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Mapping Cyberspace: Visualizing, Analysing and Exploring Virtual Worlds

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With the development of computer technologies such as the Internet and virtual reality, the notion of cyberspace has been emerging and it has been increasingly studied by researchers in various disciplines involving the computer sciences, sociology, geography, and cartography. Cybermaps, as special maps for cyberspace, have been produced and used as a tool for understanding various aspects of cyberspace virtual worlds. Virtual worlds can be distinguished in many ways from the physical world we live in. Because of these distinctions, it is a big challenge for cartographers to offer some clarification. This paper addresses various mapping issues such as visualizing, analysing and exploring cyberspace from different aspects.

INTRODUCTION

The term cyberspace is increasingly used in our information technology age. It was initially coined by Gibson in his well-known science fiction novel *Neuromancer* (Gibson, 1984). Cyberspace is defined as a computer-generated landscape, i.e. the virtual space of a global computer network, linking all people, computers, and sources of various information in the world through which one could navigate. It has become a more and more dominant aspect of our society. Nowadays, academic research increasingly depends on cyberspace. Researchers use email in order to exchange information with colleagues world-wide, generate homepages for research reports, and for the dissemination of their papers and projects. They even hold online conferences through Internet technology. More and more virtual campuses and universities are being set up. Moreover, our daily life is gradually shifting towards cyberspace, as it is increasingly used for shopping, entertainment, meetings, and chatting.

Cartography, hitherto regarded as a discipline for mapping the real world, is experiencing a big challenge to map cyberspace (Jiang and Ormeling, 1997). Most cartographic principles can also be used for mapping cyberspace. Various cybermaps have been discussed regarding their uses for navigation, analysis and persuasion. However, cyberspace is rather different from the real world we live in. For example, the Earth is an irregular sphere, and mapping it requires flattening it to a two dimensional plane, for which direction, distance, area and scale are critical factors. For cyberspace no such simple model as the globe exists. Instead various different models of virtual space can be constructed. These differences provide a big challenge for mapping virtual worlds.

Traditional cartography is based on Euclidean geometry because the correct representation of distances and directions is an important concern in such activities as navigation, exploration and land management. This traditional focus has already been changed somehow since the 1930s by the emergence of topology and topological mapping. Here, the primary concern was not to render areas or object categories, but to focus on connectivity, i.e. on the fact of whether or not locations (nodes) have been linked. As a good example, the London Underground map shows whether stations are connected by lines or not, and indicates the interchange possibilities to move from one line to another.

The importance of the distance factor is decreasing due to the development of telecommunications and because of the Internet as an information dissemination support. Instead of distance it is relations that become increasingly important for understanding network structures. This change causes many differences between cybermaps and traditional maps. However, there are many similarities between cyberspace and geographic space; for example, both are too large to perceive in their entirety.

This paper is oriented towards a general conceptual discussion of three categories of cybermaps. A distinction is made first between three views of cyberspace that can be discerned: the first which considers cyberspace as a set of physical anchorages, the second which concentrates on the topological relationships and the third which regards cyberspace as an animated 3D computer-based model. Thus the first view leads to cybermaps with representations of the Earth as a base map; the second view leads to maps of topological relationships and the third produces general purpose maps for virtual worlds. As opposed to direction and distance, it is connectivity and integration of topology that appear to be critical in mapping cyberspace.

The remainder of this paper is organized as follows; a brief review of the cartographic approaches to mapping both physical and virtual spaces; a focus on visualizing the Internet as a space anchored to the real world; analysing the topology of the Internet; ways of exploring and mapping 3D computer-based virtual worlds; and finally a conclusion.

SPACE AND MAPS VERSUS CYBERSPACE AND CYBERMAPS

Space is probably one of the most essential and paradoxical concepts that human beings face. Space is always present in our everyday life, for instance, travelling all over the world, being in a country, a city, even in a building. Basically two kinds of space can be identified in terms of size of space from the point of view of perception (Ittelson, 1973; Acredolo, 1981): small space which can be seen from a single viewpoint and large space which is beyond human body perception and cannot be seen from a single vantage point. To understand and perceive large space, maps are often used to represent it on a small-scale paper plane. In other words, we need maps because space is too large to perceive, to understand, to navigate and to explore. Maps provide a visualization tool for understanding and perception of space. So, traditional cartography is defined as 'the art, science and technology of making maps, together with their study as scientific documents and works of art. In this context, maps may be regarded as including all types of maps, plans, charts and sections, three-dimensional models and globes representing the earth or any celestial body at any scale' (Meynen, 1973, p. 1).

In this definition, both cartography, as a discipline for mapping and maps is defined in rather restrictive terms. Two points deserve mention here. The first is that maps were initially meant for portraying the Earth or parts of the Earth and were developed later on for any celestial body. This constraint does not remain valid, as the notion of maps has been widely used for mapping brain or other micro organs (Hall, 1992). It appears that cartography is also facing challenges to map virtual space, as is discussed here. The second concern about the above definition is scale. Scale always comes with size; for instance, we need to represent a country or a city at a reduced scale in order to fit a paper sheet. This may not be completely true for cyberspace. Cyberspace is large in the sense of its physical extent. On the other hand it is small in the sense that distance in cyberspace is non-existent. Through telepresense, people can be 'together' despite geographical and/or temporal distance. When we state that cyberspace is small, it does not mean that we do not need a map for it. On the contrary, we need a map for it as its structure has become very complex so that it cannot be perceived in its entirety.

Cyberspace maintains many differences from geographic or physical space. Firstly, for the Internet, it can be regarded as both an information infrastructure attached to the Earth and as information networks without any distance concept. Secondly, developed from the virtual reality technique, 3D computer-based models with or without Internet connection constitute another sort of cyberspace within which one can walk through or fly over with a mouse or special headset. From the traditional classification of maps into general reference maps and special purpose maps, it seems that the information infrastructure view of the Internet leads to cybermaps being classified as thematic maps. In this connection, many traditional thematic cartographic principles (e.g. Dent, 1999) can be used in mapping this kind of cyberspace.

The information networks view of the Internet leads to network mapping, which has similar cartographic fundamentals. In Bertin's *Semiology of Graphics* (1983), one chapter has been contributed to the issue. Nowadays, it is considered quite acceptable to make available to the general public various schematic maps such as subway networks, the urban bus network and suburban railroad network. Travellers are also accustomed to exposure to documents showing the airline networks. In these schematic maps, real location and metric distance become less important compared to the topological relationships. Thinking about sitemaps, represented as a topological structure, each node has no meaning whatsoever in terms of physical location, neither has a link any physical meaning other than that of showing a relationship.

It should be noted that in the above definition of cartography, 3D models and globes as special maps are at a small scale, which means one can have a bird's eye view of the model. However, the 3D models we refer to here as cyberspace are those with a huge dimension. With desktop Virtual Reality (VR) techniques, however, it is relatively easy to create large 3D landscapes beyond our computer screen; for example, ActiveWorlds mentioned later in this paper. Therefore, while exploring it, very often people feel that they are getting lost in it.

VIZUALISING INTERNET AS A SPACE ANCHORED TO THE REAL WORLD

The Internet is a world-wide network of millions of computers communicating via an agreed upon set of Internet protocols. Because so many computers are networked together, the analogy 'information superhighway' is often used. Physically speaking, all computers have their unique location on the Earth. Therefore, the Internet can be regarded as a space attached to the Earth. Thus, mapping Internet space would be mapping physical locations of computers distributed all over the World. This kind of cybermap can be thought of as a thematic map with a topographic map for a base map. Its mapping procedure follows the principle of traditional thematic mapping. In this connection, MIDS (1999) provides a huge amount of sample maps for the Internet. These cybermaps can be categorized according to themes as follows:

- Internet growth (rate),
- Internet weather forecast,
- Domain Name System (DNS),
- distribution of hosts, and
- information volume etc.

There are various aspects to be mapped as stated above. Internet addresses all have the name domain format, e.g. www.casa.ucl.ac.uk. The last part of the address after the last period is called the 'top-level domain', which can be converted into corresponding geographic locations. The 'top-level domain' also indicates the type of group within which the address is located. In general there are two types of top-level domains: the older-style organizational domains (e.g. .com, .edu, .gov) and the newer geographical domains (e.g. .uk, .au). Domain Name System (DNS) is a distributed database which contains discrete 32 bit numerical addresses for every registered computer in the World, e.g. gauss.geog.fu-berlin.de = 160.45.60.50.

'Host' is the name of a specific machine within a larger domain. Usually domain and hosts have the same physical location. The second meaning of the word 'host' has to do with the way certain computer systems have been set up. Some computers are made to support more than one user at the same time. These multi-user systems are often referred to as host computers.

Over the Internet, it is web servers that maintain detailed logs of every request made for information. Here every request is referred to as a hit. The number of hits reflects the frequency of usage of a specific web site. Both the number and distribution of hits can be mapped. When using the visual variables proposed by Bertin (1983), the various domains (.gov, .edu, .com) could be differentiated through the use of colours, and hosts and domains through differences in shape. Figure 1 suggests a set of visualizations used in mapping cyberspace, with the Earth as a flat plane. Actually it should be more realistically represented as part of globe. Mapping location, distribution and volume of the Internet according to geography is a major task for cyberspace. Various efforts have been made towards visualizing the Internet in three dimensional and dynamic ways, which provide more intuitive communication and analytical tools for the Internet (Figure 2, Munzner et al., 1996). In contrast to the Internet, the Intranet, though based on the same technology, is restricted to relations within an organization or enterprise. Except for the size of cyberspace, the Internet and Intranet have no differences. The Intranet, however, can be regarded as a subset of the Internet.

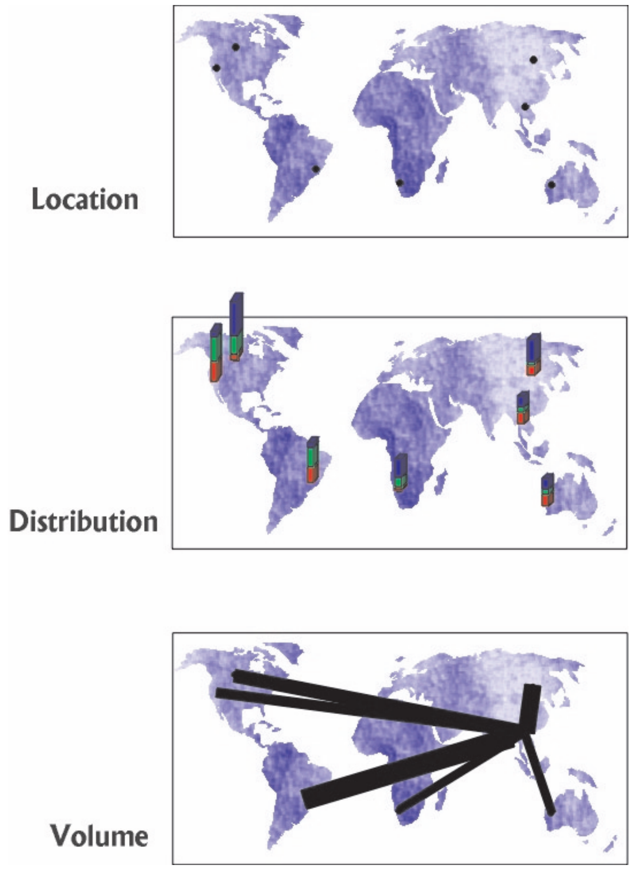


Figure 1. Visualizing different aspects of cyberspace

ANALYSING THE INFORMATION SPACE OF INTERNET

The Internet space can be qualified as a mathematical network with unit distance. For instance, researchers in Bell Laboratories are running a large project to collect routing data on the Internet (Cheswick, 1999). This mapping consists of frequent traceroute-style path probes, one to each registered Internet entity. From this, an Internet tree showing the paths to most of the nets on the Internet has been produced (Figure 3). These paths change over time, as routes reconfigure and the Internet grows. They are preserving these data and plan to run the scans for a long time. The database can help to analyse how the Internet grows, which appears to have fractal properties.

In the Internet tree shown in Figure 3, the map does not have a geographic nature; only links are shown in the cybermap. This is not only valid for the Internet structure, but for WWW as well. The idea of WWW is originated from hypertext technique with the considerable amount of multimedia information is interconnected (Nielsen, 1995). An early hypertext pioneer Ted Nelson, who coined the term 'hypertext', designed an ambitious project, Xanadu, that aimed to create a truely universal hypertext which links to all literary documents. We note that the WWW seems to provide a possibility to implement Nelson's original idea, a literary medium with which everything is deeply intertwined and online together.

Both the Internet structure and the WWW can be regarded as a complex network with considerable numbers of nodes and links. This complex structure can be generalized as a complex graph, by which we mean a graph with millions of nodes and links. From an analytical point of view, some graph measures are important in understanding cyberspace. The most important ones would be connectivity and integration. In order to describe these measures, let us assume some variables: for any particular node in a connected network, the shortest distance from the node to any other node is denoted by i, the number of nodes with the shortest distance i is denoted by N_i, the maximum shortest distance is denoted by k. Using the

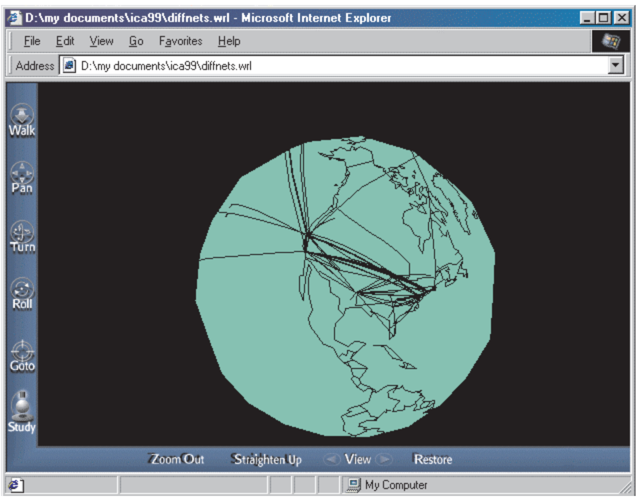


Figure 2. Visualizing the global topology of the Mbone by the use of VRML model (© 1996 IEEE)

expression $\Im = \sum_{i=1}^{k} i \times N_i$, we can describe the following important measures:

$$\Im = \begin{cases} connectivity \ iff \ i = 1 \\ local \ integration \ iff \ 2 \leqslant i \leqslant k - \delta \\ global \ integration \ iff \ i = k \end{cases}$$

where δ is a large enough constant variable, usually $k - \delta$ is less than 10 depending on the size of network.

So, from the above formal definition, connectivity is the number of nodes that are directly connected to a node. Sometimes, connectivity is called the number of immediate neighbours. Integration can be regarded as the number of neighbours within a few steps or full range of steps which leads to local and global integration respectively. These measures are taken from space syntax theory; interested readers may refer to relevant literature for more details (Hillier and Hanson, 1984).

Both connectivity and integration measure the node's status in the graph as a whole, either at a local level or a global level. These measures present some important

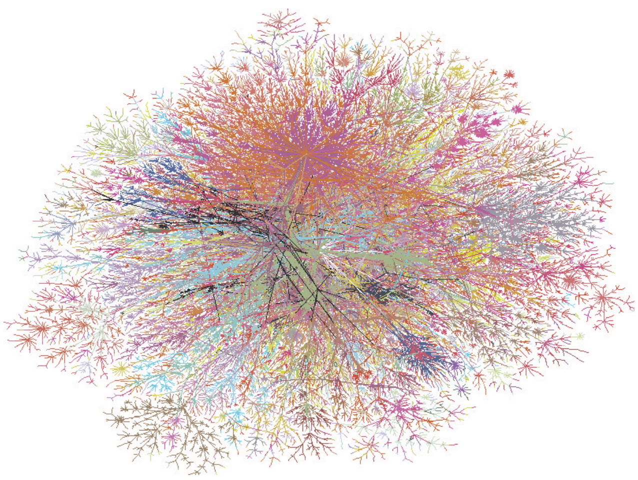


Figure 3. An Internet tree (Cheswick, 1999)

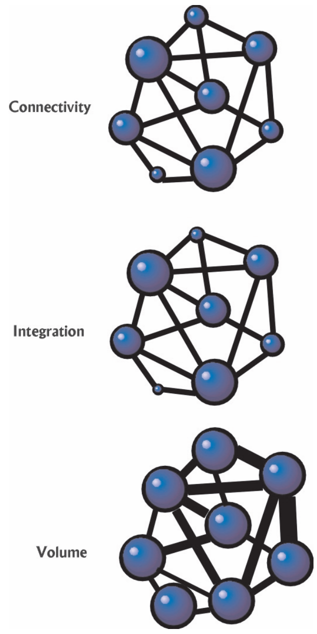


Figure 4. Visualizations of networks based on graph analysis measures

indicators for understanding cyberspace. For instance, connectivity shows how each node is connected to its immediate neighbours, and integration shows how each node is connected to the rest of nodes, being integrated or segregated. When visualized these properties or measures can be more easily understood. Figure 4 shows an example of these visualizations, where connectivity has four grades, integration has five grades, and links have six different grades. We can remark that the real situation could be much more complex which involves thousands, even millions of nodes and links.

As Internet space can be qualified as a mathematical network with unit distance, it is not metric distance which is relevant here, but links and structures. That is why the concepts of analysing and mapping integration and connectivity are so important here. Traffic volumes would be important as well, as the distance factor is now replaced by how much time it costs, for example, to transfer a file. Probably the Internet traffic is out of control of the end users, but would be very important for a telecommuncation company to choose and adopt the right route over the Internet.

As for the visualization of a network, various stretagies can be adopted. Freeman (1999) suggested several ways to make a graph or network more intuitively evident, such as the use of different colours or shapes on the nodes in order to display properties of nodes and links, or the use of animation for time-dependent changes in network structure. It appears that visualization of Internet can benefit from relevant research fields such as the visualization of social networks and molecule structures.

EXPLORING AND MAPPING VIRTUAL WORLDS

As mentioned in the introduction to this paper, the emergence of cyberspace is partly due to the development of VR technology. Computer games like SimCity are often designed with virtual worlds, together with some vivid simulations of dynamic agents. Mapping this kind of virtual world constitutes another type of cybermaps, which is not so different from maps of the physical world. Nowadays, more and more 3D virtual worlds are being developed over the Internet with networked VR techniques. ActiveWorlds is a good example in this connection, and it consists of ActiveWorlds Browser, ActiveWorlds Universe, and ActiveWorlds Builder.

ActiveWorlds Browser allows us to access 3D worlds where we can roam through different landscapes, teleport from place to place and chat to other users. It uses a considerable amount of bandwidth and can be quite slow at times. When entering a world, one appears in the shape of an avatar, that is a 3D figurine. Most worlds have a selection of avatars for us to choose from. Other users can be seen as avatars as well, and one can chat with them via a test chat screen. ActiveWorlds actually is the combination of virtual reality and Internet technology, as 3D virtual worlds can be shared by multiple users through Internet communication. It seems very different from the Netscape Browser, which initially was text oriented although one can have images, animation and 3D models through appropriate plug-in extensions. Currently ActiveWorlds is available for Windows 95/NT only.

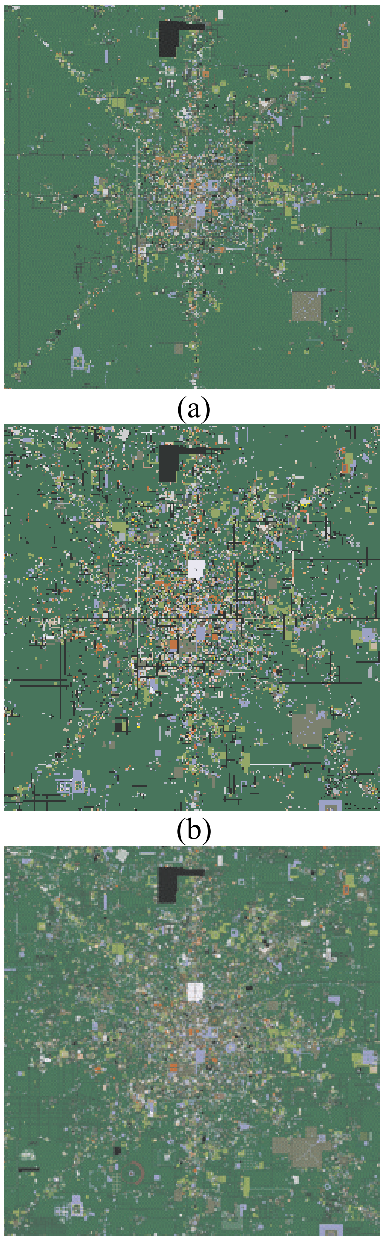
The ActiveWorlds Universe is a cyberspace which consists of numerous ActiveWorlds. Each virtual world is filled with human activities, once one enters them one can:

- shop online in 3D virtual mall;
- explore over 300 worlds in real-time, 3D, high-color graphics;
- own land and build anything you like on your property;
- meet, chat with people and interact as a fully 3D, lifelike, animated figure;
- use objects just like hyperlinks to send mail and surf the web;
- play games, ride rides, solve puzzles, navigate mazes.

(ActiveWorlds, 1999)

The ActiveWorlds builder can build one's own 3D virtual world within it. Now the technique has been applied in various fields such as film making for decor building, virtual campus, virtual cities, etc. AlphaWorld is the biggest virtual world within the ActiveWorlds Universe. It is an urbanized virtual world where each piece of land is owned by individually registered users (citizens of the virtual world). AlphaWorld appears to have evolved in much the same way as real world cities. Figure 5a shows an early stage of AlphaWorld, with a large area remaining undeveloped. As time goes by, this world has been further developed (see Figure 5b and c). This series is a set of morphological maps of the AlphaWorld.

As AlphaWorlds is too big to perceive from a single vantage point, users can still get lost in cyberspace. In order to help them get their bearings, they would need additional mapping tools. When users navigate in AlphaWorlds, for instance, a morphological birds eye view such as provided in Figure 5 will not help them much. A commonly used scenario would be using a cybermap with an active moving window to show the site currently being explored. Such a scenario helps avoid getting lost in it. Maps are thus essential to fulfil tasks such as navigation and orientation in cyberspace. The same scenario can be used for the exploration of information space.



(a)
(b)
(c)

Figure 5. Morphological map series of AlphaWorlds

CONCLUSION

In this paper, we provide three kinds of views of cyberspace: a space with physical anchorages, a topological space and 3D computer-based space visually similiar to the real world we are living in. Correspondingly three types of cybermaps are discussed from various aspects. An important research challenge is to analyse the complex topological structure, and to track its growth mechanism, which seems to be a more self-organized phenomenon. In this respect, cybermaps are very important tools for the perception and understanding of cyberspace as they help to show and analyse the hidden structure or patterns in both space and time dimensions. Traditional cartography is facing a big challenge from both the impact of information technology on traditional map making and the need to map information technology space - cyberspace. It has been illustrated that vizualisation techniques have the same impact on both geographic space and cyberspace.

ACKNOWLEDGEMENTS

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ENDNOTES

[1] Small space is actually a short name for small-scale space, the same for large space as well. We adopt this short form to avoid possible confusion in the context, as scale here used by behavioural scientists is different from map scale. See Montello (1993) for details.