Network Visualization*

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Abstract

As communication networks increase in performance and complexity, and more dependence is placed upon them, it becomes ever more important that their behaviour is understood in an efficient and timely manner. Visualisation is an established technique for the presentation of the vast volume of data yielded in monitoring such networks. It is apparent, however, that much of the work in this area has been performed in isolation, and it is timely that a review of this research is conducted. This paper surveys the techniques for the visualisation of communication networks and related measurements. The research is classified by the type of visualisation used, and is separated into three classes: geographic visualisations, where the data is presented with respect to the physical location of nodes in the network; abstract topological visualisations, where the relationships between nodes are presented independently of

*The spelling 'visualisation' is used throughout this document, however, as most of the work on this subject uses the 'ize' spelling, the title has been left in this form

physical location; and plot-based visualisation, where the focus is a single point in the network, often presented with respect to time. The research in this area is reviewed and the techniques proposed are discussed in terms of the three classes.

1 Introduction

It is important for the behaviour of a communication network to be understood by its operators and users. This understanding has to be accurate and performed in an efficient and timely manner, especially as networks become more complex, have higher performance and more dependence is placed on them. Monitoring of communication network behaviour yields vast volumes of data, related to many aspects of operation, such as current utilisation, device status and fault reports. This paper surveys techniques for the visualisation of communication network data.

Visualisation, or pictorial representation, is an established technique for the presentation of large sets of data, or of data with complex relationships. However, the appropriate presentation of data is critical [1, 2]. Whilst research has been underway to apply the idea of visualisation to network performance measurement, this work has often been conducted in isolation, and it is timely that a review of this research is conducted. This review paper summarises the research conducted to date and will provide a reference and starting point for researchers attempting to extend visualisation approaches to future high performance networks.

The paper suggests that current network performance visualisation techniques can be grouped into three classes: geographic visualisations, where importance is placed on the physical location of the measurements; abstract topological visualisations, where the relationship between measurements is the focus; and plot-based visualisations, where the the focus is usually a single point in the network, often represented with respect to time. The literature on this subject is reviewed and the techniques proposed are discussed in terms of the three classes.

This review of network visualisation techniques was undertaken as part of the EPSRC-funded UKLight[1] MASTS (Measurement at All Scales in Time and Space) project [3]. The goals of the project are to measure the evolution of the topology and traffic in and around the UKLight Network.

2 Guidelines for Developing Visualisation Tools

This section introduces general methods for creating information visualisation systems.

A useful starting point for designing advanced graphical user interfaces is the 'Visual Information-seeking Mantra': Overview first, zoom and filter, then details-on-demand. Shneiderman [4] identifies seven abstract user tasks for information visualisations:

Overview — To view the entire data set.

Zoom —To focus on specific areas of the data set.

Filter — To remove items unrelated to the current task.

Details-on-demand — To get complete information about a single item or small group of items.

Relate — To see relationships in the data set.

[1] http://www.uklight.ac.uk/ – Last visited October 2005

History — Allowing undo, replay and progressive refinement of tasks.

Extract — Allowing subsets of the data, and query parameters, to be retrieved.

He also defines seven data types (1-, 2-, 3-dimensional data, temporal and multi-dimensional data, and tree and network data).

Building on the work of Shneiderman, Carr [5] surveys the area of information visualisation and discusses visualisation design techniques from a perspective based on Shneiderman's user-task taxonomy for information visualisation. He presents some design guidelines that should be considered when designing information-seeking applications based on visualisation techniques. Based on the work of Shneiderman (and other previous work), Carr describes seven general guidelines for visualisation design:

Visualisation is not always the best solution — If the goal of the user can be determined at design time, then an algorithmic solution will be faster and more accurate.

User tasks must be supported — Such as those from Shneiderman shown above.

The graphic method should depend on the data — For example, using the main data types given by Shneiderman.

Three dimensions are not necessarily better than two — Problems such as navigation, obscuring of the data from a given view point, and judging of relative sizes and distances can be problematic.

Navigation and zooming do not replace filtering — Users need to eliminate data items to concentrate on points of interest.

Multiple views should be coordinated — Changes within one window should be reflected, where appropriate, in other windows.

Test your designs with users — As it is difficult to guarantee good usability without testing.

In summary, there are various guidelines that can be followed when designing information visualisation systems, such as those of Shneiderman and Carr.

3 Network Visualisation

This review of network visualisation techniques has been roughly separated into three sections (with a small amount of overlap). These sections are geographic visualisations (those that present data with respect to the physical location of the nodes on the network), abstract topological visualisations (those that present relationships between nodes independently of the precise physical locations), and plot-based visualisations (those presented as a traditional line graph, histogram, or similar representation). This classification is a natural clustering of the research in this area. In addition, these classes of visualisation can loosely be matched to Shneiderman's Visual Information-seeking Mantra; with geographic visualisation giving the overview, abstract topological visualisations zooming in and filtering, and plot-based visualisations providing the details.

3.1 Geographic Network Visualisation

Geographic network visualisations are where the data are laid out with respect to the physical location of the entities being presented. This is usually in the form of a map with nodes and links (or vertices and edges) representing the structure of the network. This type of visualisation is not limited to viewing the network structure. Various information can be overlaid on the map, such as the utilisation of each link.

This section surveys a selection of approaches to geographic visualisation, with a particular focus on the type of data being viewed and how some of the issues have been overcome.

[Figure 1 about here.]

One of the most basic geographic visualisations is the 'Link map' [6]. This uses line segments between each pair of connected nodes in two dimensions (see Figure 1a). Colour and line thickness can be used to represent information about the links. For larger networks, with many links, the map becomes cluttered and unreadable. This can be partially overcome by drawing the interesting links last or by only drawing partial links (see Figure 1b). Becker *et al.* give examples of this technique for viewing overloaded links in a network and idle capacity. This visualisation is part of a tool called 'SeeNet'.

Another type of geographic visualisation from 'SeeNet' [7, 6, 8] is the 'Node map' [6]. This approach displays node oriented information using simple glyphs to represent information. Glyphs such as circles can be used for one dimensional information, rectangles for two, and more complex glyphs for higher dimensionality (see Figure 1c). Colour can also be used to add an extra dimension. Becker *et al.* again give an example of overload using rectangular glyphs with the horizontal size representing incoming connections and the vertical representing outgoing connections.

Melissargos and Pu [9] present a variation of the 'Link map' for the purpose of displaying load-per-link in a geographic network structure. The links are filled with dark grey in proportion to the load (starting from both ends of the link). The remaining part of the link is in light grey and represents the free capacity. Arcs are also drawn representing demands. These are represented as dashed lines if the demand is unallocated (see Figure 1d). This visualisation is used as part of a bandwidth allocation system for circuit-switched networks.

Cox *et al.* extend the work of Becker *et al.* with three-dimensional visualisations, in a tool called 'SeeNet3D' [10, 11, 12]. They present Internet traffic information on a globe representation of the Earth. This avoids some of the traditional issues of navigation in three dimensions, as users will be familiar with the context and the movement is limited to rotation and zooming. Each country in the network is shown as a histogram bar representing the total number of packets originating there. The inter-country links are shown as colour-coded arcs of varying height that represent the amount of traffic (from green for light traffic to red for heavy traffic) (see Figure 1e). Filtering and translucency are used to aid interpretation of the data.

Cox *et al.* also present a second type of geographic visualisation, the 'Arc map' [11]. This uses a two dimensional representation of the Earth with three dimensional arcs connecting the nodes (see Figure 1f). The height, colour and thickness of the arcs represent the information. This approach partly overcomes the problem of clutter in two dimensional representations when there is a large amount of data. The arc map also doesn't have the problem of the globe view, where parts of the data are obscured from different viewpoints.

In addition, this representation is not limited to views of the whole world. As previously, translucency and filtering can be used to aid interpretation of the data.

He and Eick [13, 14] later extend the work on SeeNet3D to a more general object-oriented framework for creating interactive network visualisations. The framework provides built-in views similar to those of SeeNet3D.

SeeNet3D, and the framework from He and Eick, is further built on by Nyarko *et al.* [15] in their Network Intrusion Visualisation Application (NIVA). NIVA integrates off-the-shelf intrusion detection systems (Real Secure and Black Ice) with the three dimensional visualisations to interactively investigate and detect structured attacks across both time and space.

There are several other geographic visualisations using the globe view.

Munzner *et al.* [16] used the globe view again but this time for displaying the tunnel structure of the MBone.

Lamm and Reed visualise point-to-point communication traffic [17, 18] in another globe-based view (as part of their 'Avatar' system), with arcs showing the communication using colour, height and line thickness.

They also present data from the origin of WWW requests as histogram bars at the request origin using coloured bands and different heights to represent the different parameters of the data [18]. The height shows the relative number of packets or requests originating at a given location and the coloured bands represent the distribution of document type, domain classes, servers or time intervals between requests (see Figure 1g).

Shaffer *et al.* [19] use another globe view (as part of 'Virtue'), which visualises Wide Area Network link latency, with some interesting interaction capabilities. A 'magic lens' allows additional data, about parts of the visualisation, to be viewed and a 'cutting plane' allows metrics to be computed on selected areas of the data where edges of the graph are bisected (for example, maximum latency or bandwidth across links).

Koutsofios *et al.* [20, 21, 22, 23] use geographic visualisation, from AT&T's 'Swift-3D', presenting three-dimensional histogram bars on the flat projection of the geographic area (the United States in this case). The bars represent traffic volume at various points in the network (see Figure 1h). This was primarily aimed at telephone data but the principles are the same.

In summary, both two-dimensional and three-dimensional geographic representations of network data exist. One type of geographic visualisation is the node and link visualisation that represents the structure of the network. The major issue with the node and link visualisation is the problem of clutter for large data sets. In two dimensions this can be overcome by drawing partial links or in three dimensions the height of the links can be varied for easier understanding. The other main type of geographic visualisation is the use of histogram bars. Both of these types of visualisation can be used in three dimensions, either on a globe view that overcomes some of the navigation issues in three dimensions, or on a flat map with three-dimensional links or histogram bars that allow smaller geographic areas to be viewed.

3.2 Abstract Topological Visualisation

Abstract Topological visualisations are where the data are laid out independent of the physical location of the entities being presented. These visualisations are mainly in the form of node and link diagrams, however, whereas the geographic visualisations are restricted by the physical location of the nodes, abstract topological visualisations can place the nodes in more readable or more meaningful locations.

This section surveys a selection of approaches to abstract topological visualisation, with particular focus on the type of data being viewed and how some of the issues have been overcome.

[Figure 2 about here.]

There is much work on the theory and practice of graph layout (see, for example, [24]). The following are specific applications to visualising communication network data.

Eick and Wills [25] present a tool for examining large hierarchical networks, called 'HierNet'. They show an example use of their tool for visualising email communication within a company. The visualisation is presented as a graph of nodes and links (see Figure 2a), with each node's area representing the number of messages sent or received and the colouring showing the role of the user in the company. The links are colour-coded by number of messages. The visualisation allows the main communication foci to be easily identified. A node placement algorithm based on the strength of the link between nodes is also presented. In addition, HierNet has several interaction methods, for example, querying the data and direct manipulation.

Huffaker *et al.* [26] present the CAIDA[2] tool 'Otter', a tool for visualising arbitrary network data presented as nodes, links or paths. Otter has been used for various data sets *e.g.* multicast and unicast topology, core BGP routing, reachability and delay, SNMP and website directory structure. The user can customise the visualisation and the user interface elements. The visualisation

[2] http://www.caida.org/ – Last visited March 2006

uses a two stage layout algorithm; placing the root nodes and then the rest. Placement is performed using a circular layout (around the circumference) or using predefined positions (*e.g.* latitude and longitude) (see Figure 2b). The node placement can be manually adjusted via the user interface along with various colour-coding options and zoom functionality.

Other CAIDA applications include Mapnet [27] (for the geographic display of backbone infrastructures of multiple US IP service providers), MantaRay [28] (which visualises MBone, the Internet multicast backbone), and Plankton [29] (a tool for visualising NLANR's IRCACHE web caching hierarchy [30]).

Cheswick *et al.* [31] use a simulated spring-force algorithm for the layout of routing and reachability data visualisations. They use huge test data sets (88k nodes, 100k links). The size of the graphs cause a problem. The layouts are well presented for small graphs but become cluttered for larger data sets. Colouring is used to show relevant data *e.g.* IP address, domain information, location, ISPs and locations of firewalls. The layout can be improved by plotting minimum distance spanning trees (throwing away edges) (see Figure 2c). The graphs have been used to show routing leaks, insecure regions in the network and to debug corporate routing tables.

Estrin *et al.* [32] present the tool 'Nam' for network designers. The tool shows packet level animations. These animations are usually from ns [33] traces but can also use preprocessed data from real sources. Nam usually runs in an offline mode but can use Unix pipes to provide a real-time view. The network topology is presented in various ways; for large data sets a spring-force algorithm is used, and for smaller data sets the layout is based on the link delay (longer links for longer delay values) with user specified link directions. The packets are shown as rectangles with arrows, and queues are arrays of squares above the transmitting node (see Figure 2d). The animations show the queues filling and emptying and the packets traversing the network. There is a problem when visualising packet loss as the input data doesn't specify when the packet was lost and so this information must be deduced from the input data. Nam has also been used to visualise higher-level network information such as the topology of the MBone.

Erbacher and Frinke [34, 35] use visualisation to display the behaviour of users using Hummer IDS (Intrusion Detection System) log files, for the detection of intrusion and misuse activities. The visualisation shows nodes representing machines and links representing their connections with each other. The style and colouring of the links represent the type of connection *e.g.* short dashed links represent anonymous FTP connections. All links are directed showing the direction of the connection. The nodes show the duration since the last active access by their intensity, and the number of users by protruding spikes (see Figure 2e).

Erbacher [36, 37] (and with Sobylak [38]) extends the previous work by Erbacher and Frinke to include both original log data and other intrusion detection and analysis results. Three main visualisation capabilities are provided: glyph-based animated layout, perceptually-based node layout algorithms, and static histogram-based historical view. Extensive interaction capabilities are also provided. Points in the network are represented by circular glyphs with spokes representing the number of users. Each spoke on a glyph represents ten users. The thickness of the inner circle on a glyph represents system load. Cross hashes represent the number of different users connecting between nodes, with their thickness representing the number of connections by that user. Links show the direction of connection, its state and type (see Figure 2f). The layout algorithm is based on a modified force-based graph layout where local nodes are attracted to the bottom whereas remote nodes are attracted to the top ring. These visualisation concepts are also extended to more general network visualisation e.g. bandwidth usage [39].

Munzner and Burchard [40] use 3D hyperbolic visualisations to display the structure of the World Wide Web (or more generally any directed graph with cycles). As hyperbolic space has 'more room' than Euclidean space, more information can be visualised (see Figure 2g). The visualisation is constructed to represent the hypertext links between web pages. They are presented in 3D (WebOOGL or VRML) and contain links to the original web pages.

Cox *et al.* [11] include several abstract topological visualisations as part of their 'SeeNet3D' tool. These visualisations are part of the Drill-Down features for looking at parts of the network in more detail and can be accessed via the geographic visualisations. The first of the abstract topological visualisations is a simple circular layout, with the node of interest in the middle and adjacent nodes positioned around the circumference of a circle (for example ordered alphabetically or by location). As previously, the information about the nodes is represented by the size and colour of the node (see Figure 2h). This visualisation approach only works well for small numbers of nodes.

The number of visible nodes can be enlarged through the use of 3D as in the second of the abstract topological visualisations. This visualisation presents the data in a 3D helix view (see Figure 2i). The view is the same as the circle when viewed from above but can support more nodes by manipulating the orientation of the helix to view different parts. The representation of the nodes is the same.

The final visualisation places the nodes on the surface of a sphere adjacent to a central node in the same manner as the previous two examples (see Figure 2j). This allows even more nodes to be presented and viewed interactively.

Brown *et al.* [41] use abstract topological visualisation as part of 'Cichlid' (a general-purpose network visualisation tool) for NLANR. The visualisation is in the form of node and link graphs, which can be interacted with in real time or exported in standard video formats or single-frame images at arbitrary resolutions. The nodes in the graph can be represented by various shapes and in different colours and size, and the links represented in different colours and thickness (see Figure 2k). Nodes can also have text labels. The graphs have been used to visualise latency between sites and showing network evolution over time. One of the failings of the tool (as noted by the authors) is its lack of intuitive user interface. The interface was, at the time of writing, a complex text-based interface. The major advantages of this system is the ability to easily develop visualisations for any data set, and the separation of the data server and the visualisation client.

Takada and Koike [42] present 'Tudumi', a log visualisation system to assist system administrators in the auditing of log files to detect intrusion and anomalous behaviour. The main focus of the system is to monitor servers used by small groups of users. It focuses on three main types of user activity: remote access of the server, logging into the server, and switching user accounts. The visualisation of this data is represented as a series of layered concentric disks. The bottom disk displays information about user switching and the remaining disks represent network access and log-in information. Each user is represented by a textured node (see Figure 2l).

In summary, abstract topological visualisations are, in general, node and link graphs in either two- or three-dimensions, which represent various aspects of the interaction between nodes in network data. As the restriction on the location of nodes for geographic visualisations is not an issue here, the information can be laid out in either a more readable way (if the graph is cluttered) or in some meaningful way by clustering related nodes.

3.3 Plot-based Network Visualisation

Plot-based visualisations are where the data are presented in a more traditional graph (such as a histograms, line graph or scatterplot). These generally represent a single point in the network (although some approaches present a grid of several plots simultaneously).

This section surveys a selection of approaches to plot-based visualisation, with a particular focus on the type of data being viewed and how some of the issues have been overcome.

[Figure 3 about here.]

Eick *et al.* [43] present a visualisation approach for viewing AT&T's 5ESS switch log files. Log files can be of the order of 50,000 lines and the visualisation allows an entire log to be shown in one screen. Each file is represented as a rectangle with 1-pixel thick lines representing a line of text. The visualisation colour-codes each line of text and provides interactive filters to show *e.g.* message frequency, time correlations, patterns of messages between processors. The lines are colour-coded based on the metric of interest (e.g. error, performance). The line length and indentation follow that of the log file (see Figure 3a). The system is implemented using SeeSoft [44] and can decrease analysis time by 80% over conventional methods, increasing efficiency.

Becker *et al.* [6] also present a plot-based visualisation with 'SeeNet' called the 'Matrix Display'. This visualisation concentrates on the links in the network, addressing two fundamental problems from the geographic network displays: long links are overly prominent and many links overlap each other, impeding readability. The data is presented as a matrix with all the nodes being represented in one row and one column. Links are represented by entries in the cell (i, j) or (j, i) or both depending on the direction of the link. If the link is not directed both cells will have the same value. Cell entries are small squares, colour-coded by latency. The order of the rows and columns are roughly geographical from west-to-east on the horizontal axis and north-to-south on the vertical (see Figure 3b). The main problem with this representation is the ambiguity of the row-column order.

Oetiker [45] presents MRTG (multi router traffic grapher). The router information is retrieved via SNMP and stored using RRD (the round robin database tool). It allows the production of graphs of any size covering arbitrary time periods. The plots are line graphs which can plot multiple statistics on one graph (colour-coded for each metric) and multiple graphs can be presented as part of an HTML page.

Vinas *et al.* [46] use MRTG for evaluating the Asian Internet Interconnection Initiative (AI3) satellite-based research network test bed.

Plonka [47] present an approach similar in appearance to MRTG, also using RRD with data gathered from Cisco's NetFlow. The system analyses and reports on data exported by routers. Graph images are produced providing a continuous, near real-time view of the network traffic using RRGrapher to generate the graphs. Metrics include flow-per-second, packets-per-second, and bytes-per-second over a default 48-hour period as traditional x-y line plots. The standard graphs provide views of the traffic by network or subnet, by application or service, and by Autonomous System (using colour-coding), but the system is highly configurable.

Pongsiri *et al.* [48] present a visualisation of network traffic that shows hourly traffic trends and the dependencies between traffic parameters, for viewing long-term traffic features that characterise Internet related traffic. Time of day, port and protocol (among others) are used as parameters for the visualisation. The visualisation has the interesting approach of binning packet size (and port number) for easier display on 3D plots, allowing the user to see trends in broad classes of the data (see Figure 3c). The packet size over time is plotted in two dimensions, and group packet size is plotted against their frequency over time in three.

Hall *et al.* [49] present a multi-protocol visualisation system that makes it possible to identify both inter- and intra-protocol behaviour. One of the visualisation methods used is a traditional style data plotter for scattergraphs, histograms and probability and cumulative density functions; with the added ability to view the raw data that relates to individual data points and information on how it was processed. In addition to the plotter is the 'TCP visualisation tool', which plots sequence numbers against time. Data segments are vertical lines scaled to the data length, acknowledgements are points, and additional useful data can also be shown. Colour-coding is used to give additional detail and plots, of *e.g.* delay, can be shown along side (see Figure 3d). The final visualisation is a 'web browser activity visualisation tool', which shows data transferred in an HTTP connection. Scaled horizontal lines represent data transmissions with ticks showing packet arrival times. Textual information is overlaid showing the URL and IP information (see Figure 3e).

Following on from the work of Chernoff [50], Parish *et al.* [51] consider visualisation of network performance data in an easy to assimilate form. An approach has been considered whereby an object's shape is distorted in proportion to the values of a set of measurement data. A casual viewing of the object therefore immediately indicates the relative values of the measurements. Delay and loss metrics are visualised using a Figural Deformity Visualisation (FDV), also know as Icon Plots. This works by deforming a given shape within a number of degrees of freedom in easily visible ways, in a manner similar to Chernoff faces. Each measurement is mapped to one of the degrees of freedom and the whole object will deform to the relative values of those measurements. The example given in the paper is of the letter 'E', where the degrees of freedom correspond to the current delay, the 50th percentile, the 95th percentile and the 99th percentile. Multiple FDVs are laid out in a two dimensional grid representing the ingress and egress of various nodes in a network, allowing the state of the network to be assessed at a glance (see Figure 3f).

Lakkaraju *et al.* [52] present NVisionIP, which provides a visualisation of an entire Class B network, allowing users to drill down and gather more details about hosts on the network. The system works at three levels of detail:

Galaxy View — The IP addresses of the machine are viewed in two dimensions with the X-coordinate representing the subnet and the Y-coordinate representing the machine. The colour of the point gives the number of active ports at a given time (see Figure 3g). Filtering of specific ports can be performed.

Small Multiple View — Presents more detailed views of the machines on a given subnet. Bar charts are shown for a selection of specific ports (see Figure 3h).

Machine View — Presents all the details of a specific machine.

NVisionIP uses Cisco Netflow as its data source.

Lamm and Reed [18] as part of their 'Avatar' system use a three-dimensional scattercube (a generalisation of two-dimensional scatterplots, supporting analysis of very high-dimensional, non-grid based, time varying data) for the presentation of server access data. The data are presented as coloured ribbons within a set of three dimensional axes (see Figure 3i).

Melissargos *et al.* [9], as part of their bandwidth allocation system, also present a matrix view, with either 2D grids or 3D histograms (see Figure 3j). The 2D grids contain either rectangles (split into dark and light sections representing allocated and unallocated capacity) or mini pie charts representing demands. The 3D histograms represent the same as the 2D, with either dark and light regions of a cylinder representing the allocated capacity of a link (with the height proportional to the total link capacity) or a cuboid representing demands. In the case of the 2D visualisations the two dimensions represent source and destination nodes and for the 3D the source, destination and capacity or demand.

Brown *et al.* [41] also use 3D bar charts as part of 'Cichlid' (for numeric quantities in two independent variables) with the added option of creating an interpolated surface from the bar chart. The bar charts have been used for matrices of delay between pairs of sites, traffic distribution over address blocks, and traffic volume by protocol source.

Lau [53] uses a 3D scatterplot in 'Spinning Cube of Potential Doom'. This creates an animated visualisation from Bro [54] data. The plot is of Local IP against Global IP against Port number with white dots representing successful TCP connections and coloured dots representing unsuccessful, where the colour varies with the port number (see Figure 3k).

In summary, plot-based visualisations are the most common type of network visualisation. Most of the plot-based visualisations are traditional histograms, line graphs and scatterplots in two- or three-dimensions, with a few more interesting approaches (such as Icon Plots). These generally present information about a single point in the network, although multiple plots are often presented simultaneously in a matrix (or grid) form, allowing a quick overview of larger sections of the network.

4 Summary

This paper has surveyed a wide selection of approaches to the visualisation of various aspects of communication networks. The visualisations have been grouped into three main classes:

Geographic visualisation — where the data is presented with respect to the physical location of the nodes in the network.

Abstract topological visualisation — where the main focus is the relationship between nodes in the network; and the presentation is independent of physical locations.

Plot-based visualisation — where the focus is often a single point in the network; and the presentation is, for example, a more traditional xy-plot or histogram.

The different approaches to visualising network data within these classes have been examined, along with the problems that have been overcome.

This paper has presented a number of separate visualisation techniques that currently have little or no integrating features. Future work will be to research an appropriate framework for expressing visualisation demands and a study of visualisation choice in different situations. A long-term aim is for a system to automatically present information in a manner appropriate to the data and the users. It will be important to consider the workflow and knowledge requirements of the users, so that presentation of the knowledge needed rather than simply displayed metrics is achieved.

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List of Figures

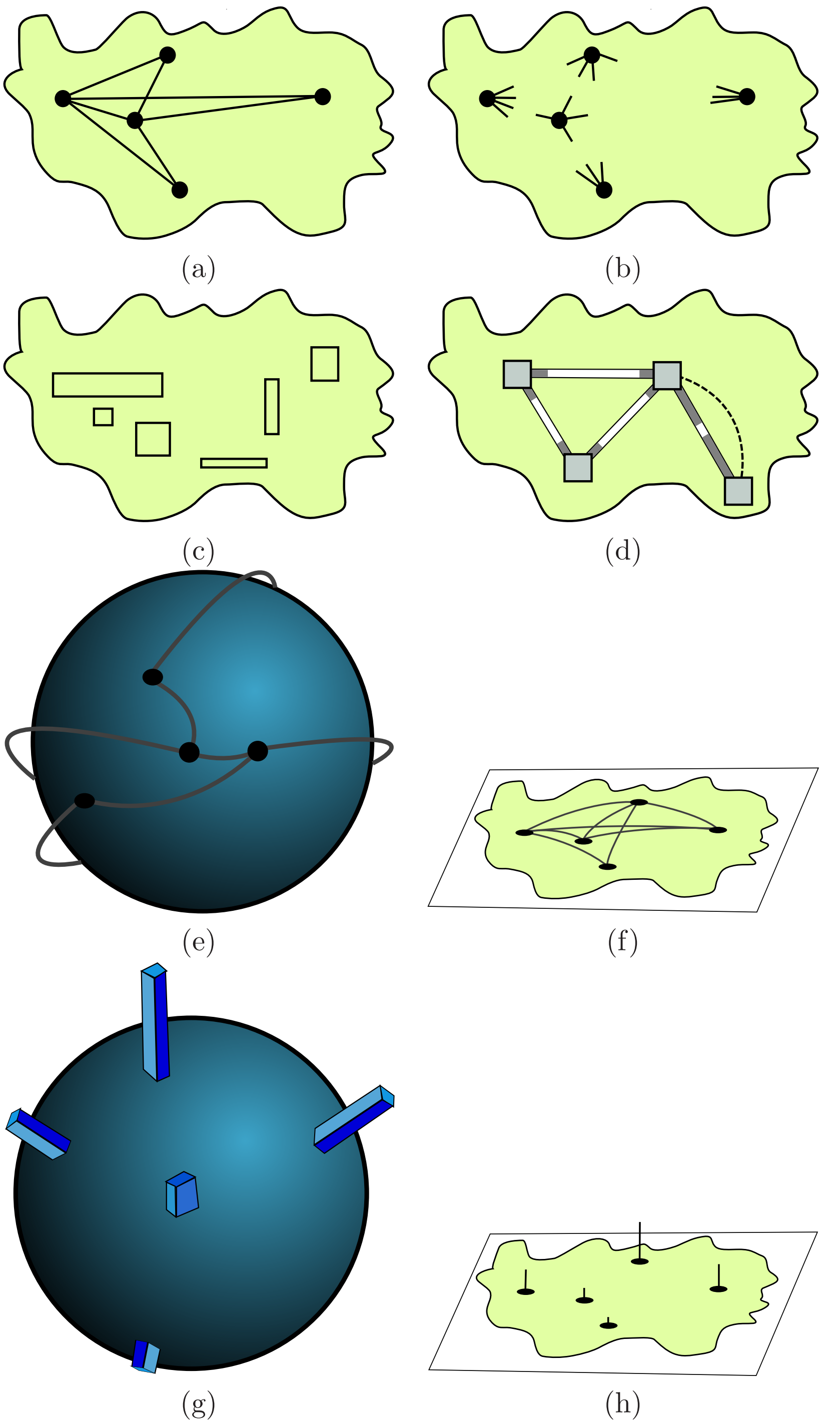
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Figure 1: Geographic Visualisations

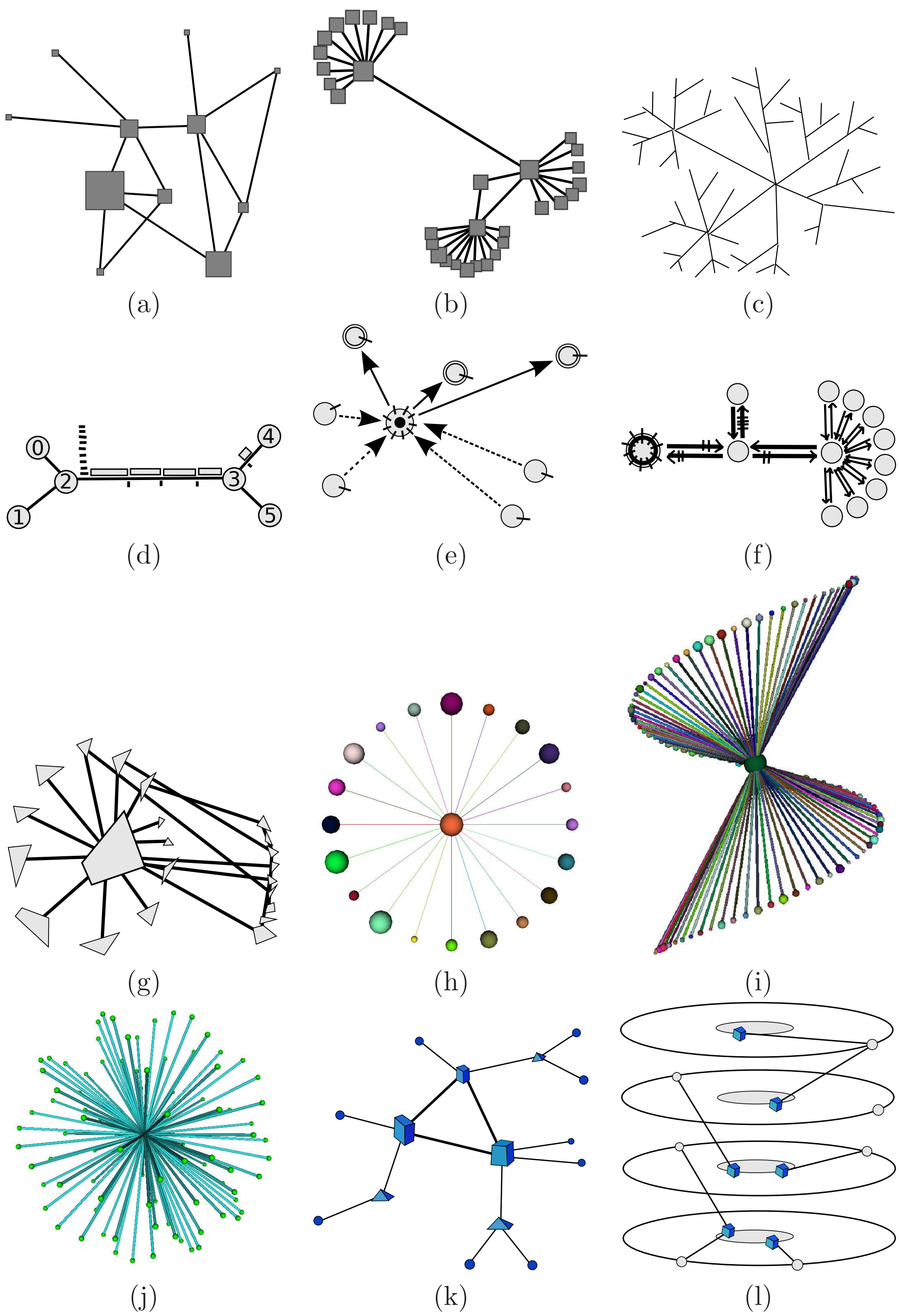

Figure 2: Abstract Topological Visualisations

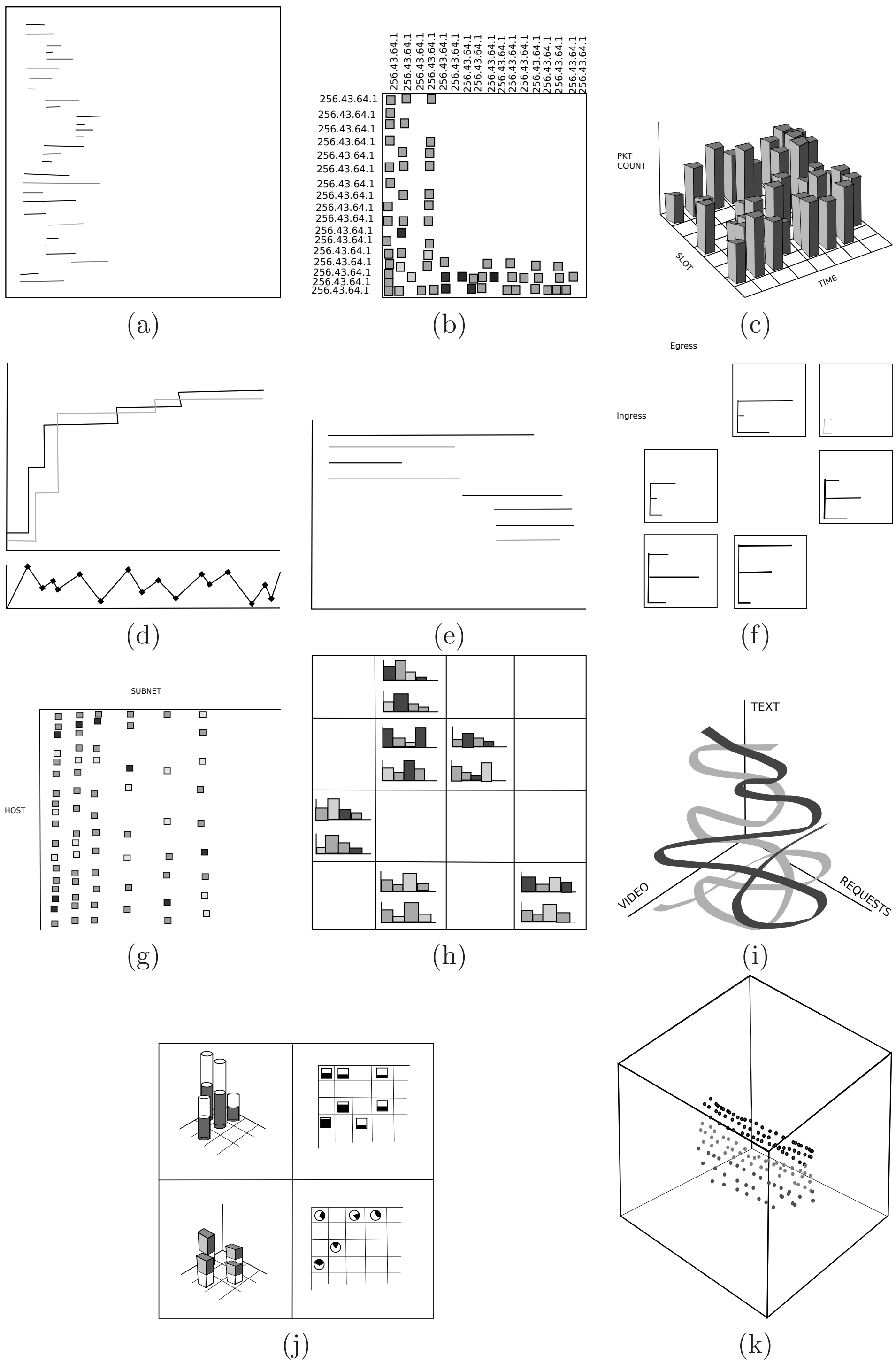

Figure 3: Plot-based Visualisations