# Representing and Visualizing Physical, Virtual and Hybrid Information Spaces

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## Introduction: Varieties of Space

The strongest convention in contemporary geographic thought is the notion that geographic space is rooted in a Euclidean geometry that defines the physical world. Although geographers have long sought to escape this paradigm through a rich array of perceptions based on ways in which we might imagine space, physical distance or its economic surrogates still provide the basic logic used by geographers to order their world and to make sense of the way activities locate in time and space. There is however a sea change in the making. As the world moves from one organized around energy to one based on information, the role of physical distance is changing as it is complemented by near instantaneous transactions which dramatically distort the effect of distance, thus changing the traditional bonds which have led to the current geographical organization of cities, regions and nation states (Cairncross, 1997).

This transition is from a society dominated by the movement and manipulation of materials to one dominated by the movement and manipulation of information. In Negroponte's (1995) terms, it is a transition from a world based on 'atoms' to one based on 'bits', from a material world to an ethereal one where the convergence of computers and communications - the devices used to manipulate and transport the 'bits' - has evolved new varieties of space, collectively referred to, in the popular lexicon, as 'cyberspace'.

Despite the rapid emergence of cyberspace and the many attempts to chart and measure its morphology and spread, a more complete and focused conception is in the idea of the 'information space'. The new information spaces that are emerging are rooted in both the material and ethereal worlds of commodities and flows, and cannot be understood without each other (Castells, 1996). If we are to explore the continued relevance of ideas based on the measurement of accessibility or propinquity defined traditionally in relation to physical locations and interactions, then we need to examine the ways in which information and energy are combining to create new spaces and new patterns of human behavior. In short, new definitions and conceptualizations of accessibility can only be defined by mapping physical or material space onto virtual or ethereal space, thus defining a nexus of hybrid

space which, we will argue here, represents the appropriate focus for a new geography of the information age.

A popular example serves to make our point. The current fascination with the online bookshop Amazon.com which is mentioned many times in this book, is based on the notion we can substitute making a physical visit to the bookshop with a virtual visit, even engaging in price comparison reducing the need for several visits to different places. However although much of our behavior in browsing and purchasing is removed from the physical realm, ultimately the book needs to be delivered in its material form and this depends on where it is warehoused and how it is shipped. In the case of Amazon.com, there are 6 warehouses in the US and 2 in Europe, strategically located to minimize physical transfer costs and to maximize access to population centers, thus reinforcing long established ideas that location ultimately depends upon physical accessibility (Dodge, 1999). Of course bookshops are probably not the best example as the product itself can easily be made virtual - it does not need to be material - although food shopping and other popular kinds of e-commerce reinforce the point.

We can visualize the interpenetration of these two kinds of space, although in themselves they are much variegated, as an intersection of two worlds. It is even possible that there is simply one world, for one cannot exist without the other although there is an assumption that the physical world existed prior to the virtual. In the sense of the virtual world being exclusively cyberspace, this is indeed the case. However, it is convenient to consider these domains as intersecting but not being coincident for this serves to show how geographers (and all other social scientists of course) often abstract them as one or the other, thus providing perspectives from one viewpoint or the other.

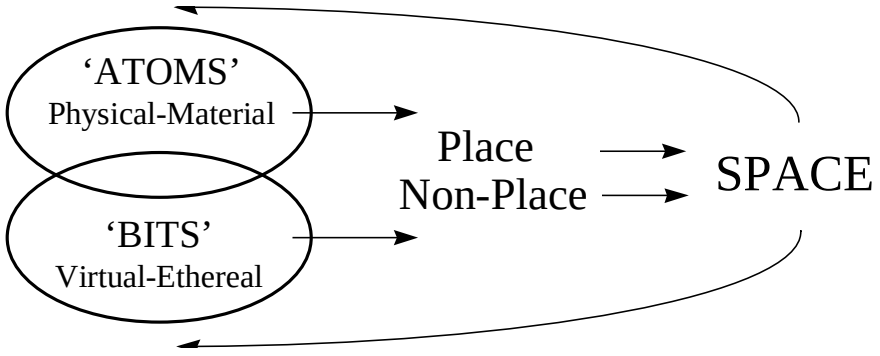


*Figure 1: Geographic Abstraction of Physical, Virtual and Hybrid Worlds*

The first level of geographic abstraction is in terms of the place or non-place urban realm (Webber, 1964) but spatial analysis usually lies beyond this to a level of abstraction where there is rarely any distinction between the aspatial and the spatial in geographic terms. In terms of our current focus on the role of accessibility in articulating and understanding the morphologies and morphogenesis of these new information spaces, Figure 1 shows that traditional accessibility and related spatial analysis might be applied to one or the other.

However, the message of this introduction is that neither are any longer complete as information space is necessarily a product of both. There is still a place for analyses of one or the other which emphasize certain characteristics to the exclusion of others, but an integrated understanding must be based on the analysis of hybrid information spaces.

So far there are few meaningful classifications of physical and virtual space, and there have been even fewer attempts at exploring how concepts and models developed for one can transfer to the other. In short, the extent to which we can generalize geographic theory from the predominantly physical domain to the virtual or rather adapt such theory to the hybrid domain is unclear. To an extent, this is what all the contributors to this book are attempting from different perspectives. There are many ideas, but most are preliminary and somewhat rudimentary. It appears that the economic geography of the production and consumption of these new technologies bears an uncanny resemblance to the old order with the role of historical accident and agglomeration economies still being significant in where such activity is located. In terms of the ways cities are restructuring, then the effect of distance is being distorted as physical ties on single locations are loosened - witness the edge city effect particularly in North America, and the growth of the global city - but as yet we have little idea of how our collective access to facilities is changing. Clearly the transition to an information age is increasing opportunities for different kinds of physical and virtual interaction dramatically for some groups, while locking out others, although even the contemporary geography of disadvantage seems to follow established social, ethnic and gender lines.

In our introduction to this part of the book, we will consider how the traditional notion of accessibility is relevant to an understanding of the way these new information spaces are being structured and how old spaces are being restructured. We will first explore these traditions and then we will speculate on how existing spatial analysis and geographic information systems and science might be used to detect the new morphologies of information (see Batty et al. 1998; Clarke 1998). We will then suggest a wider research agenda concluding with some more specific ideas as to where research might be immediately targeted.

## Prevailing Themes

### *The inadequacy of traditional definitions*

The traditional definition of accessibility focuses on physical proximity. For example, three major theoretical approaches to measuring accessibility are constraint-based measures, attraction-accessibility measures and benefit measures (see Miller (1999)). Constraint-based measures demarcate the activity locations that are available to an individual, typically from a space-time perspective. Attraction-accessibility measures measure the trade-off between the attractiveness of destinations versus their interaction costs. Benefit measures involve a similar trade-off but attempt to measure explicitly the benefits accruing to the individual from a choice set. In all three approaches, there is an

explicit assumption that physical distance is a major structuring factor that influences spatial choices and therefore accessibility.

In contrast, the virtual world ignores (or at least greatly discounts) physical space. The "cost" of virtual interaction has little to do with relative location. Instead, virtual interaction cost relates to factors such as network capacity, server capacity and current load; these translate into the latency (delay time) experienced by the user. Another cost is the difficulty in navigating the space and extracting useful information (see Dodge, this volume). This suggests the need for a major re-conceptualization and expansion of our definitions of accessibility.

It is also not obvious that traditional mapping techniques can yield significant insights into virtual spaces. The terms "virtual space" and "cyberspace" may in fact be oxymorons since there is little that is "spatial" in these realms, at least in the traditional sense. For representational and analytical tractability, formal and computational models of physical space invoke certain restrictions on its topological and geometric properties. These typically include metric space properties for distance measures such as non-negativity, identity, symmetry and triangular inequality (see Beguin and Thisse 1979; Smith 1989). A cyber-spatial analysis by Murion (this volume) suggests that latency, the most obvious distance measure in virtual space, does not obey the properties of metric space. We can handle the relaxation of metric space properties only if they are carefully controlled (see Muller 1982; Smith 1989). Moreover, current GIS software does not treat non-Euclidean space in an appropriate way.

An alternative to direct mapping of virtual space implied by virtual interaction is to map locations of the physical and logical components of virtual space within physical space. An example is mapping the locations of internet hubs, host computers, domain names or backbone networks within physical space as a measure of accessibility to cyber-space. Empirical analysis by Moss and Townsend (this volume) suggests caution. The spatial/geographical metaphor may not be appropriate, particularly since information flow in most networks apparently does not correlate with geographical space (see Mitchell 1995).

*Interactions between virtual space and physical space*

Although virtual space is aspatial and does not correlate well with geographic space, it is clear that virtual space and physical space influence each other. Activity in virtual space can affect activity in physical space and vice-versa. For example, virtual interaction can be both a substitute and a complement to physical interaction. An example of the former relationship is when an individual shops online rather than visiting a retail establishment. An example of the latter case is when an individual uses the web to find a new restaurant or plan a vacation.

To date, there is little research on the interactions between activities in virtual space and physical space (but see, however, Salomon (1986); and Shen (1998)). There is a tradition

within the geographic literature on measuring the interaction between physical interaction and perceived/experienced geographic space. For example, Abler (1975) explores the impact of space-adjusting technologies on human activities in geographic space while Janelle (1968, 1969, 1991) has pioneered the concept of space-time convergence to describe the radical impacts of transportation on spatial relationships. Reginald Golledge and Waldo Tobler have developed analytical techniques for transforming geographic space based on the perceived distances and observed interaction patterns (see, e.g., Golledge and Spector (1978); Tobler and Wineburg (1971); Tobler (1976), Tobler (1978)), but the usefulness of these techniques for visualizing hybrid space has not yet been explored.

Identifying significant centers and locations in both the virtual and material worlds is also an important task for future research. Of equal importance to measuring flows is research into the content of such flows and into the processes that mediate these flows. Markets are increasingly structured in real time across electronic networks. This poses a level of complexity on the real world that makes traditional market analytical techniques untenable. Also important is developing clear notions of the demand for and supply of information, particularly with respect to highly diverse networks where there are already very clear distinctions in terms of usage. What is available and what is required for what purposes are very different notions that must be identified, not only in relation to new information spaces but how these spaces map onto existing physical spaces. These may be articulated at various scales from social networks to global markets.

*The quality of interaction in physical, virtual and hybrid worlds*

Questions as to the quality of interactions in physical, virtual and hybrid worlds are also central themes. Despite progress in immersive and virtual reality technologies, it is likely that qualitative differences between interaction using physical and virtual modes will persist for some time. Previous research on consumer search behavior clearly demonstrates that individuals use different modes depending on the type of information sought (see Miller (1993) for a review). As virtual and hybrid worlds expand to encompass more aspects of daily life, it is likely that a complex partitioning of activities among these modes will occur. The nature of this partitioning is far from clear.

A related theme concerns the quality of information within physical, virtual and hybrid spaces. Vagueness and fluidity characterize virtual spaces. Apparently good and bad information spaces can be contrasted with good and bad information within these spaces with no one-to-one correspondence between each. The transitory nature of the digital world contrasts with the material world where information spaces are usually structured in terms of built form that has a life span with some permanence. This focus on temporality is an issue which serves to test the limits of our debate, reinforcing the long standing idea that time geography and accessibility in time as well as or rather than space is of much more significance here than we had hitherto thought.

The cliché of the digital world - that networks enable people to interact with 'anyone', 'anywhere', at 'any time' and in 'any place' - illustrates our crude vision of the emerging

digital world. Here our focus is much more considered with an emphasis on how humans interact with one another in space and time, adapting to access the 'right amount' and the 'right' information in the 'right time' and in the 'right place'. Harvey and McNab (this volume) clearly illustrate these issues with their discussion of interpersonal temporal accessibility at the global scale. The ability to interact in real-time may be the critical factor that distinguishes among world cultures rather than traditional notions of geographic separation and determinism.

### *Navigation tools for information space*

Another theme that weaves its way through all of our debate involves the development of tools and protocols to enable efficient navigation through information space. This instrumental viewpoint suggests that good geographical metaphors grounded in good theory about the information society should be at the basis of navigation tools that link behavior to purpose. Much visualization work is concerned with the development of better tools. These tools are being developed and tempered by the various institutional structures that require them. At the same time, we are beginning to learn more about new information spaces using the very tools designed for using these spaces in a routine fashion. As we develop tools to explore these new spaces, these tools are being used in routine way to navigate them. At the same time, the existence of these tools modifies these spaces. This is a kind of relativism that is rarely highlighted in the material world.

## The Morphology of Cyberspace

Although there are few indicators of the kinds of structure and behavior, form and process, that are determining the shape of these new information spaces, there are already some hints as to what we might expect. As in traditional studies of geographic space, these are dominated by explanations and models of the morphology of cyberspace in its many forms, rather then the processes through which it is evolving. This emphasis on form rather than process is one of the most problematic features of social research. It is not only difficult to observe social and economic processes at work, it is often impossible to infer the *modus operandi* of human decision-making that is determined by multiple causes and contextual circumstances. In the case of cyberspace, this is doubly difficult in that getting access to observe processes that take place invisibly across networks requires very special analytical skills and even then, the completeness of any survey is forever in doubt.

Cyberspace like other spaces has a form that is being mapped, and a natural starting point is to see whether or not the frictionless world that has emerged has any parallel in traditional geographic spaces. The macro-properties of traditional physical space has largely been charted and explained using ideas from social physics. Interaction patterns and accessibility measures were originally developed in analogy with the laws of classical physics, with gravitational force and potential energy being concepts of great relevance in "explaining" or at least summarizing how space becomes structured. In terms of interaction, Murnion (this volume) has made several studies of interaction over the

Internet using traditional models but with distance being replaced by new measures of 'latency' which have shifted the focus away from Euclidean distance and its surrogates - time or cost - to network measures which depend upon switching and relays and the capacity of telecommunications.

Even more specific results which appeal to social physics are being produced. Bernado Huberman and his colleagues at Xerox Parc in a series of studies of the size and shape of the web have produced quite conclusive evidence that the net is scaling in that servers and server capacity is distributed according to the rank-size rule (Markoff, 1999). This has implications for the structure of the net as a hierarchical system - remember that Christaller's central place system generates rank-size or at least scaling laws of center size - while work which is grounded in the distribution of web hosts geographically bears out similar scaling. Moss and Townsend (this volume) reveal that same kind of pattern for the New York region, while Shiode and Dodge (1998) provide a dramatic graphic of this kind of spatial organization in their picture of web hosts in South East England which we show in Figure 2. Contrast this with Stewart and Warntz's (1958) maps of population potential of North American and Britain which is at the basis of the physical measurement of accessibility across many scales.

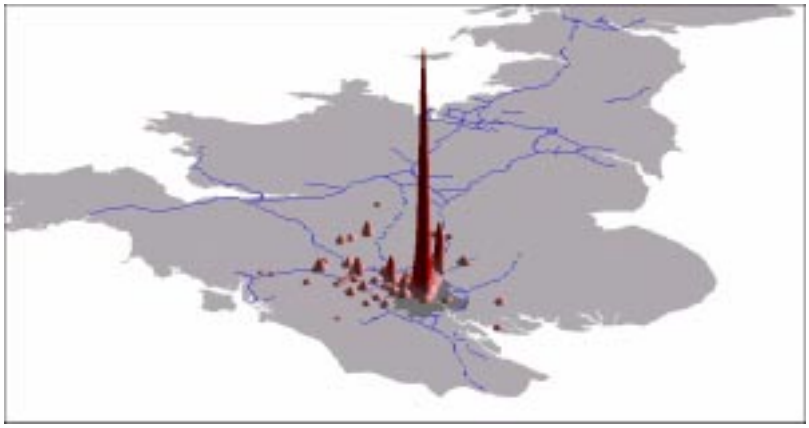

*Figure 2: The New Geography of Economic Potential: Accessibility to Internet Hubs (from Shiode and Dodge, 1998)*

Casual evidence also reveals the importance of the local and the global in the morphology of cyberspace. Any casual examination of your email log will reveal distance decay around your local site which is obvious enough in that most email deals with human activity through a virtual medium in a local physical space. However for academics and increasingly for the public at large logged into the web, such local interaction is being supplemented with global interaction which binds our social networks together in ways that serve to strengthen the global economy. New network studies of the small world problem (Watts and Strogatz, 1998) suggest that such occasional global ties increase

interaction much more significantly than the number of such ties might suggest and thus studies of the net and nets using such ideas appear promising.

In terms of the shape of the net, there is enough evidence to show that this too is scaling - fractal - in that links (through web sites for example) are scaling in importance, and follow the classic dendritic pattern that we find in many areas of morphology from the growth of crystals to the growth of cities and other organisms and organizations. In Figure 3(a), we show a piece of the network diagram of the net produced by Bill Cheswick and Hal Burch at Bell Labs, which has clear fractal structure. The particular segment - its nodes and links - is not important *per se* but its fractal structure is. In 3(b) we show the morphology of a virtual community in cyberspace - Alphaworld - reported on by Dodge (this volume) which has also evolved as a fractal around the point that members enter this virtual world - at ground zero. There is no friction of distance in Alphaworld but its physics is dictated by who came first and the town has evolved around ground zero and along easily recognizable radial routes.

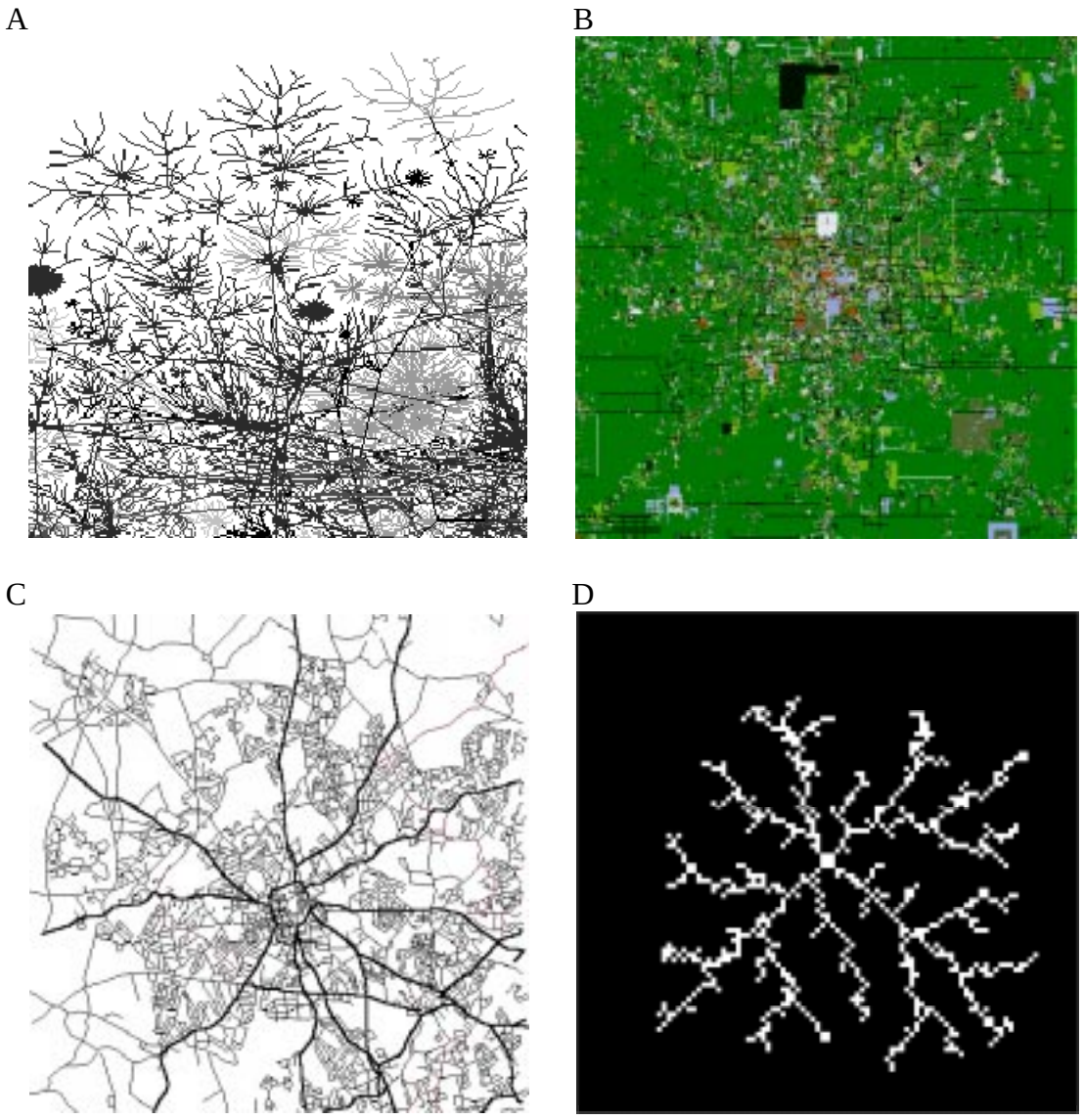


*Figure 3: The Morphologies of Virtual and Physical Space*

*a. the fractal structure of the Internet (http://cm.bell-labs.com/cm/cs/who/ches/map/index.html); b. the spatial structure of a virtual world - Alphaworld (from Dodge, this volume); c. the route structure of a medium-sized English town; and d. a model of urban growth based on diffusion-limited aggregation*

We can compare these to more traditional ways of measuring urban space. In Figure 3(c), there is a picture of the road network in a medium sized English town (Wolverhampton: population circa 250,000) which is clearly fractal although this might be at any scale, and finally in Figure 3(d) we show crystal growth using the process of diffusion-limited aggregation which has been used to measure and model several real towns. All these examples show that the physical and the virtual worlds have much in common and this suggests that models of physical space such as accessibility may have more to offer in the study of new information spaces than we have assumed hitherto.

These are but brief forays into a speculative realm that forms a much wider research agenda set by all the contributions in this book. Here we will conclude our introduction to this section by sketching this agenda in terms of measuring and modeling hybrid information spaces.

## A Research Agenda

We will now attempt to cull all these deliberations into a plan for future research based on (i) what do we know ? and what do we have ? (ii) what are appropriate future research directions ? and; (iii) what are appropriate research questions? We will deal with these in turn. Although the various debates which follow in the chapters within this section cover a wide range of issues, we will map out our research agenda in terms of the initial themes which we have introduced here, stating these as questions which frame research directions.

We begin by considering "What Do We Know about Visualizing and Representing Information Space?" A thorough review of these questions is required. This might be accomplished through research projects but it is more likely to come from the current generation of researchers such as those of us writing here coming to conclusions similar to our own and spontaneously developing such reviews and statements. There are several themes that might spin-off from such reviews and we will list these:

*Representing Networks*: this includes reviewing different ways of coding and identifying networks based on extensions of graph theoretic measures, methods of sampling and so on that can account of their virtual as well as physical/logical nature.

*Conceptualizing Activity Spaces and Accessibility Measures*: these are relevant to the virtual world but have developed to date largely for spatial issues in the real world

*Cataloguing Market Data*: this includes reviewing methods for counting and observing network flows and new concentrations of information in real and virtual space

*Exploring the Role of Geographic Information Science in the Analysis of Virtual and Hybrid Information Spaces*: this focuses on assessing how far existing methods of GIS in particular and spatial analysis in general are useful for mapping new information spaces

*Exploring the Role of Scientific Visualization in Measuring and Mapping*: this requires reviewing how new methods of visualization for spatial and non-spatial data in spaces with many dimensions might be used to chart new information spaces

These reviews begin to merge into major research questions which define the research frontier, and there are some obvious areas which require research programmes: again we state three of these to provide some sense of where we consider the focus should be:

> *Researching the Flow and Cost of Information*: how flows can be identified and linked to the emergence of new spaces which in turn map onto existing market, social, and institutional processes.
>
> *Tools of Cybernavigation*: the development of new tools for both exploring and moving through information spaces that are based on insights into the emergence of such spaces, the interface between activity in real and virtual worlds and developments in human-computer interaction.
>
> *Mapping Activity Spaces*: exploring ways in which existing approaches within time geography can be informed and extended by network paradigms, network flow data, and scientific visualization.
>
> *Visualization of Connections between Virtual and Real/Material Geographies*: providing insights into how information spaces are connected to real spaces through augmenting existing measures of accessibility and the development of new ones

Much more specific research issues can also be identified which might drive forward the research agenda. There is an urgent need for a major initiative in the collection of network data and its subsequent analysis with respect to the search for new information spaces. These initiatives could take many forms and we list four here:

- an Internet census: a data archive for the Internet
- the definition of private networks
- the collection of behavioral data associated with many varieties of network
- the role of time sampling in the use of networks

We also need to evaluate the role of existing tools in spatial analysis and develop new tools relevant to the issues we have identified pertaining to the analysis of information spaces within an information society. This should focus in particular on principles and tools in contemporary cartography and scientific visualization. We also need to develop new theories which generalize the concept of distance from physical to the virtual domains, and from this would flow models and visualizations of accessibility in real, virtual and hybrid spaces based on generalizations of geographic distance in formal, logical and computational terms.

This research agenda is wide and deep but although there are many straws in the wind, it would appear that much geographic and spatial knowledge developed in the last 100 years, although broadly relevant in a philosophic sense to new inquiries into information

spaces, needs to be redefined, reworked and restructured in a way that meets the challenges we have identified here, and the way these are elaborated in the articles which follow.

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