graph drawings viewing, by positioning interconnected vertices into well separated positions without edges occlusions. The interacting and exploring of the drawings with combined attributes (colors, sizes of vertices) enables viewers to have drawings with good viewings. Further, we restricted our attention to edge-edge occlusion, but we may consider the same problem for different classes of graphs. In addition, conventional force-directed methods cannot guarantee the generation of good drawings for all kinds of graphs because the repulsive forces among some vertices (rings) might be too weak or too strong.

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