International Planning Studies
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713426761

The computable city

Michael Batty [a]
[a] Centre for Advanced Spatial Analysis, University College London, London, UK

Online Publication Date: 01 June 1997

To cite this Article Batty, Michael(1997)'The computable city',International Planning Studies,2:2,155 — 173
To link to this Article: DOI: 10.1080/13563479708721676
URL: http://dx.doi.org/10.1080/13563479708721676

The Computable City

MICHAEL BATTY

Centre for Advanced Spatial Analysis, University College London, 1–19 Torrington Place, London WCE 6BT, UK.

ABSTRACT *By the year 2050, everything around us will be some form of computer. Already, we are seeing a massive convergence of computers and communications through various forms of media. Computerized highways are in prospect and smart buildings are almost upon us. As planners we are accustomed to using computers to advance our science and art but it would appear that the city itself is turning into a constellation of computers. The implications of this for city planning are enormous. New data sources emerging in real time, and software to understand many elements of the working of cities such as simulation games and GIS, are now widespread. The juxtaposition of media that a generation ago would have been regarded as unthinkable is generating entirely new opportunities for understanding and planning cities. This paper raises these issues through a travelogue across the Internet. Ideas for what is becoming possible in our domain are illustrated from that latest of networking triumphs, the World Wide Web, from which we draw examples of cities* in situ, in vitro, *in the abstract, in real time and in cyberspace. Point to our homepage* http://www.casa.ucl.ac.uk/ *and then click to generate these.*

A Continuing Revolution

In his recent novel *3001*, Arthur C. Clarke (1997) paints a picture of the far distant future which is based around the kinds of computer technologies which are rapidly being developed at the present time. When humans look back 1000 years, he argues, they will realize that now is the time when the great transition from a world based on manual-mechanical technologies gave way to one based on digital, when interacting and changing the world moved from being dominantly material to being dominantly ethereal, virtual. The invention of printing, which occurred in China and the west between 1000 and 1500 AD, was an obvious prerequisite to modern society in that it enabled mass communication of ideas. But not until the invention of electricity in the late 19th century and the computer in the mid-20th was the possibility even raised that the world was not only communicable but also computable, and that the future might be as much about changing the world in virtual reality as in material reality.

This sounds like the stuff of science fiction but it is happening. The rapid convergence of computers and communications is pushing visual technologies such as television, video, still photography and all kinds of graphics into the digital media, while computation itself is drifting into the ether, away from stand-alone hardware–software boxes onto networks which allow actual computation to be achieved both locally and remotely but always with data and software located at some distant source. Readers may be sceptical about this convergence although the evidence is everywhere. For five years, it has been

1356-3475/97/020155-19

possible to buy low-cost computers with television embedded within, and CD-ROM players are now standard even on the most modest of laptops. Few will buy a computer within the next year which does not have any sort of network connection for ever more software is being delivered across the net as vendors aggressively engage in the use of the network society for marketing.

These developments are, to say the least, unexpected. This is in many ways the hallmark of any profound social and technological revolution such as the one that began with the invention of the digital computer more than 50 years ago. Six years ago (1991), television inside computers was a novelty. State-of-the-art workstations at Sun Microsystems contained such media but their migration to low-cost Macintoshes, for example, took the world so much by surprise that few have been purchased. Most customers still do not expect to see such devices. Embedding fax and video within computers is now standard but what happens today inside a digital box, happens on the net tomorrow. Fax and video are now basic to the net with all the consequences for undercutting the cost and monopolies of the telecommunications companies and all the problems of continuous surveillance. It is possible to have real-time video hookups across the net essentially providing 'free' video-conferencing. Combined with developments in virtual reality, the day is not far off when distant communications will become a mix of the real and the virtual, which will augment one another in yet further unexpected ways.

What is so remarkable about all these events and many others which are besieging us daily is not that they are technologically surprising but that the speed at which they are being developed is so astonishing (Negroponte, 1995). Computers, after all, as the pioneers such as Turing, von Neumann and others told us 50 years ago, are universal machines, but we still find this hard to absorb. Technologies which lead to sweeping changes within society usually result from innovations whose impact is largely unforeseen at the time of their creation (Hapgood, 1993). Computers provide the very best example of this phenomenon. In the immediate aftermath of their simultaneous invention in a number of places during the Second World War, the conventional view amongst the industry's founders was that no more than a handful would ever be required, and these would be used solely for scientific purposes. Thirty years later, just prior to the development of the personal computer, IBM, Hewlett Packard and DEC—the leaders of the mainframe and minicomputer industries—all went on record as doubting that the microprocessor could ever become the basis for devices as ubiquitous as the television and the telephone.

The history of computing is full of such examples. Even the greatest visionaries such as von Neumann, who predicted that computers would revolutionize science (Macrae, 1992), and Vannevar Bush (1945) who foresaw the development of multimedia, failed to see the profound impact these technologies would have on material production as well as social behaviour. Not only was the path to miniaturization barely foreseen but, perhaps more importantly, the convergence of computers and telecommunications, which now represents the cutting edge of the revolution, was largely unanticipated. At present, there is much speculation that interactive television, multimedia and networking will change behaviour in ways we cannot envisage, yet the really radical notion that all our material infrastructure from communications to shelter is turning into computers still seems far fetched. But within 50 years, everything around us will be some form of computer and the ways we will access this and use it to interact with each other will be through software. By the mid-21st century, cars will be computers, buildings will be computers, entire cities will be computers, all wreaking profound changes on the form and functioning of our environment and the ways we will seek to understand and change it.

The interaction of computers across networks reflected in Sun's slogan "The computer is the network, the network is the computer", is generating a deep qualitative change in what computers are being used for. The telephone and the television provided new media for active and passive interaction but the computer is generating a qualitative change in computational interaction which is considerably more powerful than any interactive media developed so far. The dominant paradigm for this is, of course, the network (Kelly, 1994), which is enabling many new functions and forms of behaviour to be developed. Apart from the obvious possibilities of remote computing, access to information services such as data, libraries, software for computing, text processing and design etc. over the net is enabling entirely new ways of working as well as new forms of work. Such opportunities generate different forms of interaction which both substitute for and complement one another in a myriad of unanticipated ways, thus leading to new forms of social behaviour. This, in effect, is but one of many indicators that social structure and behaviour is becoming ever more complex, with important implications for our understanding and planning of cities and regions.

Until quite recently, the predominant role for computers in planning was in understanding urban problems and exploring and testing potential solutions. But it is increasingly clear that computers are now changing the very systems that we are seeking to understand using those same computers, and this in itself is generating important consequences for how we use computers in planning, consequences which have barely been raised to date. We will explore this conundrum here, suggesting that it is important to examine the ways in which computers are changing the methods for understanding as well as changing the structure and dynamics of the city itself. This is the phenomenon that we will refer to as *The Computable City*. In the past, the ways we have used computers to understand and help in planning the future city have been quite different from our concern for how computers and information technologies change the city but with the recent proliferation of local and global information networks, these two domains have begun to collide and coincide. This is best seen in the fact that computer hardware and networks as well as software used traditionally by professional researchers and planners to understand the city are now being used by a variety of interests and agents whose concern is somewhat different, involving the very actions and behaviour that we usually see as composing the fabric and structures to be understood and planned for. Of course, this coincidence of those planning and those planned for is hardly new. Social scientists have, for long, pondered the intersection of interests between planners and the planned, and the degree to which an appropriate understanding of urban behaviour can be seen in terms of one domain rather than the other. But in the context of computation and particularly the use of networks and computers, this difference and coincidence takes on a new significance which we shall begin, albeit in a rather preliminary and somewhat cavalier way, to discuss here.

In the rest of this paper, we will first outline a simple framework for reconciling our knowledge about how we use computers to begin to plan for cities that are composed of these very same machines. The network paradigm that is emerging is helpful to us here and we will illustrate several examples of the ways in which computation is changing our perceptions of the city using the latest Internet fashion of the moment, the World Wide Web (WWW), to present our thoughts. We explore how we can use computers to watch real cities, how we can simulate abstractions of cities, how we can use computers to learn about cities, and how we can live and work within virtual cities. Our examples simply give us a glimpse of the kind of computable city which is emerging, one which is changing daily and which will have changed substantially by the time this paper appears in a journal. This obsolescence is useful. It impresses the idea on any reader who happens to explore the online links noted here just how quick the pace of change is in this arena, and perhaps more importantly, just how many people may have read this paper on the web prior to the printed version.

Computers for Planning: Planning for Computers

Most of our applications of computers for understanding and planning cities have been for purposes of analysis, modelling and design, for storing data, and perhaps more recently for communicating data and ideas. Only very recently has the notion that computers might be more than simply a means for a better understanding and that computation might be more than simply scientific analysis become significant. Over 30 years ago, Meier (1962) speculated upon the notion of the city as a formal mechanism for communications and there has been a stream of work on the new geography of high-technology production and services (Castells, 1989) but in a sense this has remained very separate from the use of computers within the planning process. Different ideologies and interests pertain to these two domains and, so far, their study has had little in common.

It is the synthesis of computers and telecommunications that threatens to change all this. The emergence of computer networks which are able to monitor systems in real time while simultaneously allowing analysis of those same systems is something that is very new, at least on a widespread scale. The increasing convergence of the non-routine and the routine in the same set of technologies is making possible the study and analysis of systems in a way that was not possible hitherto. Furthermore, the fact that so much routine behaviour which has an impact on the city is now being 'influenced' by electronic networks is changing the very phenomena which planners and spatial analysts have traditionally studied. It is a cliché to say that computers and telecommunications are annihilating distance as much as they are changing time but there are substantial changes under way which will probably change the very notion of the city which we have grown up with. Moreover, what is going to be very clear in the future is that to study cities in any manner, it will be necessary to use diverse methods of computation which will vary from the straightforward browsing of digital data to much more sophisticated methods of simulating futures. To plan those same cities, we will have to complement our set of planning tools with those that involve the design, operation and selection of different types of networks and information.

This is a complex prospect and we need some way of making sense of it all. First let us make a distinction between the material and non-material worlds which in terms of cities we may think of as infrastructure and the way populations behave within that infrastructure respectively. The study and planning of cities has always adopted this distinction with respect to how human behaviour influences physical form and space although these limits have been the subject of intense debate in the last 30 years. Part of human behaviour is our quest to understand and plan the city although many have argued that this activity must be treated no differently from any other types of behaviour which comprise the city. Nevertheless, a distinction must be made, otherwise there would be no separate professional activity or concern. When computers were first invented 50 years ago, they gradually encroached upon these professional concerns and by the 1960s had become significant enough to constitute a separate field of inquiry, notwithstanding the controversies such approaches implied. But only recently have computers, through networks, begun to affect dramatically both the infrastructure of the city and those other forms of behaviour which planners and urban analysts view as determining spatial and social structures.

In short, computers which were once thought of as solely being instruments for a better understanding, for science, are rapidly becoming part of the infrastructure itself, controlling new infrastructure through their software, influencing the use of that infrastructure, and thus affecting space and location. In one view, the line between computers being used to aid our understanding of cities and their being used to operate and control cities has not only become blurred but has virtually dissolved. In another sense, computers are becoming increasingly important everywhere and the asymmetry posed by their exclusive use for analysis and design in the past and their all-pervasive influence in the city is now disappearing. In both cases, the implication is that computers will have to be used to understand cities which are built of computers. There will be no other way.

It is easy to make too much of these events. For some, cities will never be perceived as being formed from computers and networks and, of course, ours is only a partial view. For a long time to come, the line between computers in cities and everything else will be a clear one and it will be necessary to extend our understanding across this line. In fact, this means that our understanding of cities and their planning is more complex than ever it was a generation or more ago, for now we need to consider new forms of network as well as the traditional ones based on material physical infrastructures. Besides adding to complexity through increased opportunities for interaction and new forms of organization, cities are becoming increasingly invisible to study and analysis in traditional ways as more and more electronic media appear. As we will argue later, it is very likely that the degree of complexity will soon overwhelm traditional approaches to social control and this is already seen in the massive decentralization which computers are hastening (Kelly, 1994; Resnick, 1994).

In this paper, the lens through which we are viewing the city is the computer and we will direct all subsequent discussion this way. We will, in fact, make a distinction between real cities as viewed using computers and abstract cities as simulated on computers. By real cities, we mean those elements of cities which we might study using computers that detect and control elements such as transportation networks, utilities, remote sensors and other data. In contrast, the study of abstract cities involves the use of computers for analysis and modelling, removed somewhat from the routine and non-routine functioning of cities in which control is the *modus operandi*. Between these two poles lies the use of computers for interacting within cities, for buying and selling, for leisure, for work and for a host of activities that were previously carried out without computers. This is the virtual city, it is cyberspace, the world of email, the net and such like. Connected to this is the world of structured learning which in terms of our understanding of cities involves the real, the abstract and the virtual in diverse combinations.

Our perspective is hardly well formed, nor is it comprehensive but our purpose here is to raise questions and illustrate examples of what is happening. To this end, we will discuss these different views of the computable city in terms of how we might use computers to watch real cities using online data, to simulate abstractions of cities perhaps using the same online data, to learn about cities using both these media, and lastly to explore the new world of the virtual city in which traditional forms of interaction are being both substituted for and complemented by the new media.

Watching Real Cities

From the beginning in the 1950s, computers have been used to store and process data of use to city planners. Before the dawn of the digital computer, as far back as Herman Hollerith, computational devices were used for such data. Indeed, the original momentum for widespread digital computation came from the development of information systems for transactions processing. Although most digital data for cities until quite recently have been available for non-routine functions such as those collected by the population censuses, routine data are now becoming available. Real-time data from industrial concerns have been available for a while as have financial data but now data pertaining to functions relevant to physical and spatial problems are online. Satellite data are routinely available at the global level over the Internet as illustrated by the numerous online weather reports but the most significant types of data pertain to traffic and movement. Real-time traffic volumes and speeds, levels of congestion and accident hot spots are available at an increasing number of sites if one has the technology to access this, thus making possible analysis which is close to real time. Three examples which have recently appeared on the WWW make the point.

Our first is available from the California Department of Transportation—CALTRANS—and associated sites involved in monitoring traffic in the State. Real-time reporting of traffic speed and volumes in tabular or map form is available for a cluster of cities. We illustrate the case of San Diego in Figure 1 where we show traffic volumes on the main highways (*http://www.scubed.com:8001/caltrans/sd/big_map.shtml*) which change every 15 minutes as new data are fed across the net to the Web. The data are probably still only of novelty value and it is unlikely that much real-time analysis can yet be done with these. But the fact that data collection is possible at all and that it is in the public domain is likely to change routine decision making concerning trips while enabling longer term non-routine analysis of congestion and capacity. Of course, with the development of navigational instrumentation in automobiles, this kind of data might be immediately useful and in time it is this which will be routinely available for all major highways and for all vehicles which can make use of it. Business and government, of course, have long used such data but this does begin to reveal that the problem will be how to use the data. The problem is no longer whether the data can be collected or exist but how to act on them. As with most remotely sensed data, the volumes are so great that most is lost and

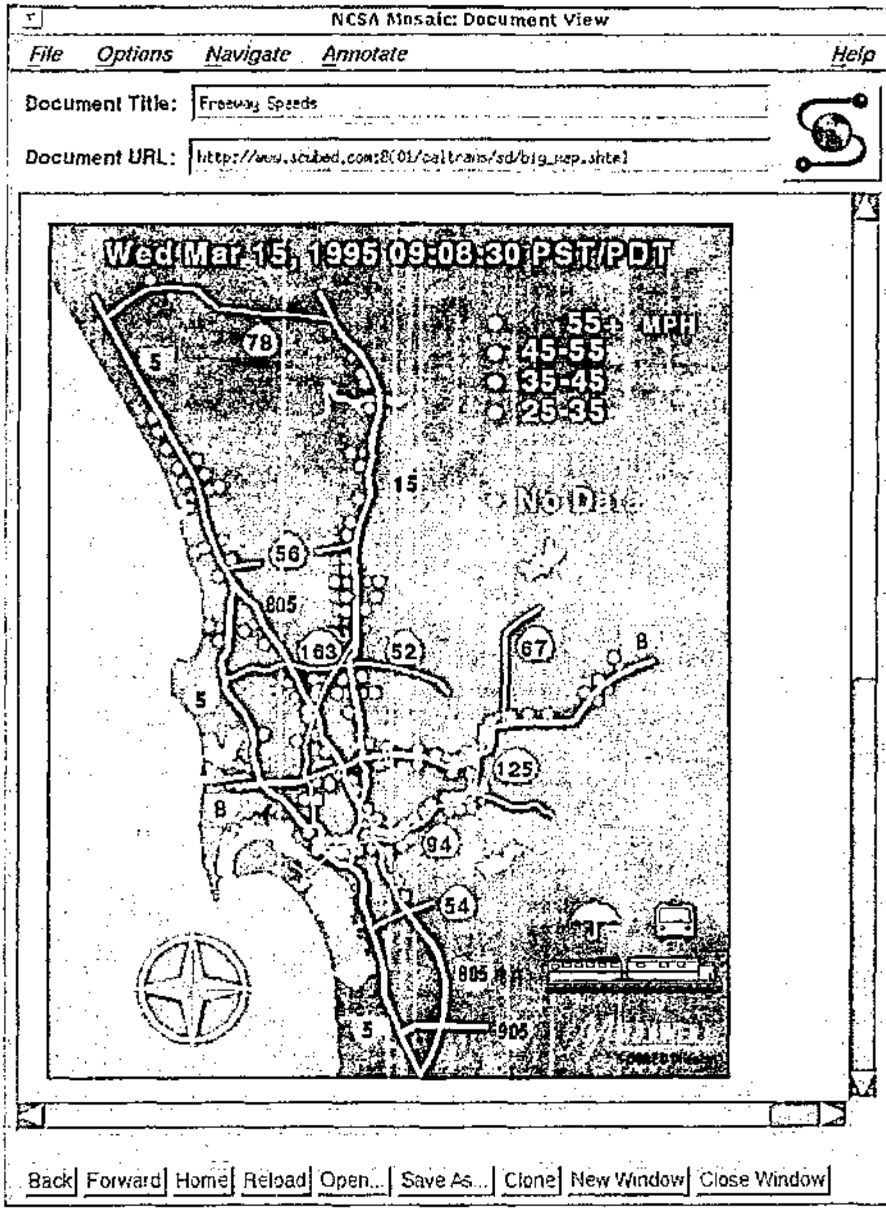

Figure 1. Traffic in real time in San Diego.

there is an urgent task to develop analytical software which can use the data to best purpose.

Our second example is more obvious but equally innovative. The Lawrence Berkeley Lab at the University of California has the entire 1990 US Census of Population online. It is possible for any user in the world who has access to an Internet account (and the cost for connection can be as low as $3 per week for a commercial service!) to download any element from this data set to a remote machine at a variety of spatial scales from the block group up to the

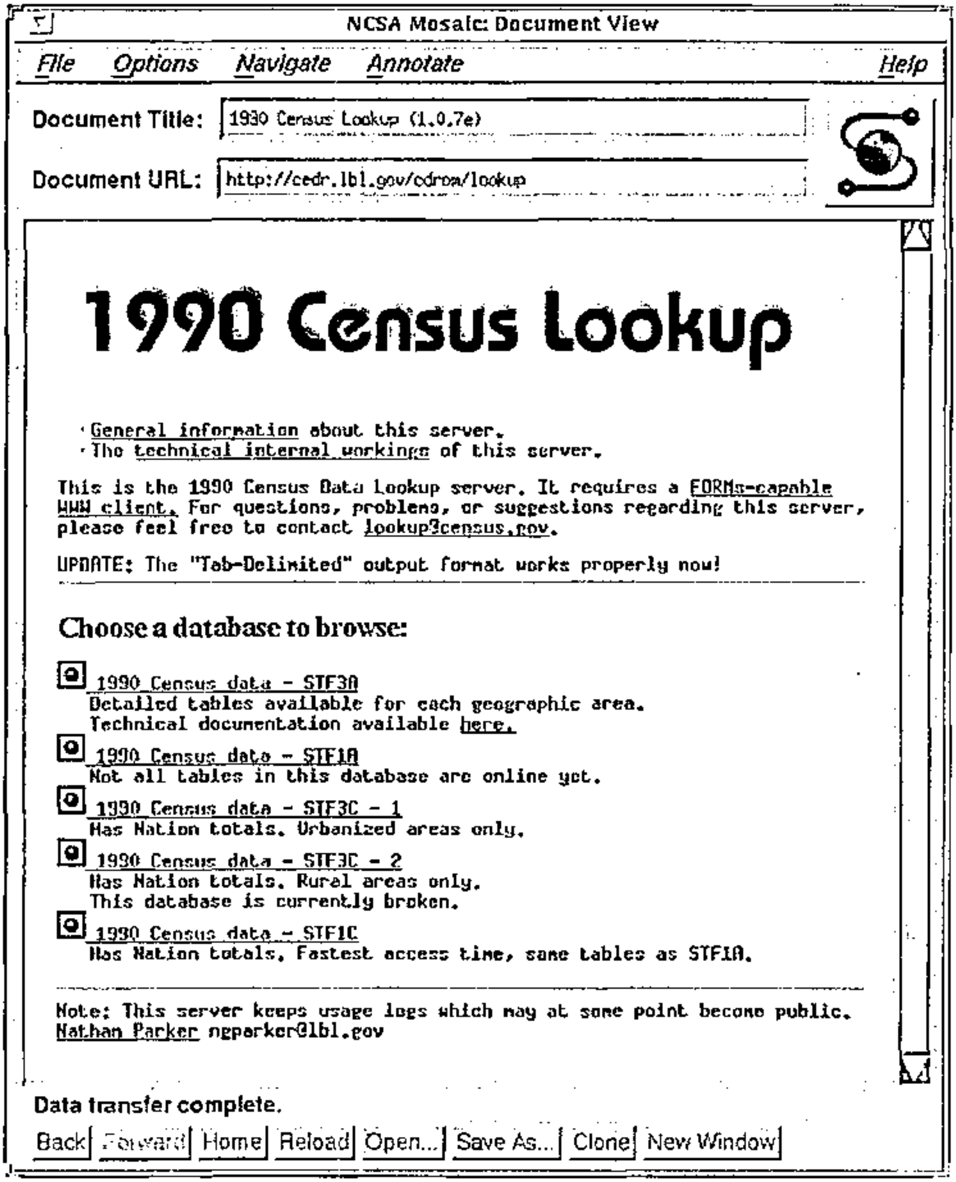

Figure 2. Downloading 1990 Census data from the Lawrence Berkeley Lab.

entire USA. Reportedly, the LBL will do the same for the 1980, 1970 and 1960 Censuses in the near future, thus providing a remarkable resource which throws into confusion much of the debate about data costing and value added. However, the problem is not simply one of data volumes but of interpretation. Software is required and this means some form of GIS or non-spatial information system which can enable the data to be viewed either visually or numerically. Figure 2 (*http://cedr.lbl.gov/cdrom/lookup/*) shows the typical layout for this home page which outlines the service for 1990 data. Downloading can be slow, especially at peak times, on the information highway. The US Bureau

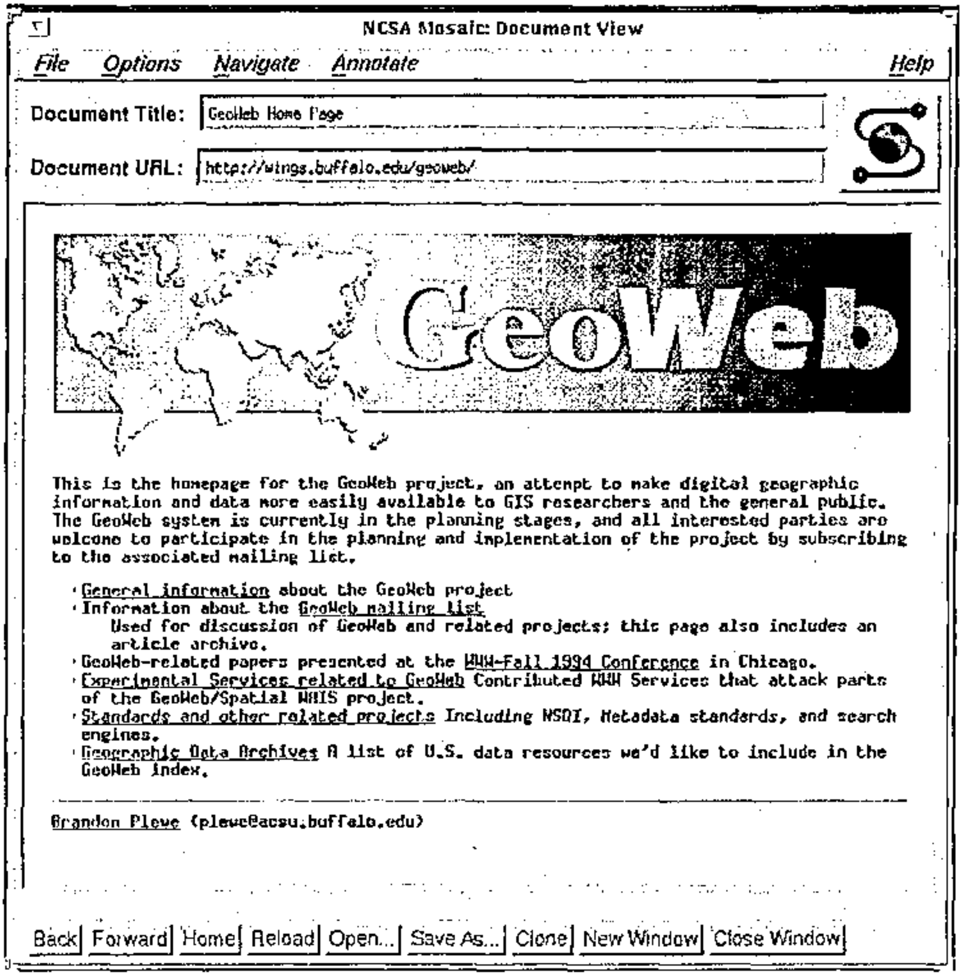

Figure 3. The GeoWeb homepage.

of the Census and the US Geological Service (USGS) are also in the process of installing services which will enable spatial data such as TIGER files, land-use cover and digital terrain models to be downloaded for many areas within the USA.

Our last example pertaining to data involves a network of pointers called *GeoWeb* which acts as a user-friendly guide to geographical data which are online. Devised by Brandon Plewe (1995) at SUNY-Buffalo as a pilot model for building spatial data infrastructure, it enables one to browse through a veritable treasure trove of spatial data available over the Internet. It is in fact more a resource to learn about what data are available and what software can be used in their access and analysis rather than a means for downloading the raw material. The home page is shown in Figure 3 (*http://wings.buffalo.edu/geoweb/*). As such, *GeoWeb* is an excellent illustration of the way the World Wide Web can be accessed and searched. The screens shown here are from the browser called *Mosaic* which enables different documents to be accessed using

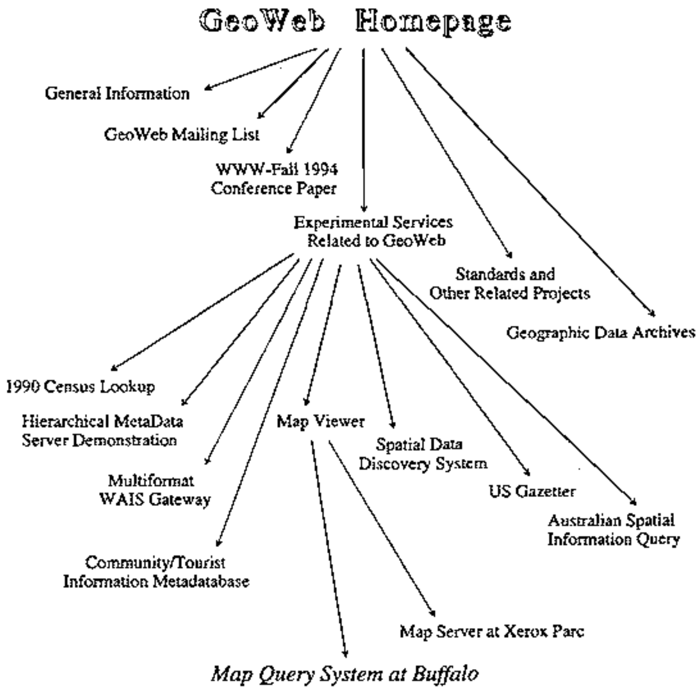

Figure 4. Web layers within GeoWeb.

hypertext—hotlinks which point to other documents which summarize resources at different locations on the Web. By clicking on these hotlinks, the searcher moves across the net to the physical location of the document and resource, thus building up a web of interactions. This, of course, is the way the net can be explored but it also the way new webs can built across the net. The pointers soon explode as Figure 4, which is a map of four layers within *GeoWeb*, implies. This is the kind of complexity that is characteristic of the information society and which makes traditional responses to its study quite inadequate.

Simulating Abstractions of Cities

The traditional use of computers in planning has been for analysis and forecasting from a data or a modelling perspective. All we can do here is to point to the kind of abstractions that are being developed as computation creeps out into society at large. The broad domain of knowledge in this area is still mainly encompassed by traditional applications of computers in planning but the emergence of networking and online data resources is changing the field dramatically. Evidence of this comes from the use of serious computer games such as *SimCity*. Reportedly, *SimCity* was the most popular-selling computer game in the UK at Christmas 1995 (Macmillan, 1996), with many more people being exposed to the game than there are professionals concerned with the study and planning of cities. This contrast is even starker in that straw polls reveal that a majority of professionals in this area have never even heard of the game. The

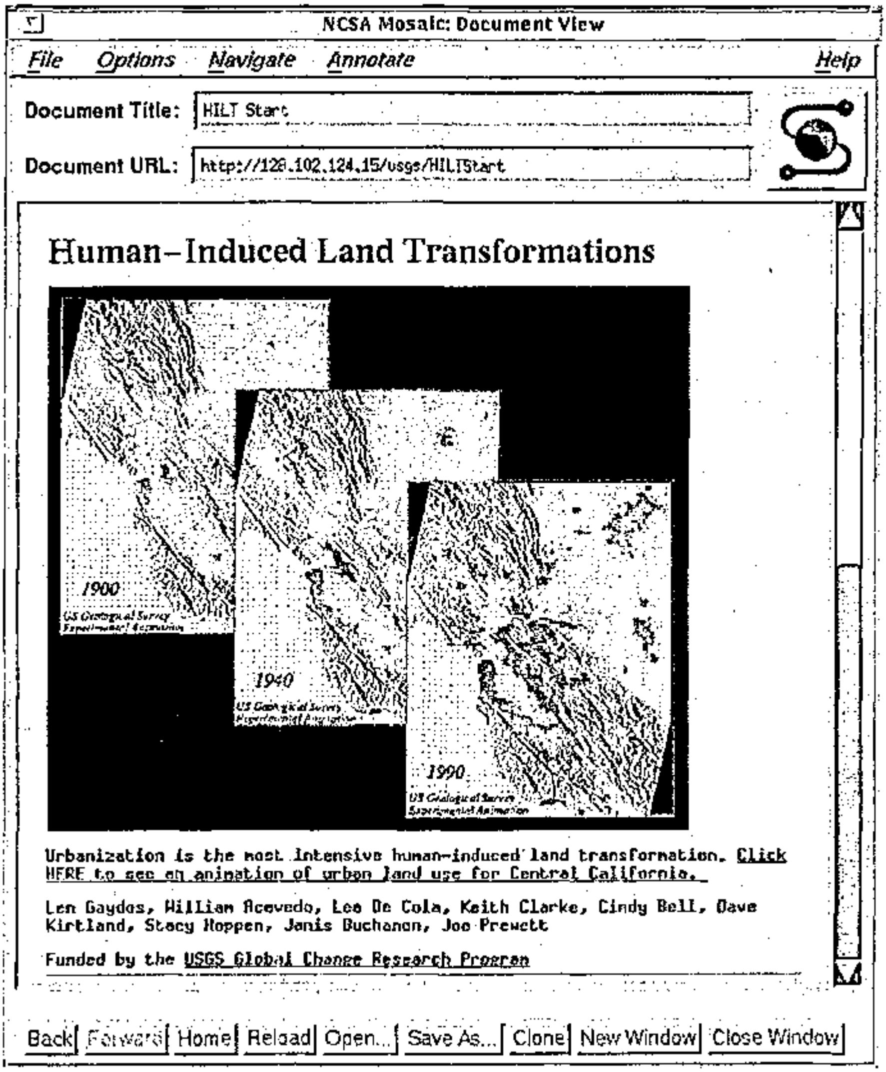

Figure 5. Simulation of urban development in the San Francisco Bay area.

implications for who understands cities best and who should be involved in their planning are dramatic.

On the net, some interesting modelling applications are emerging. There are countless GIS tutorials but descriptive simulations, some with a 'hands-on' feel, are becoming available. We will examine two. First at USGS at NASA Ames in Silicon Valley, a group led by Len Gaydos have put together a simulation of urban growth in the San Francisco Bay Area as part of a wider project dealing with the human consequences of land-use change. Urban development in the Bay Area from 1820 has been morphed together from old maps and since 1972 from satellite imagery. Some stills from this development are shown in Figure 5 (*http://128.10-2.124.15/usgs/HILTStart*) but the real excitement begins when you click on the pointer beneath these maps which starts the mpeg movie player generating an animation of urban growth in the Bay Area. From this document, you can extract the data for this simulation and also explore a simple model of this growth developed by Keith Clarke and Lee de Cola based on cellular automata (CA) (Kirtland *et al.*, 1994). As yet, you cannot run this model online but there are several documents on the Web where users who log on from remote locations can run applications if the software is mounted on their own machines. We also have a similar simulation of the Buffalo region up and running which we are constructing in *Imagine* and *ARC/INFO* as a prelude to the application of various fractal and CA models of urban growth (Batty & Longley, 1994; Batty & Xie, 1994) which you can access at *http://www.geog.buffalo.edu/* by pointing and clicking on the hotlink *The Buffalo Project*. There you can also access Shane Murnion's *ARC/INFO* tutorial which tells you how to construct an application and echo the results on the Web if you have the software online.

Our second example is also taken from urban morphology although the analysis contained therein is rather different. Bill Hillier and his group at University College London have been applying ideas of space syntax to urban form for a decade or more, as initially illustrated in Hillier & Hanson (1984). These are models of urban structure in which space is explored that exists between buildings rather than within them. In a sense, the analysis seeks to interpret how space is formed by examining the external rather than internal disposition of functions and the way the space is configured in terms of its use. They have developed many applications for many cities and some of these are illustrated in their WWW server whose home page is presented in Figure 6 (*http://doric.bart.ucl.ac.uk/*). Perhaps the most useful aspect of their pages so far is the easy-to-use tutorial concerning space syntax which they are developing and which provides a clear analysis of the modelling techniques in use.

Space syntax of this kind requires very elaborate radial route networks of cities, usually coded according to criteria associated with the definition of exterior space. The nearest thing to a worldwide resource containing this type of data is the line feature data called the TIGER files which enable the geometry of the entire USA to be reconstructed at Census block level. If you go into *GeoWeb* and point your way to the Census (*http://www.census.gov/tiger/tiger.html*) you will find a useful summary of these resources with some examples of these data online. How long will it be before the kind of space syntax analysis developed by Hillier can be linked to data in the TIGER files? And will this be possible across the Web? Much will depend on how data and software are made available and to whom but the prospect of other users engaging in such analysis is almost upon us. Although we cannot point to specific sources, simple GIS packages do exist on the Web which can already be used to analyse and visualize the kind of Census data which exist at LBL.

Learning about Cities

In one sense, learning cuts across all of the applications we have introduced, for the very activity of accessing computer networks and exploring resources is so new that it will represent a basic learning experience for a while yet. If you log onto the Buffalo homepage, then you will find that besides providing a catalogue to the facilities, faculty and staff at the Geography Department and the NCGIA, there are various resources connected to instruction. We have already

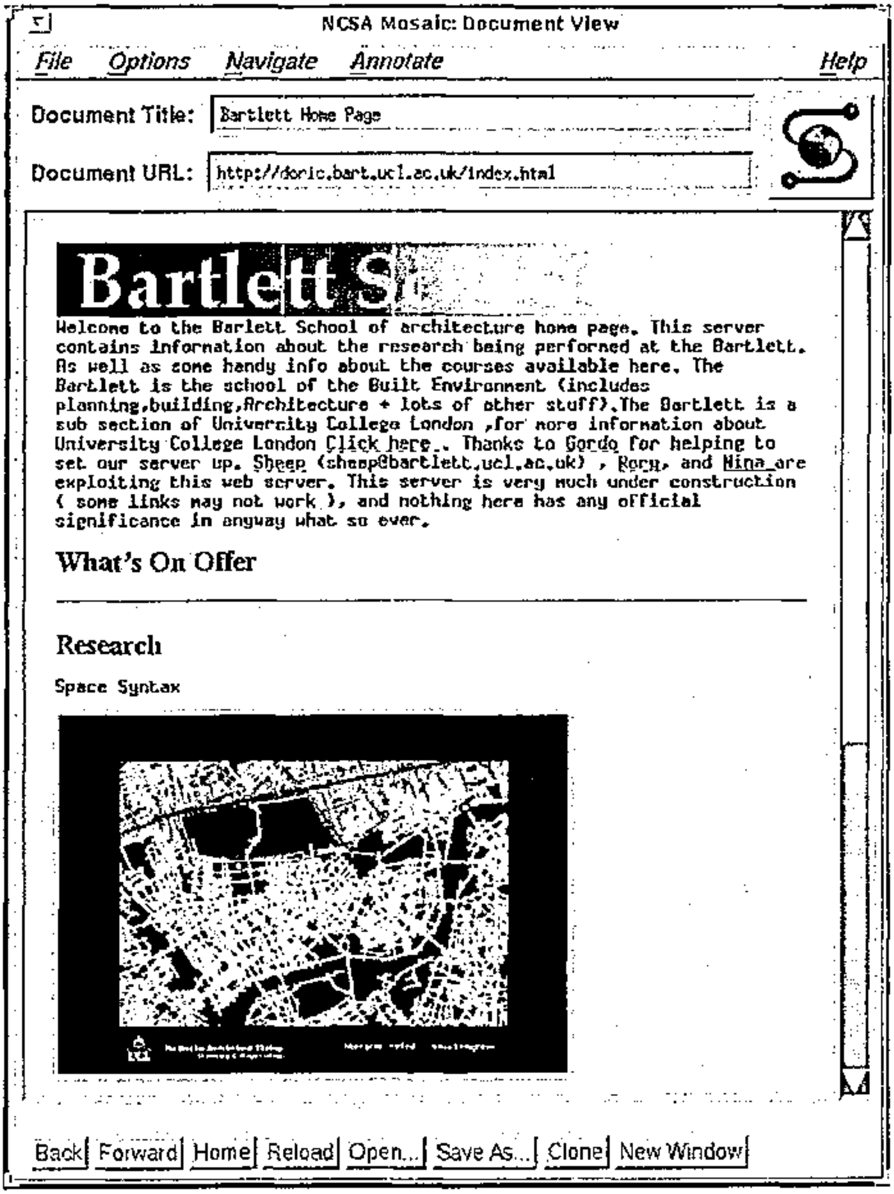

Figure 6. Modelling space syntax.

noted structured tutorials such as Bill Hillier's space syntax and Shane Murnion's *ARC/INFO* document, but on the Buffalo homepage, three courses are being developed with their own homepages in which students and faculty are thinking aloud, online, so to speak. We will examine the course entitled *The Geography of the Information Society* and explain what we have been doing. Figure 7 (*http://www.geog.buffalo.edu/Geo666/*) shows the homepage. As the title suggests, the course provides a wide-ranging introduction to exactly the material of this paper—*The Computable City* by any other name (and the self-referential style

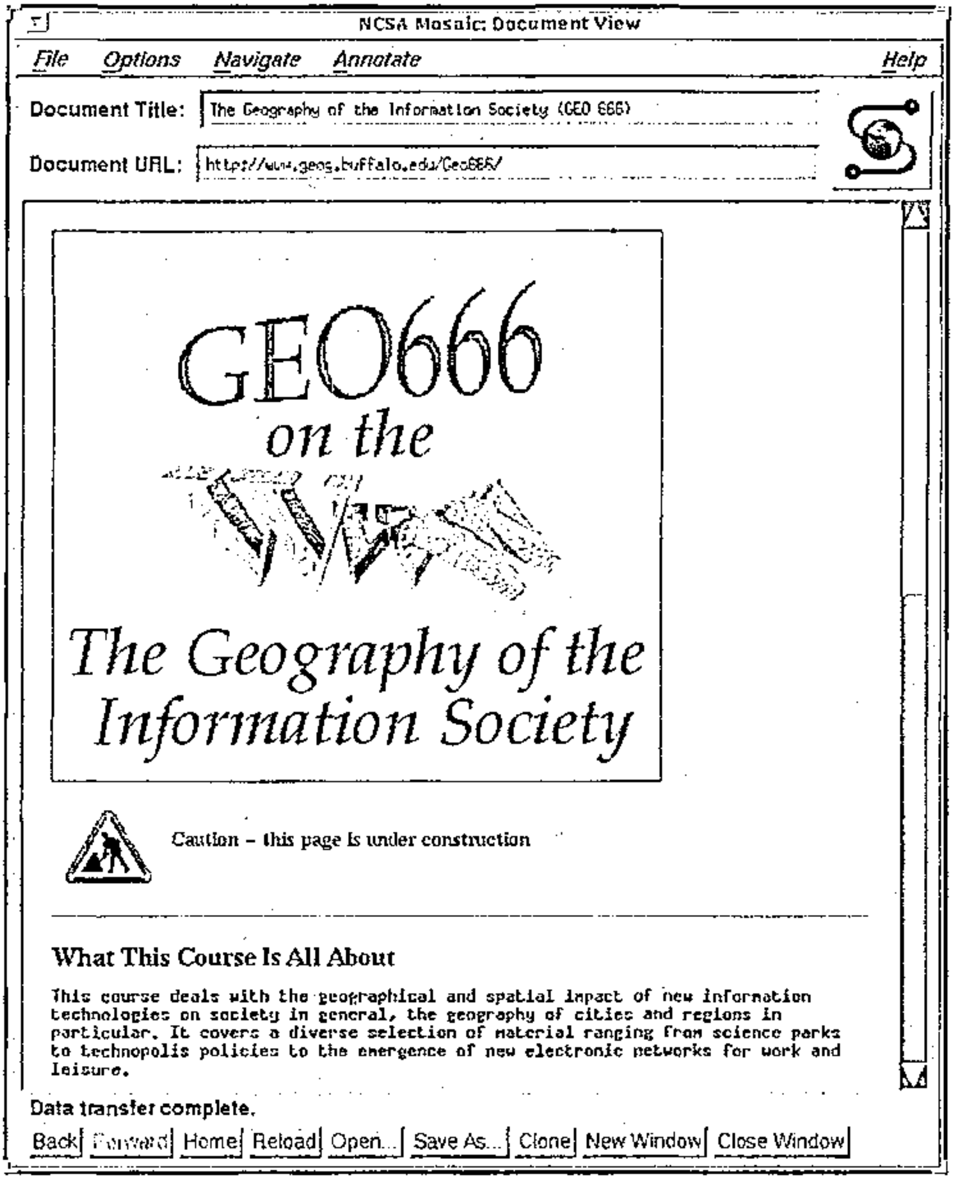

Figure 7. Graduate instruction: The Geography of the Information Society.

which dominates this paper is in fact quite characteristic of the complexity which we are all facing with respect to the rapid computerization of society). The course is structured into four parts: first a review of the emergence of postindustrial society, and the growth of information networks, computers, software, orgware and so on; second an outline of the geography of high-tech manufacturing, services and globalization; third, the development of information infrastructure in cities largely involving telecommunications but also smart electronic highways; and finally, the emergence of cyberspace and virtual communities.

If you click on this homepage, you will see a logo (Figure 7), an outline of the course, and a list of participants: the instructor and students whose names when clicked reveal their own homepages on which they can experiment with anything they like—biographical details, pointers elsewhere revealing their preferences, papers they have written and so on. Also presented is a course schedule which if clicked provides a set of hierarchical pointers to papers written by each student for particular sessions, as well as pointers to the rest of the world. For example, in the section on technopolis and science parks, pointers are given to places like Tsukuba Science City, Blacksburg Electronic Village, Research Triangle Park, Computer Manufacturing in Austin TX, and so on. Finally there are pointers to what we call *Neat Cyberspace*, examples of which we will give in the next section. The whole idea of this exercise is to provide us with ways not only to present our work to others and get feedback—you can send us email about this from within the Web pages—but also pointers to parts of the Web where others have similar concerns to ours. Of course, to pretend that this is all there is to the course is fanciful and dangerous and there are many topic areas even within computer-oriented planning that would not be appropriately studied through the Web. But at least this gives an idea of what can be done, even though it is all 'under construction'.

Our second example is perhaps already more elaborate. Bill Mitchell and Mitch Kapor taught a course entitled *Digital Communities* at MIT in the fall of 1995. Their homepage is illustrated in Figure 8 (*http://alberti.mit.edu/arch/4.207/homepage.html*). The design is similar to that which we have adopted although references to literature are more extensive and the document is more complete in that the course has already been taught and all the student papers prepared. What is important about these attempts is that they build on one another. Our page points to theirs, but not theirs to ours as yet, but nevertheless, the way the web is woven is an all important part of the learning experience. Indeed, Bill Mitchell's book *City of Bits* on computation in architecture and urban design takes the self-referential style of this paper even further. Pointing and clicking on *http://www-mitpress.mit.edu/City_of_Bits/* provides the reader/user/browser with not only a guide to the book but also a way of adding his or her own material to the book, thus extending the discussion to the grass roots and changing the very basis of information about the phenomenon! In a way, this is the network paradigm in its purest and most archaic form. The kind of complexity that is writ large in these kinds of perspectives on the Internet gives some sense of how overwhelming is the study of the information society. How to map and chart, indeed even explore this kind of complexity is something that we have not yet faced but of course, this is the very essence of the computable city. Moreover, how all this interfaces with more traditional infrastructures and behaviours as well as more traditional approaches adds other layers to this complexity.

Living in Virtual Cities

We have already glimpsed the idea of the virtual city through examples such as *GeoWeb* and through our pointers to the information society. There is much written about this kind of cyberspace and how the net is being populated by nerds and hackers whose very existence involves living online. But the most

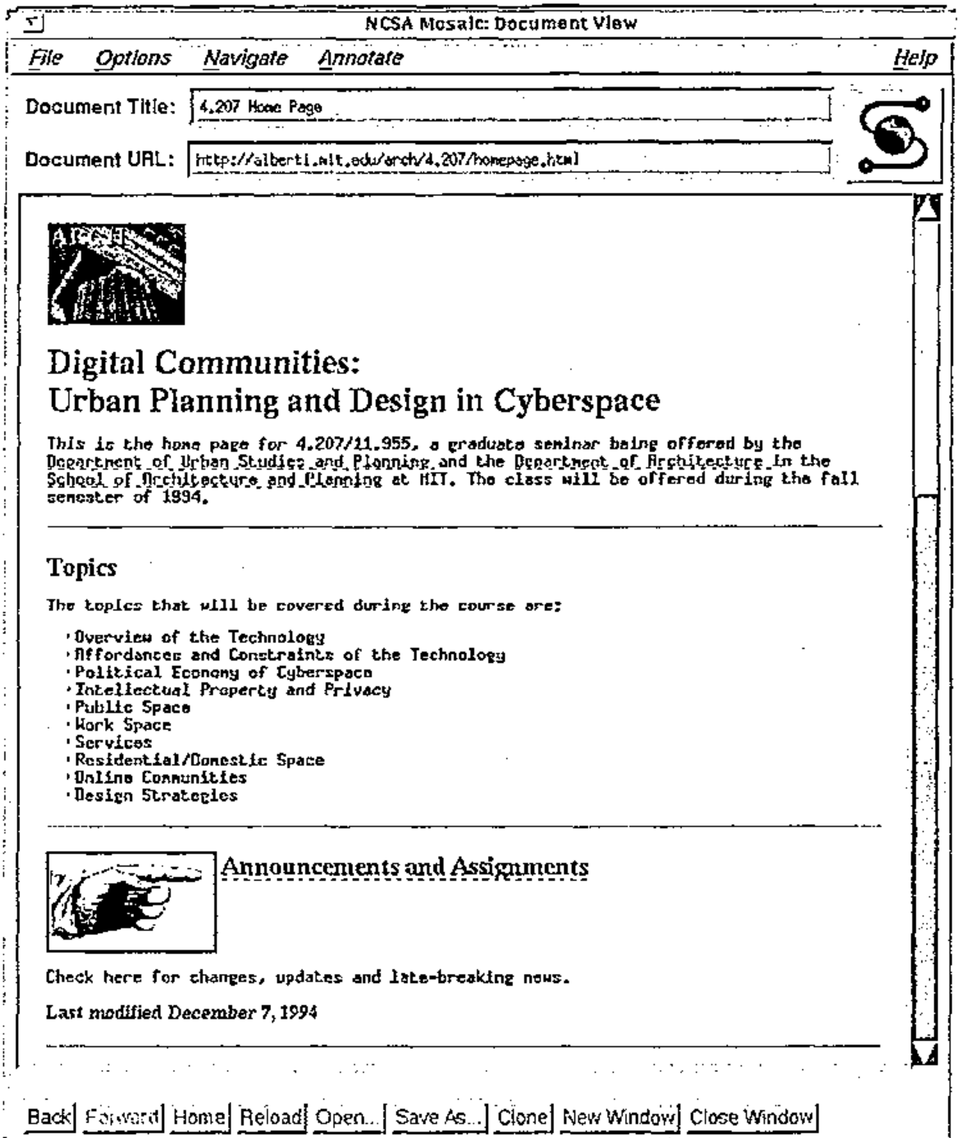

Figure 8. More graduate instruction: Digital Communities.

exciting prospect involves the emergence of services which have traditionally been associated with non-electronic access and in this penultimate section we will provide a couple of examples. But first some words about the Internet for it is important to see this in the broader context of the network society. The Internet has become the *de facto* symbol of the network society in that its growth, once begun, has spun out of control. It has become the skeleton for global computer-communications interaction. Although elaborate networks proliferate in the private and public sectors, most of them are gatewayed to the Internet where the range of services is enormous and increasing at rates often in excess

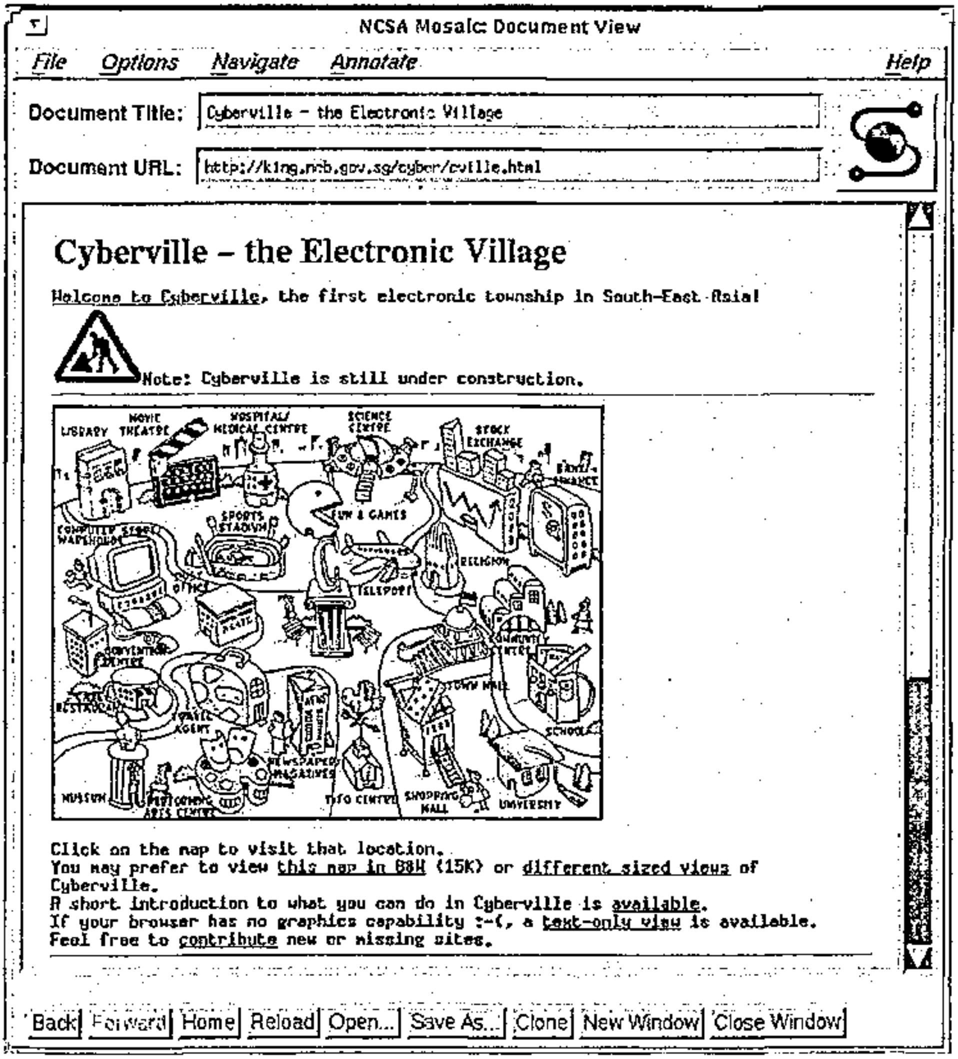

Figure 9. Cyberville.

of 10% each month. It is here that cyberspace is most fully developed, with an increasing range of routine and not-so-routine functions which enable users to shop, study, work and play in a virtual world. In fact, the idea of virtual reality is perhaps a rather extreme way of characterizing cyberspace and the net as, in essence, its functions simply replace and complement traditional modes of communication and interaction with electronic ones.

Two examples simply touch the edge of this virtual world. In Singapore, at the National Computer Board, they have constructed an interface to the net which they call *Cyberville*. This is simply a way of exploring cyberspace but it is modelled on the analogy of a small town, a so-called electronic village containing all the kinds of physical land-use functions or public/private buildings which one might associate with a well-balanced community. This image is in essence the homepage of *Cyberville*, shown in Figure 9, accessible at *http://king.ncb.gov.sg/cyber/cville.html* which has become the kind of icon used in many places for accessing and organizing entry to the Web. Click on any of the functions—stock exchange, science centre, university, town hall, movie theatre and so on—and you move across the net of pages that display and point you to Web sites which contain those functions. In short, *Cyberville* is an intelligently organized entry point to the Web for users who wish to focus on the sorts of services one can access electronically. For example, if you click on the stock market, you can eventually find yourself at MIT's AI Lab where they have an experimental stock market analyser, indeed if you click on any of these items, you can begin to travel the Web moving from site to site according to the structure embedded into each homepage, but directed initially by *Cyberville*. This is a clever way of organizing entry to such electronic spaces and some day all of our entry points will be so configured, at least for the end user, if not for most others.

One last example illustrates the point again. We will not show the homepage but if you click on *http://houston.infohwy.com/index.htm* this transports you to *Cyberia* which is an electronic shopping mall in Houston (probably the only way to shop, safely, in that city!). Credit card information can be entered and orders processed but often all the links are 'down' as users and owners continue to figure out not only the economics of the Web but more importantly its security. Once there, however, on the Web, the variety of experiences can be overwhelming and the search can be endless. How many sites and documents there are is unknown. Plewe (1995) estimates that in December 1994 over one million documents existed, by July 1995 this had increased to three million, in March 1997 this was around 35 million and the informed prediction for the year 2000 is that there will be one billion web pages (*Wired*, March 1997; US edition). But this may even be an underestimate for there are now 40 million or more users of the Internet and this number is increasing by over 20% per year (Batty & Barr, 1994). Once television becomes interactive and once video and other media can be shipped over the net on demand (for this implies that all media will be digital, hence each copy will be almost zero cost), the kind of complexity that we see here will be extensive. It is then that virtual cities will intermingle with real cities, when the abstract and the real will merge into one another, and it is then that our traditional concepts of understanding, let alone planning the city will simply disappear. This is a challenge that we must begin to address if we are to cope with these changes.

The Future

In one sense, the future is clear: computers in planning are no longer exclusively concerned with the use of new methods of analysis, modelling and design but with all aspects of cities and planning as befits their role as universal machines, some examples of which we have alluded to here. But there is an urgent need to generalize our debate in the light of the way cities themselves are changing, the way activities are decentralizing in both time and space and the way new network forms are dispersing and concentrating spatial activities in very different ways from the past. Those who work with computation are well placed to make important contributions to this broader debate for the use of new forms of computer and network, new digital data sources and new software across the net in itself represents the way the city is changing. New insights will come only if new forms of computation are developed, requiring all who study the city to become immersed in its intrinsic computability.

Acknowledgements

This paper was first presented as the keynote address at the Fourth International Conference on Computers in Urban Planning and Urban Management, Melbourne, 11 July 1995.

References

Batty, M. & Barr, B. (1994) The electronic frontier: exploring and mapping Cyberspace, *Futures*, 26, pp. 699–712.

Batty, M. & Longley, P. (1994) *Fractal Cities: A Geometry of Form and Function* (London and San Diego: Academic Press).

Batty, M. & Xie, Y. (1994) From cells to cities, *Environment and Planning* B, 21, pp. s31–s48 (*http://www.geog.buffalo.edu./Geo666/batty/buffalo.html*).

Bush, V. (1945) As we may think, *Atlantic Monthly*, 176, pp. 101–108.

Castells, M. (1989) *The Informational City* (Oxford: Blackwell).

Clarke, A.C. (1997) *3001: The Final Odyssey* (New York: Ballantine Books) (*http://www.randomhouse.com/delrey/*).

Hapgood, F. (1993) *Up the Infinite Corridor: MIT and the Technical Imagination* (Reading, MA: Addison-Wesley).

Hillier, B. & Hanson, J. (1984) *The Social Logic of Space* (Cambridge: Cambridge University Press) (*http://doric.bart.ucl.ac.uk/web/Research.html*).

Kelly, K. (1994) *Out of Control: The New Biology of Machines* (London: Fourth Estate).

Kirtland, D., Gaydos, L., Clarke, K., De Cola, L., Acevedo, W. & Bell, C. (1994) An analysis of transformations in the San Francisco Bay/Sacramento Area, *World Resource Review*, 6, pp. 206–217 (*http://128.102.125.15/usgs/WRR_Page/*).

Macmillan, W.D. (1996) Fun and games: serious toys for city modelling, in: P. Longley & M. Batty (Eds) *Spatial Analysis: Modelling in a GIS Environment* (Cambridge: GeoInformation International), pp. 153–165.

Macrae, N. (1992) *John von Neumann* (New York: Pantheon Books).

Meier, R.L. (1962) *A Communications Theory of Urban Growth* (Cambridge, MA: MIT Press).

Mitchell, W.J. (1995) *City of Bits: Space, Place and the InfoBahn* (Cambridge, MA: MIT Press) (*http://www-mitpress.mit.edu/City_ of_Bits/*).

Negroponte, N. (1995) *Being Digital* (New York: Alfred A. Knopf).

Plewe, B. (1995) *The GeoWeb Project: using WAIS and the World Wide Web to aid location of distributed data sets* unpublished MA thesis, State University of New York, Buffalo, New York (*http://wings.buffalo.edu/geoweb/*).

Resnick, M. (1994) *Turtles, Termites and Traffic Jams: Explorations in Massively Parallel MicroWorlds* (Cambridge, MA: MIT Press). (*http://www.media.mit.edu/groups/el/Projects/starlogo*).