GEOMI: GEOmetry for Maximum Insight

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Abstract. This paper describes the GEOMI system, a visual analysis tool for the visualisation and analysis of large and complex networks. GEOMI provides a collection of network analysis methods, graph layout algorithms and several graph navigation and interaction methods. GEOMI is part of a new generation of visual analysis tools combining graph visualisation techniques with network analysis methods. GEOMI is available from `http://www.cs.usyd.edu.au/~visual/valacon/geomi/`.

1 Introduction

The GEOMI system is a visual analysis tool for the visualisation and analysis of large and complex networks such as web-graphs, social networks, biological networks, sensor networks and transportation networks. Such visual analysis tools take advantage of the graphics capabilities of computers to support the analysis of network structure. Using GEOMI, one can visually explore networks and discover patterns and trends that can provide critical insights. GEOMI is being developed by VALACON (Visualisation and Analysis of Large and Complex Networks) project team members in the National ICT Australia (NICTA) IMAGEN program.

Figure 1 briefly describes the architecture of GEOMI. Its core consists of three main components: network analysis, graph layout and interaction, using an extended version of WilmaScope [1] as its graph visualisation library. GEOMI can easily be extended by various types of plug-ins. It integrates the JUNG library [2] as a plug-in to utilise its many network analysis algorithms. We also have added many new plug-ins for network analysis, graph layout as well as interaction methods. In summary, GEOMI currently provides the following functionalities:
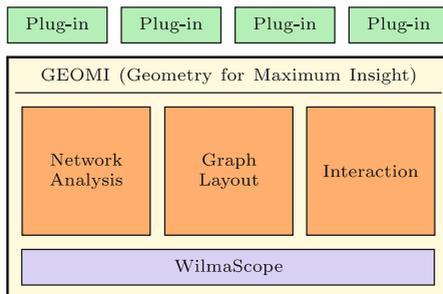
Fig. 1. The system architecture of GEOMI

1. Graph generators: clustered graph, clustered general graph, clustered tree, GML graph reader, grid, Erd.-Ren. random graph, scale-free graph, stratified graph, tree, CGF graph reader, random clustered graph converter.
2. Network analysis: shortest path/random walk betweenness centrality, closeness centrality, degree centrality, eccentricity centrality, eigenvector centrality, uniqueness centrality, 3D parallel coordinates, blockmodel, hierarchical centrality comparison, orbital centrality comparison, k-means clustering.
3. Graph algorithms: bi-connected components, biggest component, directed cycle removal, edge weight filter, longest path layering, parallel edge filter.
4. Graph layout: circular, clustered circular, clustered clone tree, clustered force directed, clustered free tree, clustered rod tree, column, cone tree, force directed, free tree, hierarchical, high-dimensional embedding, multiscale, random, rod tree, simulated annealing, spectral, stratified.
5. Interaction: HTML graph generator, head gesture interaction.

This paper is organised as follows: GEOMI's plug-ins for network analysis, graph layout, and interaction are presented in Sect. 2, 3, and 4, respectively. Section 5 concludes the paper.

2 Network Analysis Plug-Ins

2.1 Centrality Analysis

Centrality analysis is an effective tool to study graph nodes. The importance of nodes is measured by their degree, their neighbouring nodes, or other node/graph properties. Centrality analysis has found many applications in social and biological networks. The centralities implemented in GEOMI are listed in Sect. 1. GEOMI can map the results of centrality analysis to node visual attributes.

2.2 Centrality Comparison

Comparing the relative importance of a node in different centrality measures provides an overview of the node from different perspectives. Besides mapping centralities to various visual node attributes, three methods designed specifically for centrality comparison are implemented in GEOMI. See [3] for details.

3D Parallel Coordinates. This method treats every node with multiple centrality values as a multivariate data point. To demonstrate nodes sharing the same value, they are displayed using the third dimension. In Fig. 2, each axis represents a centrality measure and nodes with the same centrality value are shown in the third dimension. The graph used here is the "Krackhardt's Hightech managers" dataset, which is well-known in social network analysis.

Orbital Comparison. The idea of orbit-based comparison of centralities can be summarised as follows: copies of the analysed network are stacked, every copy
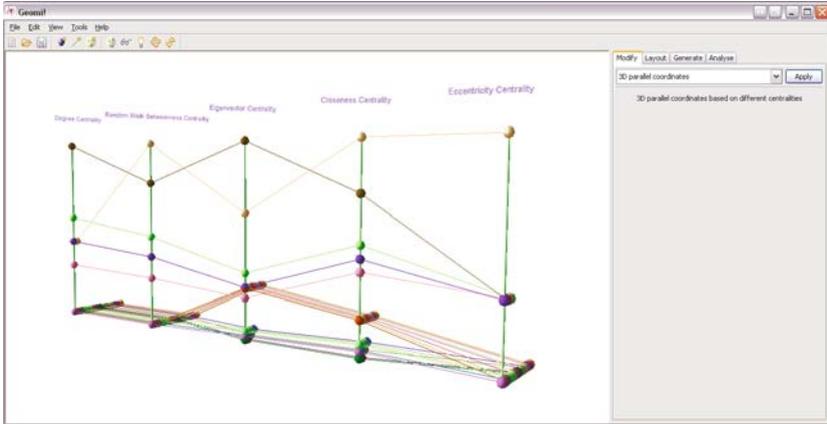

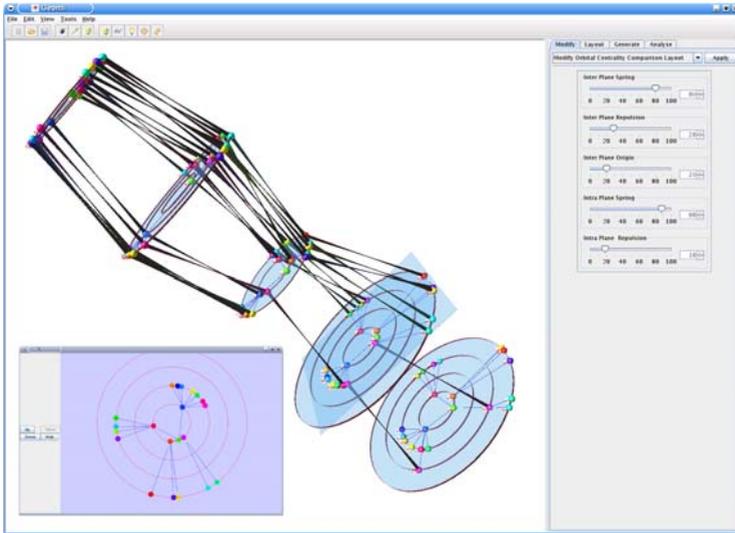**Fig. 2.** 3D parallel coordinates

Fig. 3. The created stack of networks with centralities used for orbital placement of the nodes. On the bottom left the detail view shows the highlighted plane and on the right side the layout modification plug-in controls are shown.
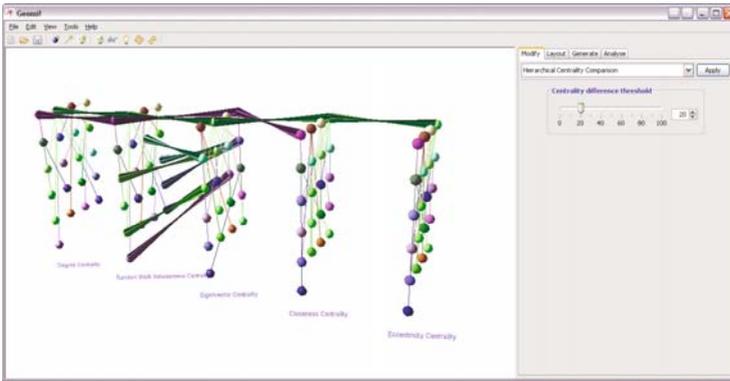
Fig. 4. Hierarchical comparison

is used to visualise one centrality measure and within a copy the nodes are placed on concentric circles depending on the centrality value of the vertex. Figure 3 shows an example. The dataset used here is the same as the one in Fig. 2.

Hierarchical Comparison. The hierarchal comparison is similar to orbital comparison, but uses a hierarchical layout instead. For each graph the layering is based on centrality values, i.e., nodes in the upper layer have larger centrality values than those in the lower layer. Within each layer nodes are ordered to reduce edge crossings. Figure 4 shows the result of hierarchical comparison. The user has the option to show nodes whose centrality value changes significantly between measures. In this example, edges are shown only if the centrality of the connected nodes differs by more than 20% in two consecutive measures.
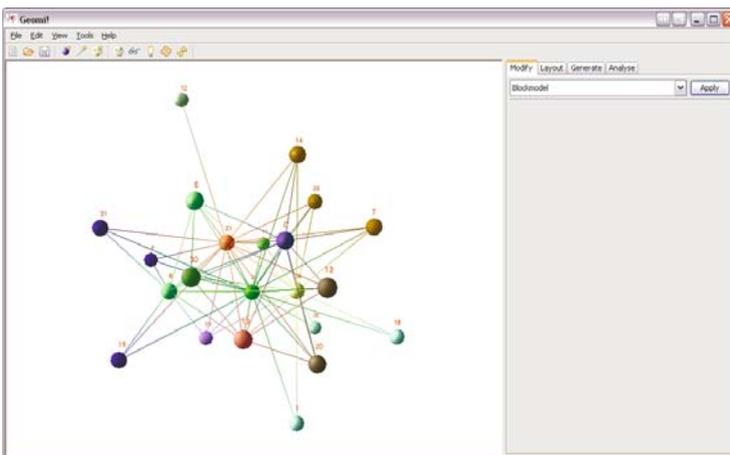

Fig. 5. Blockmodel analysis

2.3   Group Analysis

While centrality analysis focuses on the properties of individual nodes, group analysis focuses on the overall graph structure. One of the group analysis methods implemented in GEOMI is blockmodel [4], which groups nodes according to the graph structure associated with them. After blockmodel analysis, the nodes that are *structurally equivalent* are put into the same cluster. The implementation in GEOMI is that two nodes are structurally equivalent if they have the same neighbour set, which is the original definition for structural equivalence. In Fig. 5, same colour is assigned to nodes that are structurally equivalent.

3   Graph Layout Plug-Ins

3.1   Hierarchical Layout

The Hierarchical Layout plug-in implements the algorithm for drawing directed graphs in three dimensions [5], a 3D extension to the Sugiyama method which includes an additional step after the layering step. It further partition the layer into a set of $k > 1$ subsets, called *walls*. For details, see [5].

Currently the following algorithms are available for each step of the algorithm:

– Layer-assignment algorithms: longest-path, longest-path followed by node promotion, network simplex, minwidth. [6, 7]
– Wall-assignment algorithms: balanced min-cut, zig-zag, dominating wall, k-wall min-span, k-wall balanced. [8, 5]
– Node-ordering algorithms: layer-by-layer sweep with barycenter heuristic for two-layer crossing reduction.
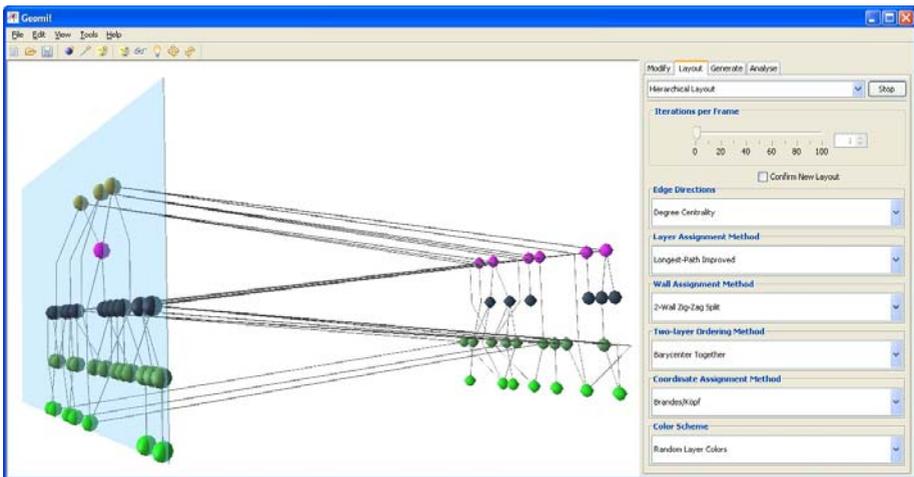– Horizontal assignment: Brandes-Köpf algorithm [9].

Fig. 6. HLP applied to one of the Rome graphs

An example of one of the Rome graphs with 62 nodes and 79 edges is illustrated in Figure 6. The algorithms used for each step of the extended Sugiyama method are listed in the dialogue box in right-hand side of the screen. The user can choose a method for each step of the algorithm. Further, the user can also choose a colour scheme for the hierarchical layout.

3.2   3D Tree Layout Plug-Ins

GEOMI supports three linear time 3D tree drawing algorithms that can support nodes with different sizes - namely *cone tree*, *rod tree* and *free tree* (see Fig. 7). This layout is also used for drawing clustered graphs in three dimensions. For details, see [10].
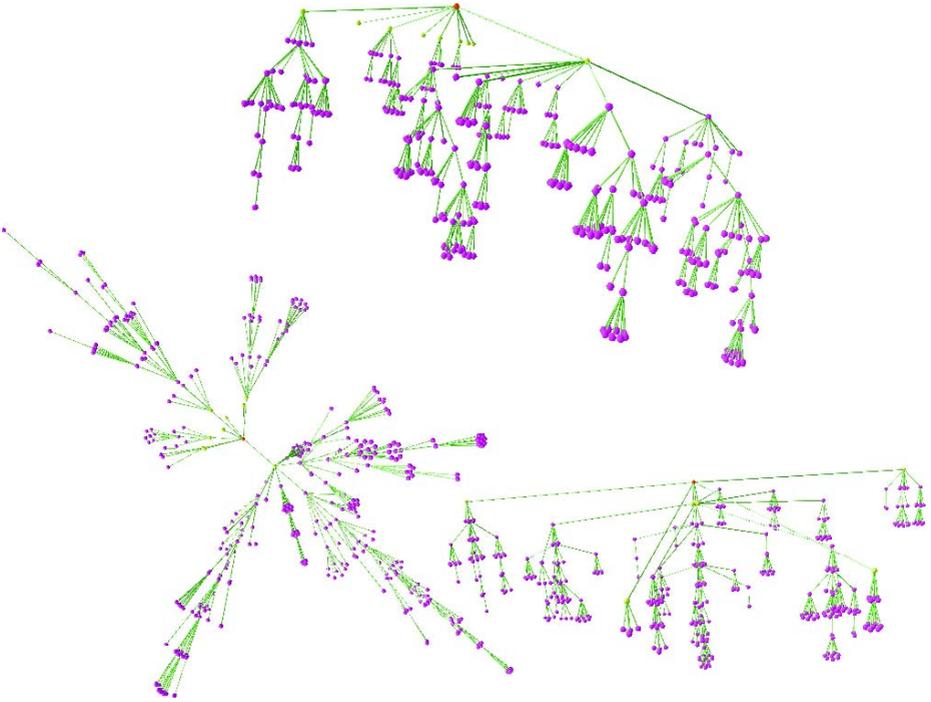

Fig. 7. Tree layout styles in GEOMI

If the given graph is not a tree, the plug-ins can automatically compute a spanning tree for the graph and compute the layout of the spanning tree. All non-tree edges are then added back to the final drawing.

3.3   Circular Layout Plug-In

A circular layout plug-in is implemented for visualisation of social networks using the two pass crossing reduction algorithm [11].

3.4   Clustered Graph Layout Plug-Ins

Clustered Graph Generator. A clustered graph in GEOMI can be generated in three ways. Firstly, it can be randomly generated. Two random clustered graph generators have been implemented to generate clustered trees and clustered general graphs. In both generators, the user can control the graph generation process by changing a number of parameters. Secondly, a clustered graph can be generated by reading from the clustered graph data file. Thirdly, a normal GEOMI graph can be converted into a clustered graph by applying a clustering algorithm.

Clustered Graph Layout. A series of six clustered graph layout plug-ins has been created by combinations of three 3D tree layouts and two 2D cluster layouts. It implements the four step method for drawing clustered graphs in 3D. For details, see [10].

The plug-in provides a control panel by using the super graph layout control panel as a sub-panel. This also consists of a general clustered graph layout control sub-panel that allow users to control the general clustered graph layout process. See Fig. 8 for an example.
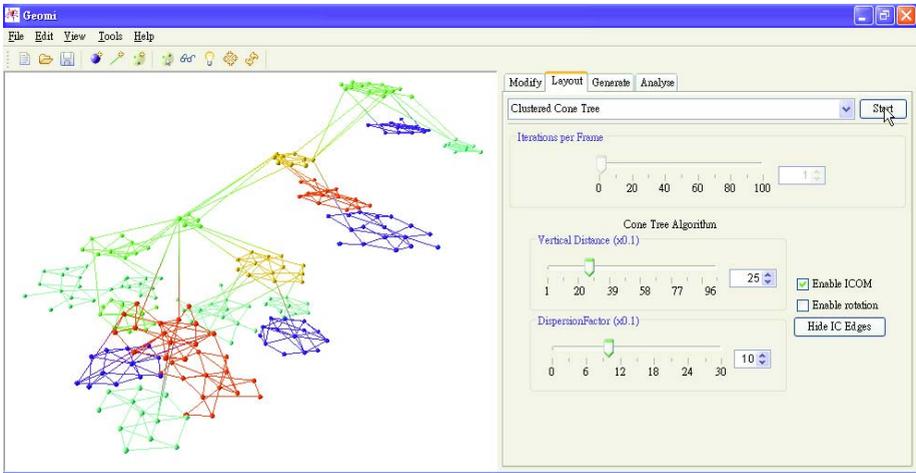

Fig. 8. A clustered graph layout plug-in. This example shows a layout that draws each cluster using circular layout and combined the whole clustered graph as cone tree.

3.5   Scale-Free Network Plug-In

The scale-free layout plug-in is an implementation of the FADE fast force directed algorithm allowing for interactive modification of the force parameters. It also allows for layering based on degree centrality which is particularly useful for visualisation of scale-free networks, see [12].

The edge force controls allow the user to turn edge forces on or off. It also allows for the resilience of the edges to be increased or decreased. Other options
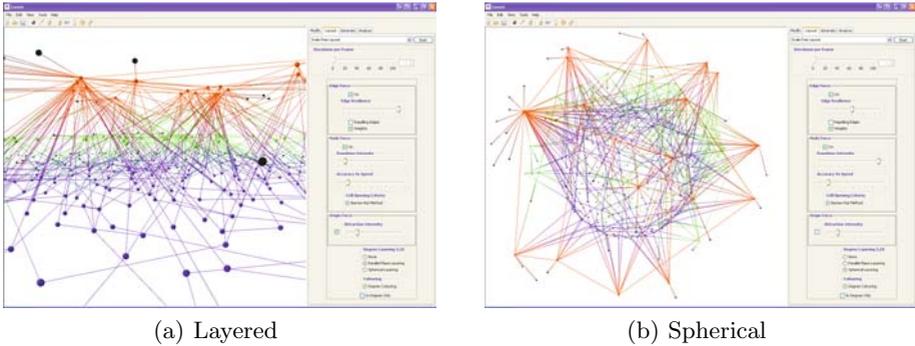
(a) Layered   (b) Spherical

Fig. 9. Scale-free plug-in

include the ability to have edges repel instead of attract and to use the weights associated with an edge in calculating the edge force.

The node force controls allow the user to turn node forces on or off. It also allows the user to modify the extent of the repulsion force as well as the accuracy parameter of the FADE algorithm, which allows for an accuracy vs speed trade-off. An attractive force towards the origin can also be turned on or off and modified.

The degree layering controls allow the user to restrict nodes to layers based on degree. The nodes can be restricted to either *parallel planes* (see Fig. 9(a)) or *concentric spheres* (see Fig. 9(b)). The nodes are partitioned into layers such that nodes with degree greater than or equal to 10 are at the highest layer and nodes with degree less than 5 are on the lowest layer. Single degree nodes are placed on their neighbour's level. The user can also select to colour the different partitions differently and can select to have only incoming edges count towards the degree total.

3.6   Temporal Network Plug-In

Temporal networks, which describe graph changes over time, attract growing research interests for their analysis. The $2\frac{1}{2}$D method is one of the solutions to represent temporal network data. In such a method, a graph snapshot at a particular time is placed on a 2D plane, in which a layout algorithm can be applied; a series of such planes are stacked together following time order to show the changes. In order to identify a particular node in different time plane, same nodes in different planes are connected by edges. Combined with navigation tools in GEOMI, users can trace the change of each individual node's relationship to others and also can evaluate the evolution of the whole network in general.

This method is implemented in GEOMI as a generator plug-in. It can convert a series of data files, with one file containing information of one time frame only, into GEOMI data structure, so that layout methods (force-directed layout by default) can be used. Potentially, all layout algorithms and analysis methods in GEOMI can be applied, even with different layout and in different plane.
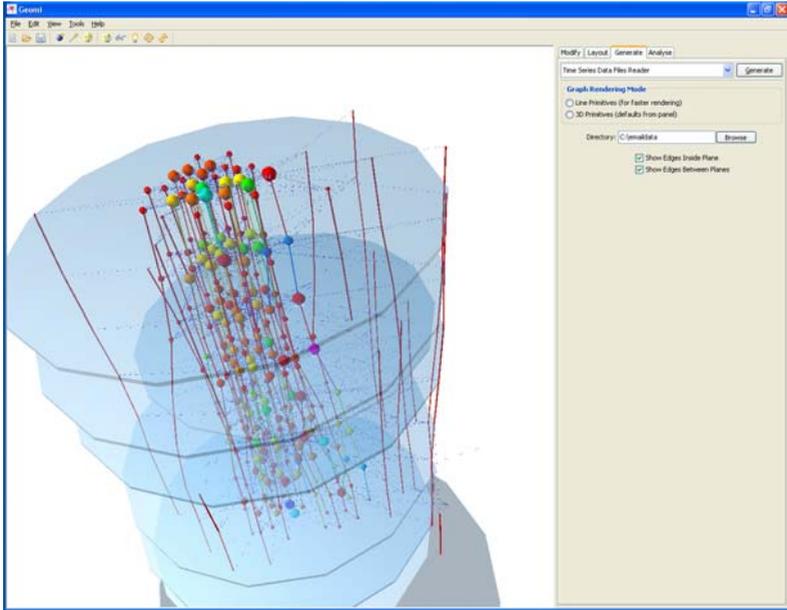
Fig. 10. Email connections of a research group represented in time series

As an example, Fig. 10 shows the email connections of a certain research group. Each plane represents one month while each node is one person. The edges between nodes in same plate shows the email traffic between person. In addition, degree centrality is mapped to node size while node colour represents betweenness centrality.

4   Interaction Plug-Ins

4.1   HTML Graph Generator

The HTML graph generator plug-in generates an undirected web-graph where web pages are represented by graph nodes and hyper-links are represented by edges between two nodes. Two nodes are connected by an edge if one is referenced by a hyper-link in the other. Given a URL and the depth of parsing, a web crawler is employed starting at the specified URL. A fetched web page is parsed for hyper-links and their respective web pages are acquired recursively. A graph node is added for every acquired page and edges are added accordingly. As the graph is being generated on the fly the force directed layout algorithm is started by default to calculate the layout of the dynamically growing graph.

The generated graph in conjunction with different centrality analysis tools may be used to extract website structural information. Various page properties may be defined and identified. In the initial web-graph, the high degree of the node indicates the most referencing pages, pages that have the most
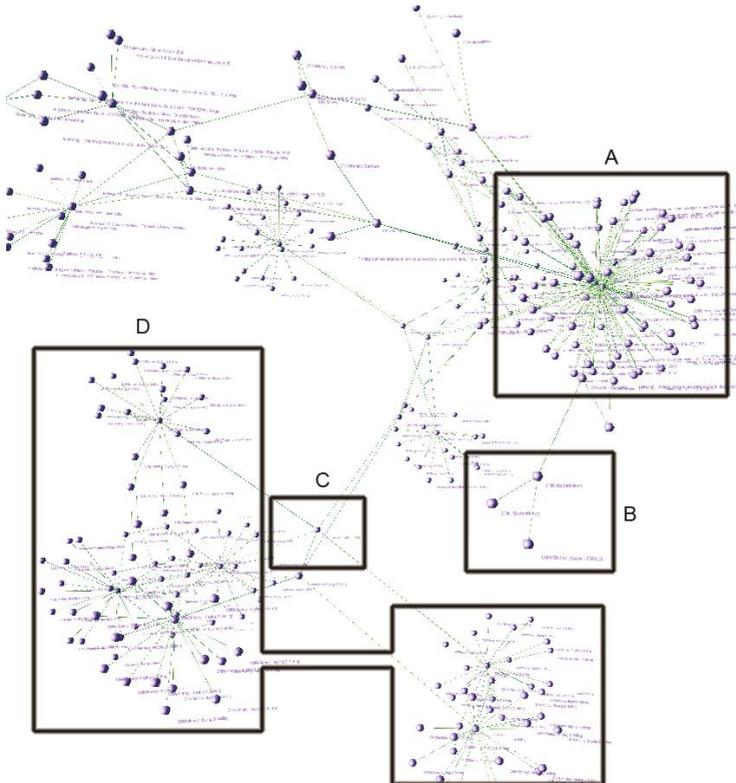
**Fig. 11.** Anatomy of the `http://www.cnn.com` page

hyper-links to other pages as shown in Fig. 11A. On the other hand, low de-
gree nodes or pendent nodes, shown in Fig. 11B, may express remote pages
access to them may not be easy or trivial from the root of the web-graph,
or the start URL. The web-graph may be used to categorize pages accord-
ing to some predefined conventions that identify the importance of a page.
For example the page shown in Fig. 11C is considered to be an important
one for if a user misses this page while navigating the website, all the infor-
mation in subgraph in Fig. 11D will be kept hidden from the user, in other
words, the user will not be aware of them. A demo movie is available from
`http://www.cs.usyd.edu.au/~visual/valacon/geomi/movies/`.

4.2   Head Gesture Plug-In

The head gesture plug-in allows immersive navigation of the data using 3D
head gestures instead of the classical mouse input. The plug-in relies on two
gesture recognition modules, receiving inputs from two low-cost web cameras
located orthogonally, one in front of the user, one on her/his side. See Fig. 12. A
demo movie is available from `http://www.cs.usyd.edu.au/~visual/valacon/`
`geomi/movies/`.
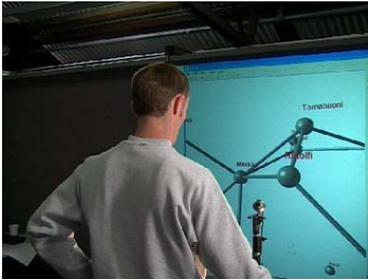
(a) Nodding down triggers a view from above
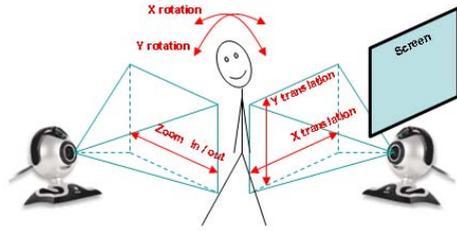
(b) 3D Gesture detection and corresponding actions

Fig. 12. GEOMI gesture plug-in

The user can literally walk into the network, move closer to nodes or clusters by simply aiming in their direction. Nodding and tilting the head rotate the entire network along the X and Y axis respectively. The command mapping is as follows:

Head movement	Navigation
Horizontal sideways	Mirrored X translation
Vertical up/down	Mirrored Y translation
Horizontal back/forth (towards screen)	Zoom out/in
Nodding up/down	X rotation
Tilting left/right	Y rotation

5   Conclusion

GEOMI is a generic visual analysis tool and can be extended to a special tool for visual analysis of biological networks or social networks. We will add more analysis methods, graph algorithms and layout methods including interaction methods. The analysis methods include social network analysis and graph mining methods. Layouts methods include implementation of algorithms for various graph models such as planar graphs and general graphs, and network models such as evolution networks and dynamic networks. Interaction methods include navigation methods and various user interactions.

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