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3D Graph Drawings: Good Viewing for Occluded Vertices

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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 technological advances have led to the production of a lot of data, and consequently have led to many large and complex models of 3D graph drawings in many domains. Good Drawing (Visualization) resolves the problems of the occluded structures of the graph drawings and amplifies human understanding, thus leading to new insights, findings and predictions.
We present method for drawing 3D graphs which uses a force-directed algorithm as a framework.
The main result of this work is that, 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.
In the implementation, we interactively visualize many 3D graphs of different size and complexity to support our method. We show that Gephi Software is capable of producing good viewpoints for 3D graph drawing, by its built-in force directed layout algorithms.
Keywords:3D Graph Drawings, 3D Graph Visualization, Vertex-Vertex Occlusion, Good Viewpoint, Gephi.

I. Introduction

The field of graph drawing is a basic visualization tool. For graphs of up to hundreds of nodes(vertices) and edges, there are many effective techniques available. The visualization of relational information as a drawing of a graph in space. Traditionally, graph drawing research has concentrated on creating two-dimensional drawings. However, in this decade, researchers have begun to explore and analyze the possibilities offered by three dimensional data are often made by means of dimension reduction techniques, that means three-dimensional graph drawing is mapped to a two-dimensional image via a projection.

Experiments suggest that people can 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 is the issue [5], [16].

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 [12].

We focus on the problem of drawing graph with straight-line edges. By using an approach of force-directed algorithms which are the most effective techniques for handling undirected graphs, the algorithms are based on virtual physical models.

Force-directed approach introduces a heuristic and an energy functionto map the graph drawing, by achieves its local minimum when the layout is nice. Variants of this approach differ in the definition of the energy, and in the optimization method that finds its minimum.

The final resulting layout of the force-directed approach brings the system to equilibrium(conversion), where the total forces 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 [15], [4], [2]. Major advantages of force-directed methods are their relatively simple implementation and their flexibility (heuristic improvements are easily added), but there are some problems with them too. One severe problem is the difficulty of minimizing the energy function when dealing with large graphs. The above methods focus on graphs of up to 100 vertices. For larger graphs the convergence to a minimum, if possible at all, is very slow [10].

In this paper, we propose a model that is based uponFruchterman manReingoldalgorithm [4] to address the problem of vertex-vertex occlusions of three dimensional graph drawings. Fruchterman and Reingold algorithm is a force directed layout algorithm. Our model produces good viewpoints of three dimensional graph drawings without vertex-

vertex occlusions. The model aims to draw a 3D graph that has a good viewpoints on three dimensional plane placing vertices and edges of the graph on the screen by computing forces on vertices, in order to produce a pleasant arrangement that allows simplifying the understanding of the graph.

The rest of the paper is organized as follows. Section 2, reviews related work. In Section 3, we present our method that based on Fruchterman and Reingold algorithm [4] for three dimensional graph. Section 4, discusses the results, and describes the quality of the resulting drawings on the layout side. Finally, we give some conclusions and describe future research in Section 5.

II. Related Work

The problem of the occlusion in graph drawing (graph visualization) has beenstudied for many years, in this section, we outline the published work on force-directed graph drawing.

Affordable high quality 3D graphics in every PC has motivated a great deal of research in 3D graph drawing over the last ten years. The proceedings of theannual Graph Drawing conferences document these developments [8].

There are many examined with the force directed methods, the resulting drawing can reduce visual complexity and occlusion, and ease navigation. For examples:

Ware[19] 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. Kamada and Kawai [15] model the forces slightly differently, with springs following Hooke's law, between every pair of nodes. A preprocessing step sets the strength of each spring proportional to the graph theoretic distance between its end nodes. From this they derive an objective function for optimal placement of a node(vertex) based on the combined springs from all the other nodes. They solve for each node in turn using a Newton-Raphson method and move the node to the optimal position found. The process moving a vertex changes the forces affecting vertices, so this algorithm must also be run iteratively until the layout reaches a converged point. On the other hand, Fruchterman and Reingold [4] modified Eades' algorithm to more closely approximate the physical analogy of electrostatic repulsive force between any two nodes u and v, at positions p_u and p_v respectively.

III. Force-Directed Approach to Vertex-vertex occlusion

In this section, we present a force-directed graph layout method for vertex-vertex occlusion. Graphlayout methods, such as the Fruchterman and Reingoldalgorithm [4], are used to place the vertices and edgesof the graph on a two- (or three-) dimensional space. In order to address the problem of vertex-vertex occlusion, we propose a model that based on Fruchterman and Reingold algorithm, to draw a graph that has an aesthetically pleasing layout.

3.1 Fruchterman and Reingold algorithm

The algorithm is the force directed layout that 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 a convergence (equilibrium) is obtained [4], [18].

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 [14].

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:

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

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

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. The Fruchterman and Reingold algorithm is applied for several iterations. During each iteration, the vertices are moved in proportion to the calculated attractive or repulsive forces until the desired layout 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.

3.2 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. In application of threedimensional 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. A user recognizes these relationships by applying cognitive routines that query their intermediatelevel representation of the graph drawing, and build up a semantic interpretation (a mental map)[13], [3], [17].

3.3 Vertex-Vertex Occlusions

Generally, occlusions occur when a projection maps two three-dimensional points to the same two dimensional point. We say the front point occludes the rear point. The concept of occlusion underlies many models of good viewpoints [13].

A good projection of 3D graph drawings to 2D graph drawings should prevent overlaps between the graph elements, avoiding vertex-vertex, vertex-edge, and edge-edge occlusions [11].

We focus in this paper on one type of occlusions calledvertex-vertex occlusion, whichoccurs when a pair of vertices from the three-dimensional graph drawing map to a single vertex in the two-dimensional image. The abstract graph of the image appears to have a single vertex in place of the original two, and any edges incident to the original vertices now appear incident to the combined vertex (see Figure 1).

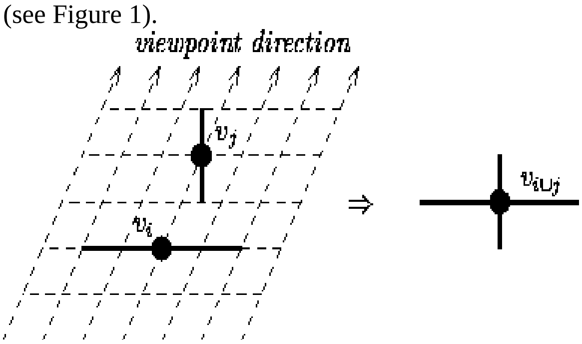


Figure 1: A vertex-vertex occlusion. [3]

It may be possible for a given 2D (or 3D) graph to be drawn in a plane (or a volume) without any vertex-vertex occlusion. Indeed, achieving such a graph layout is the objective of the Fruchterman and Reingoldalgorithm [4].

Similar to most force-directed layout algorithms, our method makes good viewing for 3D drawings that have vertex-vertex occlusions by assigns a force to each vertex and aims to minimize the overall energy of the system. Therepulsive forces affect adjacent vertices positions and each pair of vertices that connected by an edge, pushing vertices away in order to prevent occlusion between vertices and to spread the vertices out uniformly throughout the drawing area. On the other hand attractive force pulls vertices connected by edges closer together. It is applied to every pair of vertices connected by an edge (see Figure 2). The repulsive force pushes vertices apart. It is applied to every pair of vertices (see Figure 2).

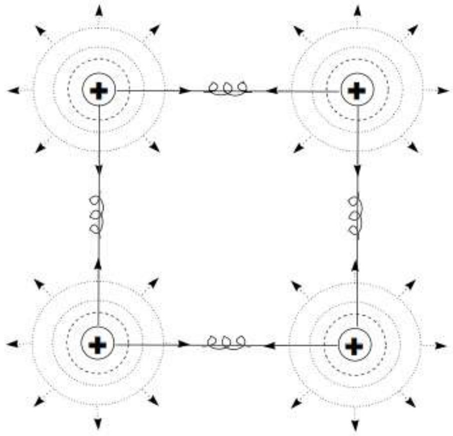


Figure 2: Repulsive and attractive forces of graphelements (vertices and edges)

The magnitudes of attractive and repulsion forces are calculated by equations (1, 2),We use Gephi software,Fruchterman and Reingold approach for computing these forces, that is found in section 4.

IV. Results and Discussions

4.1 Implementation

We implemented Fruchterman and Reingold algorithm using the visualization capabilities of the Gephi application [6],[1]. 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[6] 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[9]. Gephi is an interactive visualization platform for all kinds of graphs, 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 section 4.2 for some sets of 3D graphs.

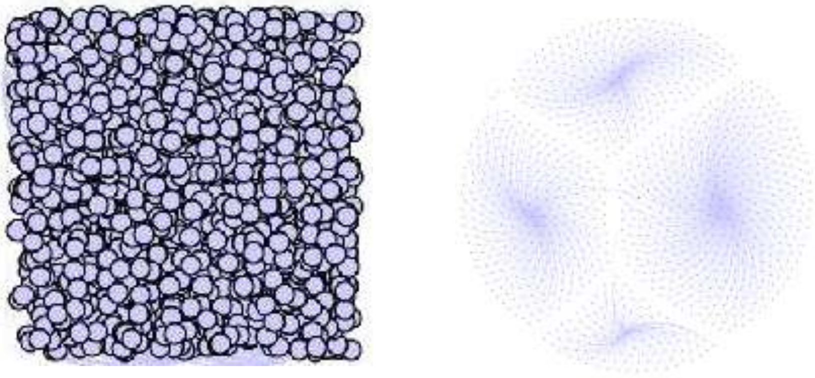
Table1liststhe data of 3D graphs that has been taken from [7], the graphs have vertex-vertex occlusions. We use Gephi application to check the graphsand got the graph properties that are shown in Table 1, these properties reflect number of vertices, edges, the connected components, shorted paths, graph density and average degree of graphs.

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

Graph	**Graph Type**	**|V |**	**|E|**	**Connected Components**	**Number of shortest paths**	**Graph Density**	**Average Degree**
phase1_chr1	Undirected	1097	1092	1097	351274	0.002	1.991
DAGmar1	directed	400	4240	400	44559	0.027	10.600
phase1_chr1	directed	1097	1092	1097	1092	0.001	0.995
DAGmar2	Undirected	400	4240	399	159600	0.053	21.200

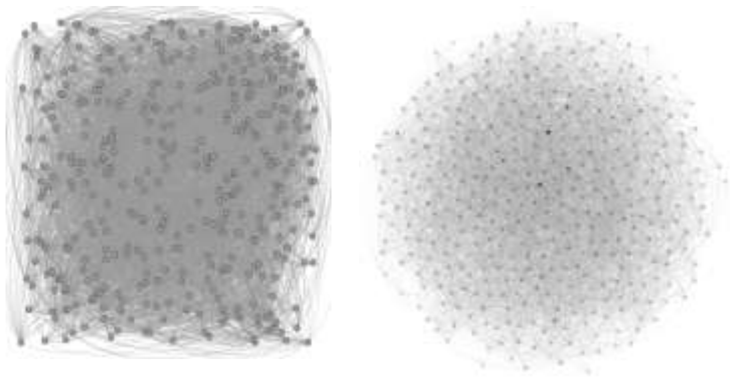
4.2 Discussions

Experiment results show that the efficiency and effectiveness Fruchterman and Reingold algorithm in addressing vertex-vertex occlusions of 3D graph drawings. Thus, algorithm is good at separating vertices as much as possible in the drawing space. In Figure 3(a), a 3D graph drawing (1097 vertices, 1092 edges) which has vertex-vertex occlusion, whereas in Figure3(b) the graph drawing has no vertex-vertex occlusion,(vertices do not occlude each other in general). Another example is 3D graph drawing (400 vertices, 4240 edges), Figure4(a),the graph suffers from vertex-vertex occlusion, whereas the 3D graph drawing in Figure 4(b)has good viewing after applying the algorithm.



(a)With vertex-vertex occlusion (b)Without vertex-vertex occlusion

Figure 3: Snapshots of the drawings of graphs



(a)With vertex-vertex occlusion (b)Without vertex-vertex occlusion

Figure 4: Snapshots of the drawings of graphs

V. Conclusions

In this paper,we propose a method to address the problem of vertex-vertex occlusions for three dimensional graphs. Our methoduses Fruchterman and Reingold algorithm for drawing three dimensional graphs forsets of 3D graphs that had been taken from [7]. We also have discussed the various graph drawings techniques, specifically forced directed layout approaches which could draw good viewpoints of three dimensional graph drawings by minimizing vertex-vertex occlusion. 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 [7]. The resultsshow that the algorithmdraws 3D drawings by providing the viewer with goodgraph drawings viewing. The algorithm positions interconnected vertices into wellseparated positions without vertices occlusions. The resulting drawings have good viewings,the exploring of 3D drawings is useful if combined with user interaction and graph attributes value such as the colorand the size of vertices.

Further, we restricted our attention to vertex-vertex occlusion, but we may consider the same problem for different classes of graphs.

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