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Cyberspatial cognition and individual access to information: the behavioral foundation of cybergeography

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Abstract. **In this paper I will examine individual access to information on the Internet through a cognitive – behavioral perspective. I argue that the objective structure of information resources in cyberspace is not helpful for understanding the experience of individual accessibility in cyberspace. Instead, cyberspatial cognition is crucial in constituting the effective cyber-environment and shaping human cyberspatial behavior. I propose a behavioral model of cyber-accessibility and examine how notions underlying conventional accessibility measures such as impedance and opportunity set can be extended for measuring individual cyber-accessibility. I argue that theories about spatial learning, cognitive mapping, and decisionmaking behavior are helpful for understanding individual cyberspatial behavior. This suggests that behavioral theories and models may provide a theoretical foundation for cybergeography.**

Introduction

With the rapid growth in the information resources and transaction opportunities available on the Internet, the number of individuals accessing the Internet has increased dramatically in recent years. As a result, access to the Internet will soon become an important need in everyday life and an indicator of social equality in the near future. Just like access to jobs and other urban opportunities in the physical world, access to information resources in cyberspace constitutes a new and significant dimension of social differentiation among different population subgroups (Georgia Tech Research Corporation, 1998; McConnaughey and Lader, 1998; Moss and Mitra, 1998; Shapiro, 1997). To decipher these new patterns of social and spatial disparity, methods for representing and evaluating access to Internet resources are now urgently needed.

As the study of accessibility in the physical world has long been a major concern of urban researchers and geographers, various methods for analyzing accessibility have been formulated in their theories or models. Yet, as these methods are based on physical notions of distance and spatial relations in geographic space, they may not be applicable for understanding accessibility in cyberspace (Couclelis, 1996). If there is little relationship between the time or cost an electronic packet takes to travel between two locations in cyberspace and the physical distance between them in geographic space, what role can the traditional accessibility concepts and methods play in helping us to understand accessibility in cyberspace? Can geographic theories and methods provide useful conceptual apparatus for representing and measuring accessibility in the hybrid physical – virtual world?

In response to this theoretical challenge, I examine current approaches and propose a conceptual framework for examining the problem of individual accessibility in cyberspace. Drawing upon insights from three areas of research, I explore how operational measures of individual accessibility may be formulated based on this conceptualization. The first area is the study of accessibility in urban – transportation geography where various formal specifications of access indices were developed (Ingram, 1971; Kwan, 1998; Miller, 1999; Morris et al, 1979; Talen and Anselin, 1998). As the concepts of impedance, distance, attractiveness, opportunity sets, individual accessibility, and space – time constraints have specific meaning in this literature, they are reexamined in the context of cyberspace for providing a basis for formulating operational accessibility measures. The second area I refer to is the study of human spatial cognition, travel, and wayfinding in behavioral geography and environmental psychology (Allen, 1999; Gärling et al, 1994; Golledge, 1999; Montello, 1998). As use of the Internet involves many cognitive processes similar to those in the physical world, such as spatial learning and navigation in unfamiliar environments, theories of cognitive mapping and wayfinding behavior in the physical world may provide insights for understanding human cyberspatial behavior. The third area of research I draw upon is the studies of human – computer interaction (HCI) by computer and information scientists. Although this is a relatively new area, the literature has shed light on many important issues pertaining to how individuals access information resources on the Internet (Abrams et al, 1998; Huberman et al, 1998; Pirolli and Card, 1995; Yan et al, 1996). Through integrating insights from these three areas of research, I hope to identify useful theoretical constructs for establishing a behavioral foundation for cybergeography.

Some clarification should be given about the nature and scope of this study. First, analogous to access to urban opportunities, many factors affect a person's access to Internet resources throughout the entire process. These include access to the technology (similar to having a car in the physical world), knowledge about the resources available in cyberspace (spatial knowledge about the urban environment), the ease of navigation between web pages or sites (the ease of movement on a transportation network), and skills in web navigation (the ability to drive). The conceptual framework proposed in this paper attempts to incorporate these factors in terms of general theoretical constructs such as distance or impedance. Insofar as these constructs can be operationalized to take into account the effect of these factors on accessibility in cyberspace, such a framework is helpful for capturing the structure of the problem and enhancing our understanding of it. More importantly, it enables the analysis of accessibility in the hybrid physical – virtual world through extending the accessibility concepts for geographic space to cyberspace.

Second, I focus here on providing a framework for evaluating differences in individual accessibility to information resources within the Internet (that is, after users are connected to the Internet). The term 'individual accessibility' not only refers to the access experience of individuals, but it also alludes to a contrast with the notion of 'place accessibility', where accessibility is evaluated as an attribute of a particular location in geographic space [see the discussion in Hanson (1995) and Pirie (1979)]. The importance of focusing on the individual stems from the fact that place-based or area-based accessibility measures may not reflect the actual experience of individuals in their everyday lives (Kwan, 1998; 1999a; Pirie, 1979). Third, the paper deals only with that part of the World Wide web (WWW) where the underlying information structure is not apparent to the user [whereas cyberspace comprises many types of place and space (Batty, 1997)]. I do not presume that the proposed framework will be equally applicable to other areas of the Internet where the interaction environment is represented explicitly in terms of place-like simulated environments. These include multiuser domains (MUDs), MOOs (MUD object oriented) and virtual world representations such as AlphaWorld [see the discussion in Dodge (1999) and Taylor (1997)]. Fourth, while the insights of social – cultural studies on cyberspace are fully acknowledged, this literature is not discussed in the paper (for example, see Adams, 1997; Jones, 1997; Kitchin, 1997).

The paper begins with an examination of recent studies where geographic concepts and methods have been applied to analyze accessibility to and within the Internet. Limitations of these studies are discussed. Three major themes are then explored in subsequent sections: (a) From the user's perspective, what kind of space is cyberspace? (b) Given the nature of this cognitive cyber-environment, what representation or conceptual model is useful for the study of individual accessibility in cyberspace? (c) Based on this representation, what operational measures may be formulated for the measurement of individual accessibility in cyberspace?

Approaches to the study of accessibility to or within cyberspace

Recent studies by urban researchers and geographers on accessibility to and within the Internet can be divided into three types: (a) area-based studies; (b) network-based information flow modeling; and (c) network-based analysis of information structure in cyberspace.

(a) Area-based studies on access to the Internet

Area-based studies examine the geographical patterns of Internet usage or access in cities or regions. They analyze Internet usage by means of area-based data and aggregate indices. These include the number or proportion of people with access to personal computers and Internet services, and the number of Internet domains, hosts or IP addresses found in a city or region (for example, see Batty and Barr, 1994; Dodge, 1996; Dodge and Shiode, 1998; Moss and Townsend, 1997; 1998; Shiode and Dodge, 1998). By the use of aggregate data and cartographic or GIS methods, these studies revealed the spatial and social inequality in the distribution of Internet infrastructure or access services. They have greatly enhanced our understanding of the spatial patterns of Internet usage or access.

The data and methods used in these area-based studies, however, are not suitable for the evaluation of differences between individuals or access within the Internet. First, as interpersonal differences in access to Internet resources are mostly lost in the area-based aggregate analysis, these studies cannot reflect fine-scale differences in the access experience of individuals belonging to various gender or ethnic subgroups. Further, as these measures are based on the physical elements of the Internet (such as the number of hosts), data are collected and organized with respect to specific geographical locations or areas, and results are often ‘mappable’ in geographic space (Dodge, 1996; Jiang and Ormeling, 1997). However, this reliance on geo-referencing breaks down when the analyst attempts to investigate individual accessibility within the Internet.

When an electronic packet can travel from the USA to New Zealand or Japan and back in less than one second, time – space convergence is literally complete (Gillespie and Williams, 1988).(1) The physical distance between the origin and destination of an electronic packet also seems to bear little relationship with the duration taken to traverse this distance (MCI, 1998; MIDS, 1998).(2) Further, although an individual’s experience of using the Internet may engender a sense of ‘place’ or ‘community’, it does not seem to lead to a sense of distance or direction as there is no geographical landmark or physical movement in ‘cyberspace’ for telling either distance or orientation. All these pose a serious challenge to existing geographical concepts and methods, which are largely built upon distance-based location theories and geo-referenced spatial relations (Couclelis, 1996; Graham, 1998). When there is no friction of distance

(1) This result was obtained by the author using TraceRoute.

(2) The duration for an actual Internet session, however, varies greatly and depends on many factors such as load and traffic, performance of the routers and servers along the route, and performance of the software used (see MCI, 1997; Mecklermedia Corp., 1998). Although round-trip ‘transfer’ time over the Net seldom exceeds five seconds (see MCI, 1998; MIDS, 1998), actual transactions often appear to be much slower to web users because of the performance of access devices and connecting services in the locality (Comber, 1995). Further, for users connecting to Internet service providers (ISP) via modems, the number of users currently logged onto the system and the maximum modem speed allowed by the modem server may contribute to a significant proportion of the access duration of a particular Internet session.

and the Cartesian logic of space does not hold, what conceptual apparatus and operational methods can be used for evaluating individual access to resources on the Internet, given its seemingly placeless and timeless characteristics?

(b) Network-based information flow modeling

In response to the need for a new metric for evaluating accessibility within cyberspace, two types of network-based studies have emerged in recent years. Both conceptualize the Internet in terms of a network topology, focusing either on information flow within its infrastructure (that is, computer networks) or on the structure of information itself (for example, the network of hyperlinks among web sites or pages).

Considering information flow within the Internet as traffic flowing within a physical network (for example, a transportation network), Murnion (1999a; 1999b) established a network-based framework for measuring the distance and relative location between web sites based on the speed of information flow within the Internet. With the ping utility, which sends an electronic packet to a remote host and back to the original machine while recording the time for the round trip, latencies (the round-trip travel times) between Internet hosts were determined and used as a measure of distance in cyberspace. Based on these data, the latency pattern can be mapped onto geographical space, and spatial interaction models can be applied to analyze accessibility to information resources on the Internet (as in Murnion and Healey, 1998). This approach represents an innovative application of geographical methods in the analysis of interaction patterns and accessibility in cyberspace. If human behavior in cyberspace and the characteristics of the Internet infrastructure have sufficient features in common with behavior in the physical world, these geographical models will not only be applicable but are promising tools for evaluating accessibility in cyberspace. With latency as its foundation, however, this modeling framework has difficulties in providing a satisfactory metric for cyberspace.

First, latency reflects the travel time of information between Internet or web servers closely connected to the high-speed backbone (T1) or some other high-speed connections in wide or local area networks. It depends largely on load and traffic on the Internet in real time and on the performance of the network devices involved (for example, routers). But a significant proportion of the actual access duration for many users, especially those who access the Internet from home or from computers less directly connected to the backbone, depends more on other elements of the network (such as performance of local access servers or modem speed available from Internet service providers). This means that an appropriate measure of Internet distance (or time) needs to take into account all the components that contribute to the total access duration for users. Further, how much change in latency will be humanly perceptible, will exceed users' tolerance threshold or is capable of producing changes in user behavior still needs to be empirically determined.

Second, as the pattern of latency changes quite swiftly in real time depending on Internet traffic, it may be difficult to react consistently to these real-time changes in latency even for those users who are directly connected to backbone networks. Even when a consistent relationship between latency and access patterns in real time is observed, it may simply be the result of the self-organizing capability of the Internet, where electronic packets are routed through the fastest links between two servers (as this will automatically lead to more transactions with shorter latency). The use of proxy servers or web caching software that store data on remote hosts locally for accelerating information retrieval also undermines the usefulness of latency as a measure of Internet distance. There may also be the problem of spatial autocorrelation, where users tend to visit sites or interact with people in nearby geographical areas for reasons other than short cyberspatial distance.

(c) Network-based analysis of information structure in cyberspace

Another network-based approach analyzes accessibility in cyberspace in terms of the information structure of the WWW (that is, the network of hyperlinks among web sites or pages). The most distinguishable feature of the WWW is its use of hypertext with multimedia (or hypermedia) as a means of navigation for users. Hypermedia is a non-sequential nonlinear method for organizing and displaying information in the form of text, graphics, animation, sound, and video (Balasubramanian, 1994; Eklund, 1995; Sano, 1996). Its advantage lies in its ability to store data in complex and connected networks of nodes and links which allow for effective cross-referencing. In the case of the WWW, this is achieved by anchoring hyperlinks on a particular web page to other resources through embedded address pointers known as Uniform Resource Locators (URLs). Links on a web document can bring the user to a document on the same web site (relative URL) or on another site (absolute URL) (Kahn, 1998). Thus, users of the WWW can have access to a large number of documents on the Internet.

When the interconnected structure of information resources on the WWW is conceptualized in terms of a network topology, it can be considered as a 'graph' where each resource is a node and the hyperlinks constitute the links (Girardin, 1995; Munzner, 1997; Skupin and Buttenfield, 1996; Wood et al, 1995). The distance between pairs of resources (as two points in this information space) may be measured in terms of the similarity of their contents or the number of hyperlink connections between them along the shortest path on the network (Dodge, 1999). This will lead to the creation of a metric, which makes it possible to represent each resource as a point in a high-dimensional space. Using visualization techniques, the user may be able to identify the 'virtual location' of each resource in 'cyberspace' and hopefully the ease of navigating this space will increase (Girardin, 1995; Palfreyman, 1996). Under this graph-theoretic conceptualization, the objective information structure of cyberspace is represented in much the same manner as in the case of a transportation network in the physical world.

This objective representation of cyberspace, however, is not very relevant from the web user's viewpoint. Because the physical infrastructure of the Internet is largely invisible to the user, and the information structure it entails is often the work of well-trained designers, individual access to information resources cannot be understood through these 'objective' representations (Chalmers et al, 1998). For instance, as many web users tend to click on one of the first few links on a web page and never scroll further down, the shortest distance between information resources or web documents based on the hyperlink network structure may be very different from what users perceive as the shortest distance.[3] From the user's point of view, the Internet is an 'environment' consisting of resources or opportunities for getting information, interacting with others, and performing transactions (Gaines et al, 1997; Staple, 1995). For them, using the Internet and searching information on the web is a subjective experience involving many cognitive and decisionmaking processes including searching, learning, and cognitive mapping (that is, establishing a mental model of the objective environment such as the identity of objects and their relations with each other) (Golledge et al, 1994; 1995).

As the 'cognitive cyber-environment' is the effective environment within which an individual interacts with resources in cyberspace, understanding its nature is essential for understanding the factors affecting individual accessibility to these resources. This understanding will then provide important hints for answering questions about which resources in cyberspace are accessible to a particular individual in her or his everyday life. As little research has been conducted with this perspective, in the next section I will

[3] Buttenfield (1999), however, evaluated distance from the user's perspective. Pages which users linked to with higher frequency are considered 'closer' together in their minds.

attempt to provide an outline based on the limited knowledge about cyberspatial cognition available today.

Cyberspatial cognition and the cognitive cyber-environment

The following questions are pertinent for understanding human cyberspatial cognition. From the user's point of view, what kind of 'space' is cyberspace? Does a user normally have a mental 'map' of this cyberspace that can be used when looking and searching for information resources? Given the limited capacity of humans to process a huge amount of information, what are the processes involved in the formation of the opportunity set (or choice set)? How can the enormous amount of resources (that is, the universal set of all opportunities) in cyberspace be 'translated' into a person-specific feasible opportunity set? What are the implications of these for the study of individual accessibility in cyberspace? What hints can geographic theory provide for conceptualizing the nature of this problem?

Perhaps the most common experience from interaction with resources in cyberspace is the contradictory sense of being 'somewhere' and 'nowhere' at the same time. The sense of 'place' as a subjective experience engendered by the use of the Internet has been described as 'the feeling of geography' that the user has in this space (Cubbison, 1996; Suler, 1998), or in the words of Bray (1996, page 1001): "... when you are in it, feels like a place." Despite this sense of 'place', however, cyberspace is often described as structureless and chaotic, with no fixed topology (Holt, 1994). Its "geography is continually in flux ... there are no centers or boundaries, no up or down, north or south .... The most common problem users experience is feeling lost, not knowing where they are in relation to anything else 'out there', not knowing where they have come from or where they might be about to go" (Leeder, 1997, page 2). "It manifests [itself] ... as a sequence of panels marching across your screen. This leads to an absence of perspective, of context, and finally, of comfort" (Bray, 1996, page 1001). Others have similarly characterized the experience as a strong sense of being 'lost in space' (Girardin, 1995; Meyrowitz, 1985). The contradictory experience of being somewhere and nowhere at the same time is perhaps the most obvious cognitive dissonance resulting from the use of the WWW.

To understand why this cognitive dissonance is such a common experience, several specific characteristics of the cognitive cyber-environment should be noted. First, the experience of cyberspace is drastically different from what we experience in our everyday lives, where space is continuous and ordered, and one part is normally followed by another (Staple, 1995). Because information resources provided through the WWW are presented to the user in the form of nonlinear hypermedia, the user can not only 'move' forward, but also move backward and 'jump' to another point without knowing its location or context. As this 'movement' pattern is very different from the travel experience in our everyday lives (in which movement is largely linear, continuous, and forward), and given that there are no landmarks and locational referencing system to anchor and consolidate this perceptual experience, the formation of a cognitive map of cyberspace is difficult. Without the sense of location, distance, and direction necessary for the formation of configurational spatial knowledge, and without a habitual movement pattern essential for developing route-based spatial knowledge, an articulated cognitive map of cyberspace cannot be established (Golledge, 1995; 1999). As a result, it is not surprising that the user often has a strong sense of disorientation (Balasubramanian, 1994; Fleming, 1998).

Another important feature of the cognitive cyber-environment is that it violates a fundamental principle about the nature of maps. In our normal understanding, the map is not the territory; that is, the territory exists wholly apart from the map of it (Staple, 1995). But in the case of cyberspace, the map and the territory often appear to be one and the same thing. This is especially so in the case of the WWW, where space appears on the computer screen as a series of documents connected to one or many others via embedded hyperlinks. The hypermedia 'map' provides the directions needed for navigating to other information resources and no knowledge about the location of these resources or about the intervening communication links is required. In a very real sense, "the session is the map" and "the Web is its own map" (Staple, 1995, page 68). Thus, cyberspace is the map itself that defines and becomes the space (Baudrillard, 1983). This characteristic of cyberspace leads to another major contradiction in the cognitive experience of cyberspace. Although the web is its own map, the map is neither 'visible' nor apparent to the user. On the one hand, it should be surprisingly easy to find resources, as many things are just a few mouse 'clicks' away following the hyperlinks. On the other hand, the real-world experience is often frustrating precisely because of the locational obscurity of these resources on the Internet (Dieberger, 1995; Sano, 1996).

Further, as the user sees only one web page at a time, the cognitive cyber-environment can be characterized as a 'large-scale environment' in which its entire 'landscape' is beyond the user's mental viewfield and that only a small portion of it can be handled by the limited human perceptual capability at a time (Åm, 1994; Darken and Sibert, 1996; Kuipers, 1978; Montello, 1993). As the ability to conceptualize the space as a whole is essential for generating configurational or survey knowledge needed for wayfinding tasks, it is difficult for the user of the WWW to navigate in such an environment without navigational aids (Fleming, 1998; Golledge et al, 1995; Thorndyke and Goldin, 1983). In addition, certain areas of cyberspace may lack the temporal stability needed by the user to establish a cognitive map of the cyber-environment through repetitive visits over time. For instance, a large number of new documents are added to the Internet each day and the URLs of many old documents become outdated at a surprising rate (Comber, 1995). In addition, cyberspace "changes daily, even hourly as new computer links are added and others decay" (Staple, 1995, page 66), and is therefore continually in flux (Leeder, 1997). This transient and ephemeral nature of parts of the cyber-environment renders the cognitive effort to establish a mental map much more difficult.

As a result of these characteristics of the cognitive cyber-environment, several problems can be identified which are crucial for understanding the problem of individual access to information resources in cyberspace. The two most difficult problems for users of the WWW are disorientation and cognitive overhead (Conklin, 1987; Kahn, 1998). The problem of disorientation or 'getting lost in cyberspace' arises from the tendency to lose one's sense of location and direction in a nonlinear environment. In a complex hypermedia environment, it is often difficult to know where one is, where one came from, and how to get to another place (Eklund, 1995; Sano, 1996). Cognitive overhead is the additional mental effort and concentration necessary for making decisions as to which links to follow and which to abandon, given a large number of choices. The process of pausing (either to jot down required information or to decide which way to go) can be very distracting. It can become a serious problem if there are a large number of nodes and links (Balasubramanian, 1994). Further, the user needs to have a substantial knowledge about particular subject or content areas in order to be able to select a sequence and strategy according to her or his needs (Eklund, 1995).

A conceptual model of individual accessibility in cyberspace

With this background on the cognitive cyber-environment, I will describe here a conceptual model before discussing issues concerning how operational measures of individual accessibility may be formulated (figure 1, see over). The conceptual model consists of three major elements: (a) the individual as an extensible agent; (b) the access interface

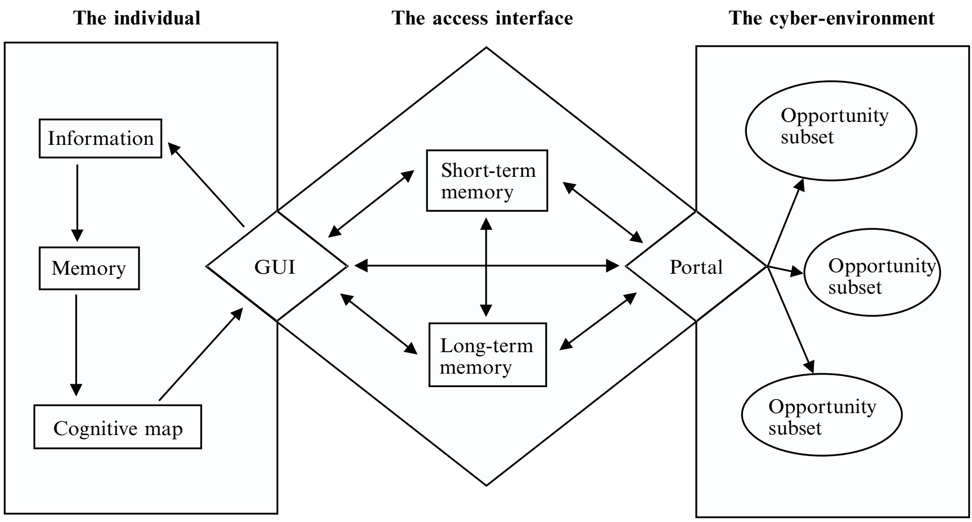

Figure 1. A conceptual model of individual accessibility in cyberspace (note: GUI, graphical user interface).

consisting of the hardware and software components used to access information resources in cyberspace; and (c) the opportunity environment in cyberspace (or the cyber-environment). This model focuses more on the cognitive–behavioral dimension of the accessibility problem in the postconnection stages. It emphasizes that accessibility to information resources in cyberspace depends not only on the availability of connecting devices and services, but also on a person's knowledge and skills in using navigational aids and search tools.

(a) The individual as an extensible agent

The concept of the individual as an extensible agent was first formulated by Janelle (1973), where extensibility represents the ability of a person to overcome the friction of distance through space-adjusting technologies, such as transportation and communication. As the conceptual reciprocal of time–space convergence, which reflects the degree to which places are approaching one another in time–distance, human extensibility measures the increased opportunities for interaction among people and places (Janelle, 1973). Adams (1995) extended this notion of extensibility through a new model of the person based on the structuration perspective, where the spatially contingent and socially embedded nature of human extensibility is emphasized. Inequality in human extensibility with respect to gender, race, and other socially significant categories is understood in terms of the mutually constitutive relations between individual experience of accessibility and macrolevel societal processes.

The notion of human extensibility provides a useful point of departure for studying individual access to information resources in cyberspace. It allows observations on individual experience or behavior to be examined in relation to wider social and political processes. One of the basic premises in this paper is that a person's extensibility depends on the availability of the means and knowledge for accessing information resources in cyberspace. Such availability is in turn the outcome of the social and spatial constraints an individual faces in a particular locale. The effect of these constraints may be observed through an examination of a person's accessibility experience in her or his everyday life. Although figure 1 describes the individual largely in cognitive–behavioral terms (see Gärling et al, 1994; Golledge et al, 1994; Kwan, 1997), it acknowledges the importance of personal factors or situations in affecting individual accessibility to resources in cyberspace. These include personal attributes such as gender, race, age, income, prior training or knowledge in using access devices, and the availability and use of off-line information sources (such as printed materials or information from colleagues).

(b) The access interface

The access interface refers to the collection of hardware, software, skills, and knowledge base needed for accessing Internet resources. This is the most crucial area for examining differences in personal accessibility between individuals belonging to various population subgroups. In figure 1, important elements in this access interface are described in terms of four categories: (a) the 'portal', which serves as the entry point to cyberspace and provides navigational and search support to the user; (b) the short-term memory, which refers to the in-session repertoire of access history and resource locations (usually in the form of session history) which vanishes as the user exits the browser; (c) the long-term memory, which is the accumulated knowledge base of all the sites visited and their address pointers (such as bookmarks and history files); and (d) the graphical user interface (GUI). Not shown in figure 1 but important in the access interface is the network connection, which includes all access devices (such as the computer and modem) and the connecting services (such as DSL, ISDN, and cable and satellite connections). The following discussion focuses largely on the first three elements in the access interface.

If spatial learning in cyberspace is similar to that in the physical world, an individual's ability to access resources in cyberspace will go through a progression—from a beginner to a novice user and finally to an experienced user (Golledge et al, 1995).(4) As a beginner, a user learns about the quality and usefulness of each site visited and starts to build up a repertoire of 'landmarks' or 'routes' for establishing a mental model of the cyber-environment (Golledge, 1995; 1999). As a user's experience increases through repeated and new visits, a regular 'home' (the start page) is established as the habitual starting point for 'entering' cyberspace and for anchoring navigational routines. As certain sites are visited regularly and recurrently, a set of transactional routines will also be established, although with occasional deviations. A well-articulated mental map of cyberspace, which provides configurational or survey knowledge essential for wayfinding, will be established for guiding future navigation and transactions in cyberspace.

This, however, is unlikely to be true in the actual experience of web users. As discussed in the previous section, cyberspace is a large-scale environment and the WWW lacks a recognizable structure to the user owing to its use of hypermedia. Because of the complexity and changeable nature of the environment, navigational or search procedures cannot be routinized easily. Further, as URLs are usually long and hard to remember, human effort is simply inadequate for the cognitive tasks required to remember many of them. As a result, the user has to resort to other means for relieving the cognitive burdens of cyber-transactions and establishing a repertoire of valuable information resources. This process may be called 'computer-assisted memory building'. Two elements of this process are identified in figure 1: the portal, and the memory structure in the access interface.

In Internet parlance, a portal is a gateway to the Internet—the page that shows up when the user launches the web browser and begins a 'journey' in the WWW (Lauzon, 1998; Lidsky, 1998). It is the habitual entry point for users when they get connected to the web, or the 'anchor site' where they return when they get lost. As anchor points (Golledge and Spector, 1978), portals not only provide users a sense of orientation, they also include many links that guide the user to other web sites or pages of interest. Many portal sites

(4) See Montello (1998) for a nondevelopmental perspective on the acquisition of spatial knowledge.

(such as Yahoo! and Excite) now also offer users the ability to create customizable home pages according to their personal interests. With the provision for customized start pages and personalized web-linkage systems, the portal is not only a helpful memory-building tool for the user. It can also provide important clues about a user's 'potential reach' in cyberspace. For instance, the use of portals that provide comprehensive and convenient links to powerful search engines (such as HotBot and AltaVista) may considerably increase the user's extensibility in cyberspace, whereas the start page of a local Internet Service Provider (ISP) may lead users largely to local sites and resources.

Another element of computer-assisted memory building is the history mechanisms provided by web browsers which allow users to establish a short-term or long-term memory about the pages they have viewed. Besides providing easy access to previously visited pages, history mechanisms can also reduce a user's cognitive and physical navigational burdens (Judge, 1998; Tauscher and Greenberg, 1997). For each user, a permanent memory is accumulated over an extended period of using the WWW and archiving the URLs of interesting sites. The most commonly used 'mnemonic devices' are bookmarks and history files that help to remember important information a user has found on the web. Bookmark pages are often perceived by users as 'landmarks', which help establish their 'personal web information spaces' (Abrams et al, 1998). As such, the computer-built long-term memory not only records the 'trails' or 'action space' of a person in cyberspace (Allen, 1999), it also reflects an individual's personal accessibility to information resources in the cyber-environment.

(c) The opportunity environment in cyberspace

Given the sheer amount of information resources in cyberspace and the limited human capability to deal with a large amount of information, a user can interact with only a tiny portion of it at a time. Even after a long period of usage, only a small subset of the entire set of opportunities will be accessible to a particular user (Huberman et al, 1998; Tauscher and Greenberg, 1997). In other words, not all opportunities in cyberspace are relevant or potentially reachable for a particular user. The opportunity environment is therefore represented as several subsets of the universal set of opportunities in cyberspace shown in figure 1. Each subset contains a collection of closely connected web resources (such as those on the same web site or domain). As the potentially reachable resources for the person in question, they together constitute the opportunity set in cyberspace.

The size and scope of this opportunity set is determined by a number of factors, including the navigational and search skills of the person, as well as the constraints or barriers to movement in cyberspace. Making informed decisions about how and where next to proceed in cyberspace often requires the mastery of a set of 'hands-on' skills, many of which are intuitive and difficult to document (Eklund, 1995; Judge, 1998; Pool, 1997; Staple, 1995). Learning these skills requires considerable cognitive effort and time. For instance, to take full advantage of the power and flexibility of Internet search engines, the user needs to spend time learning advanced search techniques, such as the use of Boolean operators, wildcards, keyword weighting, and word-variant searching (Lidsky and Kwon, 1997). Further, as different search engines are best at searching certain subject areas or items, the user also needs knowledge about the specialization of different search engines. Without these skills and knowledge, searching data and retrieving information from such a large number of opportunities can be a frustrating experience. A user's query may end up either in a large number of returned results or in zero 'hits' (Fabrikant and Buttenfield, 1997).

In addition to constraints due to navigational and search skills, barriers to movement abound in cyberspace. Movement can be constrained by areas open only to paid subscribers and registered members. Broken links and pages under construction, besides stopping movement, may lead to frustration that hampers future search. Personal attributes such as low tolerance for slow responses, personal preference, and aversive behavior (for example, avoiding certain types of cyber-transactions), as well as privacy and security concerns may further limit the 'potential reach' of a user in cyberspace (Georgia Tech Research Corporation, 1998). Further, even when a user has acquired advanced search skills, Internet directories, indexes, and yellow pages are often incomplete and outdated (Lawrence and Giles, 1998). They may also be biased by protective policies of the sponsoring companies, as in the case where other free web-hosting domains are banned from a site's directory or index (Webb, 1998). Lastly, the lack of appropriate plug-ins and support for secured transactions on the browser side may further limit a user's opportunity potential.

Considering the characteristics of the cognitive cyber-environment and the multitude of processes and factors examined in this section, it is obvious that formulating operational measures of personal accessibility for reflecting an individual's experience in cyberspace is a difficult task. The problem is not only to specify formulations for incorporating the most revealing dimensions or variables into such measures. Their operationalization is also a major challenge.

Issues on formulating operational measures of cyber-accessibility

In light of the previous discussion, in this section I will examine the limitations of conventional measures for evaluating access to information resources in cyberspace. An attempt is made to provide a vocabulary for extending the fundamental constructs for the study of cyber-accessibility.

(a) Redefining distance and impedance

A fundamental premise of all conventional accessibility measures is the physical separation of demand and supply points in geographic space. The problem of accessibility is conceptualized as a problem of overcoming the impedance due to this physical separation through movement of materials or people (Oberg, 1976; Pirie, 1979). Individual accessibility therefore depends on the spatial distribution of opportunities, available means of transport, and travel mobility (Hanson and Schwab, 1987). With physical distance between locations as the major impedance to movement, and with a given space – time distribution of opportunities in an area, various formulations of operational accessibility measures can be specified (Kwan, 1998; 1999a; Miller, 1999; Morris et al, 1979; Talen and Anselin, 1998). Further, the geometry or topology of the transportation network, and the space – time constraints faced by individuals in their everyday lives are also crucial considerations. For these conventional measures, distance-based impedance, which may be expressed in terms of time or cost, is the fundamental element. The effect of distance on the attractiveness of opportunities is usually taken into account by an impedance function.

The nature of accessibility in cyberspace, however, is drastically different from that in the physical world. In cyberspace, access to resources, and interaction between different individuals are media-based. Accessibility depends more on a multitude of processes and factors unrelated to physical distance than distance-dependent impedance. Because the fundamental construct of conventional accessibility measures no longer holds, the concept of individual accessibility needs to be redefined and the notion of distance-based impedance needs to be expanded to include other non-distance-related factors, such as the effort or time spent on transactions. As Janelle (1969) elaborated, accessibility is a measure of the ease (time, cost or effort) with which transfer occurs between the places and areas of a system. An accessibility measure therefore does not have to be based on distance-dependent impedance. Further, Falk and Abler (1980) emphasized the importance of two other kinds of distance in geographical theory besides globe (physical) distance. These are effort distances measured by the number of effort units consumed in moving from one place to another, and metaphorical distances measured by the number of contacts between places during a given time period. These notions are helpful for redefining the meaning of accessibility and for measuring personal accessibility in cyberspace.

As shown in recent studies, the amount and frequency of specific types of information-accessing activity are negatively related to the human effort required. For instance, Huberman et al (1998) and Yan et al (1996) observed that most web sessions consist of browsing only a few pages and, as the number of pages increases, the percentage of sessions decreases. Tauscher and Greenberg (1997) found that people tend to access a few pages frequently, browse in very small clusters of related pages, and generate only short sequences of repeated URL paths. Catledge and Pitkow (1995) also observed that web pages deep down in a search hierarchy are less likely to be browsed. These results strongly suggest that impedance in personal access to information resources in cyberspace, similar to the case in the physical world, can be assessed by the amount of human effort required (which is the result of the time and cognitive effort needed). This expanded notion of impedance also allows for a redefinition of the concept of distance decay, which now refers to the phenomenon of decreased transactions because of the increase in effort required, not the longer physical distance to be traversed.

(b) Determining the opportunity set and the attractiveness of opportunities

Besides distance-related impedance captured by the distance-decay function, most conventional accessibility measures also depend on the ability to delimit a relevant opportunity set in the environment and to assign a weight to each opportunity for reflecting its 'attractiveness'. As discussed earlier, owing to the large amount of resources involved, the use of hypermedia, and the complex webs of links between resources in cyberspace, the delimitation of a universal opportunity set in cyberspace is nearly impossible. Even when this can be done, the set thus identified will be so large that it is not relevant to a typical Internet user.

A better strategy is to delimit a smaller set of opportunities based on their space–time feasibility (as in the case of space–time accessibility measures). However, delimiting such a set in cyberspace is much more difficult when compared with the case of specifying an opportunity set in the physical world (for example, see Kwan and Hong, 1998; Landau et al, 1982; Miller, 1991). As no previous research has established the amount of time required for various kinds of cyber-transactions, the most difficult problem is how to identify which opportunities are accessible and to determine their total number when a person has a given amount of time. Lastly, there is the question about deciding the appropriate weight to assign to each opportunity for reflecting its attractiveness. Possible weights that can be used include the time spent on a page, the frequency with which it is accessed by a user, and some measures of its content. For instance, Yan et al (1996) observed wide variations in the time spent on a page and decided to use the number of times a page is reaccessed per session as the weight assigned to that page. More research is needed on this area in the future.

(c) Two alternatives

In view of these difficulties in formulating operational accessibility measures, two possible alternatives are now discussed: (a) adapting space–time accessibility measures for handling cyber-transactions; and (b) formulating new types of measure for evaluating accessibility in cyberspace.

Space – time accessibility measures are based on the number of opportunities accessible by a person given her or his space – time constraints (Burns, 1979; Lenntorp, 1976). These measures have a number of advantages over conventional measures owing to the use of space-time feasibility as its fundamental construct (Kwan, 1998; 1999a). The underlying concept can be illustrated by diagrams of individual space – time paths (Adams, 1995; Kwan, 1999b; 1999c; Miller, 1991). As recent research indicates, Internet users are sensitive to delays and the time needed for cyber-transactions (Sears et al, 1997). They considered the speed of connection to be important (Georgia Tech Research Corporation, 1998). If users are time-sensitive, it may be concluded that space – time constraints will remain an important influence on personal access to information resources on the Internet. Further, the space – time availability of access devices or connecting services may also affect accessibility (for example, for someone who has access to computers only in the workplace). In addition, certain transactions in cyberspace may also have their space – time fixity characteristics (in the case of scheduled chat events). Because space – time accessibility measures are based on the space – time feasibility of activities, they can be adapted for the study of individual accessibility in cyberspace.

The second, alternative approach is to formulate new types of measure for evaluating personal accessibility in cyberspace. The foundation of this kind of extension will be based on an examination of an individual's Internet portal and memory repertoire. There are several areas which may be useful points of departure. First, as bookmarks are accumulated over an extended period of time, their number and the effort put into organizing them are helpful indicators of the ease with which an individual can access web resources. Second, as bookmarks are added at a fairly constant rate, their rate of increase over time can also reveal many unique characteristics of a user's computer-assisted memory building process (Abrams et al, 1998). Third, analysis of access patterns by means of records of browsing history (such as client-side log files) has also been fruitful (Catledge and Pitkow, 1995; Yan et al, 1996). As observed by Tauscher and Greenberg (1997), users incorporate new URLs into their repertoire at a regular rate, and revisits are fairly evenly distributed. The rate of increase in the number of unique URLs in memory over time can therefore be used for revealing interpersonal differences in individual accessibility.

Conclusions

In this paper I have examined individual accessibility in cyberspace from a cognitive – behavioral perspective. It has been argued that the objective structure of information resources in cyberspace is not very relevant for understanding the subjective experience of individual access to these resources. Instead it is suggested that cyberspatial cognition is crucial in constituting the effective cyber-environment in which individuals interact with information resources in cyberspace. A conceptual model, which conceives the individual as an extensible agent, is then proposed. The model focuses on the access interface between the individual and cyberspace, and identifies the portal and history mechanisms as important elements affecting individual accessibility. Based on this model, notions fundamental in conventional accessibility measures are reexamined. These include the notion of distance, impedance, opportunity set, and attractiveness of opportunities. Two alternative approaches to measuring individual accessibility in cyberspace are then proposed.

As shown in the paper, human behavior in cyberspace bears certain similarities with spatial behavior in the physical world. Many geographic theories about spatial learning, cognitive mapping, choice, and decisionmaking behavior are therefore helpful for understanding the cognitive experience of individuals in cyberspace. For instance, many features of spatial learning and wayfinding have their equivalents in cyberspace [for example, using bookmarks as landmarks, and building long-term memory with computer-assisted history mechanisms (Allen, 1999; Golledge, 1999)]. As Darken and Sibert (1996) argued, knowledge about human wayfinding in the physical world may be applied to construct aids for wayfinding in cyberspace. This suggests that behavioral models may be able to provide the theoretical foundation for cybergeography, especially when the focus is on individual differences in personal accessibility in cyberspace.

With this approach, not only can individual-level differences be revealed, but the effect of other person-specific factors on accessibility may also be examined (for example, gender or ethnic difference in cyberspatial ability). When linked to the analysis of sociospatial processes, a contextualized understanding of the situated experience of individuals in a particular locale may become possible. Future research along this line will also help shed light on many important issues pertaining to user experience and the design of web sites. For example, if the simulated environments of virtual worlds can successfully help users to anchor their cognitive map of cyberspace to a geographic framework, these virtual environments can be used to facilitate cyberspatial learning and navigation. The popular use of spatial metaphors, which help anchor the 'unmappable' experience of cyberspace onto mental models of geographic space, in discourses about cyberspace can also be understood in terms of their cognitive function.

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