14 Human Extensibility and Individual Hybrid-accessibility in Space-time: A Multi-scale Representation Using GIS

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14.1 Introduction

With the increasing use of the Internet for getting information, transacting business and interacting with people, a wide range of activities in everyday life can now be undertaken in cyberspace. As traditional models of accessibility are based on physical notions of distance and proximity, they are inadequate for conceptualizing or analyzing individual accessibility in the physical world and cyberspace (hereafter referred to as *hybrid-accessibility*). To address the need for new models of space and time that enable us to represent individual accessibility in the information age, there are at least three major research areas: (a) the conceptual and/or behavioral foundation of individual accessibility; (b) appropriate methods for representing accessibility; and (c) feasible operational measures for evaluating individual accessibility. With the recent development and application of GIS methods in the study of accessibility in the physical world (e.g., Forer 1998, Hanson, Kominiak, and Carlin 1997, Huisman and Forer 1998, Kwan 1998, 1999a, 1999b, Miller 1991, 1999, Scott 1999, Talen 1997, Talen and Anselin 1998), it is apparent that GIS have considerable potential in each of these research areas. As shown in some of these studies, a focus on the individual enabled by GIS methods also reveals the spatial-temporal complexity in individual activity patterns and accessibility through 3D visualization or computational procedures.

Yet, even with the advent of 3D GIS tools, there are several difficulties when GIS methods are applied to represent or measure individual hybrid-accessibility. First, personal accessibility in the age of information involves multiple spatial and temporal scales (Hodge 1997), whereas current GIS are designed to handle only one geographical and/or temporal scale at a time. For instance, personal extensibility enabled by telecommunication technologies now allows an individual to access information resources at the global scale although the person's physical activities are still largely confined at the local scale. Further, the traditional temporal scale (hour/minute) is not adequate for studying cyber-transactions that may be accomplished within a few seconds. Second, GIS-based representational and computational methods, such as the space-time prism, are based on the sequential unfolding of a person's activities in the physical world. They are not developed to handle the simultaneity and temporal disjuncture that characterize many types of cyber-transactions. For example, a person may be talking over the phone and browsing a Web page at the same time. An email message sent out now may be read several hours later on the other side of the globe. These limitations of current GIS methods constitute a major challenge to any effort to represent and measure individual hybrid-accessibility in the information age.

As a preliminary attempt to address this methodological challenge, this paper explores how current GIS, given their limitations, can be deployed for the 3D interactive visualization of human extensibility in space-time. It develops and presents a method for the multi-scale, 3D representation of individual space-time paths based upon the concept of human extensibility (Janelle 1973, Adams 1995). Using geo-referenced activity diary data for an individual as an example and ArcView GIS software (© ESRI, Inc), the method is capable of revealing the spatial scope and temporal rhythms of a person's extensibility in cyberspace. It can also represent the complex interaction patterns among individuals in cyberspace using multiple and branching space-time paths within a GIS. Compared with the two-dimensional and/or cartographic representations in past studies, this method allows the researcher to interact, explore and manipulate the 3D scene (e.g., rotation, fly-through). This visualization environment not only greatly facilitates exploratory data analysis, but can also enhance our understanding of the patterns portrayed. It may provide the basis for formulating operational measures of individual hybrid-accessibility. In this paper, the nature of accessibility in the information age is first examined, and then alternative representational methods are discussed. Implementation of the GIS method using real activity diary data of an individual is described.

14.2 The Problem of Accessibility in the Information Age

In the physical world, the problem of accessibility is basically a problem of overcoming the impedance of physical separation between locations of demand and supply. Accessibility in physical space, therefore, depends largely on the spatial distribution of urban opportunities, available means of transport, and travel mobility (Burns 1979). Its foundation is the place- or location-boundedness of opportunities, where access to facilities and services is predicated on meeting the space-time co-location and co-presence requirements for spatial interaction (Giddens 1984). With distance between locations as the major impedance of movement, and with a given space-time distribution of opportunities in the urban environment, individual accessibility can be specified by these fundamental elements. In such an environment, the geometry or topology of the transportation network and the space-time constraints faced by individuals in their everyday lives are crucial for evaluating accessibility (Miller 1991).

In the virtual world enabled and created by telecommunication technologies and the Internet, however, the nature of access to opportunities or information resources is drastically different from that in the physical world. In cyberspace, access to resources and interactions between different individuals are mediated by communication technologies. It therefore depends more on the availability of these technologies to a particular person and the skills possessed than the time or cost necessary for overcoming physical separation. Except in the cases where the cost of access or interaction still depends on the physical separation of locations (e.g., long-distance phone charges), distance between locations or individuals would have little effect on individual accessibility and spatial interaction in cyberspace. When an electronic packet can travel around the globe within a second or so, time-space convergence is literally complete (Kwan 2000). Physical distance between the origin and destination of an electronic packet also seems to bear little relationship with the duration taken to traverse such distance (MCI 1998, MIDS 1998).

If physical separation between locations is playing a less important role in determining access and spatial interaction (as in cases where the Internet is used for a wide variety of activities), many fundamental determinants of accessibility in conventional models are no longer important. For instance, the *information superhighway* does not have many similarities with conventional transportation networks. Since locations are connected through worldwide computer networks that enable multiple access paths and that operate on optical fibers at light speed, the effects of physical separation between locations and of topologies of transportation networks are obliterated. Further, since telecommunication technologies and the Internet provide various means for moderating the space-time constraints of many activities, the space-time co-location and co-presence requirements for access or spatial interaction for many activities are also obliterated (e.g., voice mail, electronic bulletin boards, and the World Wide Web). It is possible for one individual to be at several (cyber) locations at the same time, and, thus, to violate the constraint that 'one individual cannot exist in two places at one time' (Carlstein 1982). The spatiotemporal configuration of resources or opportunities in cyberspace is, therefore, drastically different from what is available in the physical world.

With these complexities introduced by cyber-transactions, the problem of accessibility in the new hybrid physical-virtual world is far more complicated and difficult to deal with. This suggests that conventional models are inadequate for representing and measuring individual accessibility in such new hybrid spaces. Further, differences between accessibility in the physical and virtual worlds require new conceptual and analytical models since we are dealing now with two drastically different realms and their interface. To address the limitations of conventional methods for representing hybrid-accessibility, I examine the notion of the person as an extensible agent based on the work of Janelle (1973), Thrift (1985), and Adams (1995). Based on this concept of personal extensibility and Hägerstrand's (1970) time-geographic framework, I then describe a multi-scale three-dimensional representation of individual space-time paths using GIS.

14.3 Human Extensibility in Space-time

Janelle (1973) first formulated the concept of the individual as an extensible agent, 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). The development of communication and transportation technologies (or spatial technologies) and their associated institutions thus imply a *shrinking world* with expanding opportunities for extensibility (Adams 1995, Coucleclis 1994). Further, human extensibility not only expands a person's scope of sensory access and knowledge acquisition, it also enables a person to engage in distantiated social actions whose effect may extend across disparate geographical regions or historical episodes (Adams 1999, Thrift 1985).

Adams (1995) extended this notion of human extensibility through a new model of the person based on the structuration perspective (Giddens 1984), 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 the individual experience of accessibility and macro-level societal processes. Adams (1995) captured the dynamic and fluid nature of personal boundaries through the notion of 'people as amoebas'. The body is reconceptualized as a dynamic entity, which combines

> a body rooted in a particular place at any given time, bounded in knowledge gathering by the range of unaided sensory perception, [and] . . . any number of fluctuating, dendritic, extensions which actively engage with social and natural phenomena, at varying distances (Adams 1995, 269).

This notion of human extensibility not only provides a useful point of departure for understanding individual accessibility in the information age. It also offers a theoretical foundation for overcoming many limitations in the traditional understanding of corporeality found in Hägerstrand's time-geographic framework. As Rose's (1993) critique suggests, depicting a person's trajectory in space-time as a linear and clear-cut path has many difficulties, especially when the framework is used to understand women's everyday lives. Further, since constructs of the time-geographic framework have been used to formulate accessibility measures in the past (e.g., Burns 1979, Lenntorp 1976, Villoria 1989), a representational device capable of handling this reconceptualized extensibility is an important first step in formulating operational measures of individual hybrid-accessibility.

For this purpose, Adams (1995) developed the extensibility diagram using the cartographic medium. The diagram, based on Hägerstrand's space-time aquarium, portrays a person's daily activities and interactions with others as multiple and branching space-time paths in three dimensions, where simultaneity and temporal disjuncture of different activities are revealed. Fuzzy zones surrounding the space-time paths represent the fluidity of personal boundaries. This method, as shown in Adams (1995) and expanded upon in Chapter 13 can be used to represent a diverse range of human activities in both the physical and virtual worlds, including telephoning, driving, e-mailing, reading, remembering, meeting face-to-face, and television viewing. Although the extensibility diagram is largely a cartographic device, most of its elements are amenable to GIS implementation. As a first step to improve the representation and measurement of individual hybrid-accessibility, the next two sections explore alternative GIS methods for implementing the extensibility diagram. The focus is on incorporating the multiple spatial scales and temporal complexities (e.g., simultaneity and disjuncture) involved in individual hybrid-accessibility.

14.4 Alternative Representational Methods

Early methods used to represent human extensibility as individual space-time paths are largely graphical devices (e.g., Burns 1979, Pred and Palm 1978). For the study of individual accessibility, these representations are useful for giving an idea about the size of or changes in the space-time prism resulting from particular activities. Due to the unavailability of the geoprocessing capabilities of GIS at that time, there were only a few attempts to implement these constructs in an operational sense. Those who have resorted to computational procedures for implementing time-geographic accessibility measures, however, encountered many difficulties. Their results may deviate from what might have been obtained if the original constructs were fully implemented (see discussion in Kwan and Hong 1998).

Recent application of GIS methods in representing and measuring individual accessibility in space-time has made significant progress. For instance, Forer (1998) and Huisman and Forer (1998) implemented space-time paths and prism on a three-dimensional raster data structure for visualization and computational purposes. Their method is especially useful for aggregating individuals with similar socioeconomic characteristics and for identifying behavioral patterns. On the other hand, Miller (1991, 1999), Kwan (1998, 1999a) and Kwan and Hong (1998) developed different network-based algorithms for computing individual accessibility using vector GIS procedures. Kwan (1999b) implemented 3D visualization of space-time paths and aquarium using vector-based GIS methods and activity-travel diary data. These studies demonstrated that GIS methods have considerable potential for advancing this research area. Further, implementation of 3D representations of human extensibility is a first step to the development of GIS-based computational procedures. The suitability of two possible methods in a 3D GIS environment is discussed below.

(a) Traditional Single-scale Representation. The simplest method for representing a person's space-time path is the space-time aquarium constructed first by Hägerstrand (1970). In a schematic representation of the aquarium, the vertical axis reflects the time of day and the boundary of the horizontal plane represents the spatial scope of the study area. Individual space-time paths can then be plotted as trajectories in this three-dimensional aquarium. Individual accessibility can be evaluated through deriving the space-time prism defined by fixed activities in a person's daily activity schedule. Recent examples of implementing this representation through 3D visualization using GIS are demonstrated in Chapter 5, in Huisman and Forer (1998), and in Kwan (1999b).

When transactions in cyberspace are included, visualizations using this method encounter one major difficulty: neither the spatial nor temporal scale of the traditional space-time aquarium is adequate for reflecting the full range of activities. For instance, the spatial scale at which local activities and travel can be visualized would render activities at the regional or global level out of range and invisible to the analyst. Further, the temporal intervals for recording activities in the physical world are too long for capturing the rhythm and pace of cyber-transactions, which have sub-second travel speeds (e.g., 0.4 second) and very short transaction durations when compared with physical activities. Using the zoom-in or zoom-out capability of a GIS also does not reduce this difficulty, as experimentation by the current author suggests. Other methods for representing multiple spatial and temporal scales are needed.

(b) Multi-scale Representation Using Linked Graphical Windows. One way to enable GIS-based 3D visualization of a person's space-time path at multiple scales is through the use of several dynamically-linked graphical windows. To implement this method, an individual's activities in the physical world and in cyberspace can be displayed using several graphical *windows*, each of which focuses on transactions at a specific spatial and/or temporal scale. For example, one window may show activities or travel at the local scale (e.g., the county of residence), while another may illustrate cyber-transactions involving Web sites or individuals located in other regions of the world. Each of these windows can be dynamically linked so that manipulations during the visualization process (e.g., rotation) in one of them will be automatically reflected in other linked windows. Further, the analyst can manipulate the graphical objects in any of these linked windows. A single-scale implementation of this method is found in the multi-panel 3D plot features in the S-Plus visualization environment of MathSoft, Inc. (1997).

This apparently attractive alternative, however, also has its difficulties. Since transactions involving different spatial or temporal scales are separately displayed, it is difficult for the analyst to identify the overall space-time patterns of and the interactions among the individuals involved. For instance, for an individual who has access to the Internet only at the workplace, Web transactions undertaken at home (and most likely in the evening) would be non-existent. In the case of an employee whose work phone number is not accessible to non-work purposes, distanciated communications with friends and relatives can only take place before or after work. These kinds of interactions between activities in the physical world and cyberspace would be difficult to identify when this method is used.

Because of the limitations of these two methods, another method for the multi-scale, three-dimensional representation of individual space-time paths in hybrid physical-virtual world is discussed in the next section. This method integrates transactions at different spatial scales in one graphical window, where the overall pattern or relationships among activities at different spatial scales can be easily identified. It can represent various types of transactions that take place at the same time (simultaneity). Further, the method allows differentiation of attributes for each transaction using graphical legends. For example, color codes can show transactions at different spatial scales (local, regional, global), with different temporal characteristics (synchronous, asynchronous), and undertaken through different communication modes (one-way incoming, one-way outgoing, two-way). Most of the data pre-processing was performed using ARCINFO while the visualization was implemented using ArcView 3D Analyst.

14.5 A Multi-scale Representation of Individual Space-time Paths: An Example

(a) Data. The activity data of an individual, Pui-Fun (a fictitious name), was collected and used to implement the GIS method. This person is a software engineer who works in a telecommunications company in Columbus, Ohio. Information about her activities in the physical world was collected in the form of an activity-travel diary. Data about her activities in cyberspace were compiled from the history file of her Web browser and email directory. As these data did not come with time stamps for computing the timing and duration of her cyber-transactions, the temporal information needed for constructing the space-time path was reconstructed through a personal interview, in which she also explained each of her activities recorded on the diary day (Table 14.1). This makes a GIS-based graphic-narrative of her activities on this day possible. Further, as several Web pages were browsed during each of her *visits* to the Web sites recorded, Web browsing activities are grouped into distinctive sessions identified by the site visited (instead of presenting details of each page browsed). Table 14.1 divides her activities in terms of the local, regional (15 northeastern states in the United States) and global scales according to the location of these transactions. The following account of Pui-Fun's cyber-transactions focuses mainly on the Internet since other forms of personal extensibility such as interactions via the telephone were not recorded.

Table 14.1. Activities undertaken by Pui-Fun on the diary day

Activity start time (hr/min)	Activity end time (hr/min)	Location involved Local	Regional	Global
3:00	8:20	Home		
8:30		Work		
8:35	8:50		Chicago	
9:15	9:35		Chicago	
9:35	9:45		Charlotte	
9:45	10:00		Maywood	
14:00	14:20		Chicago	
16:15	16:25		Charlotte	
16:25	16:35		Chicago	
16:35	16:50		Maywood	
21:10	21:30		Chicago	
24:00	00:20 next day			Hong Kong
00:40 next day	3:00	Home		

Source: Activity diary and personal interview with subject, August 1998

Activity data provide information about Pui-Fun's activities in both the physical world and in cyberspace for a Saturday that she worked from 8:30 a.m. to 12 midnight (Table 14.1). This is an unusual schedule since she normally works only from 9 am to 5:30 p.m. on weekdays. On this day, Pui-Fun's husband dropped her off at work at about 8:30 a.m. As she was working with several co-workers in other branches of the company located in Chicago IL, Maywood NJ and Charlotte NC to meet the delivery deadline of a product, she regularly checked the company Web pages on which important news and updates about the project were posted. Further, she exchanged several email messages with these co-workers throughout the day since there might be last-minute debugging and testing tricks she needed to know for preparing the final shipment of the product to the client. On the diary day, Pui-Fun started her day at 8:35 a.m. with a brief session of Web browsing at the Chicago site. Then, shortly after, she browsed more extensively to make sure she did not miss anything important, covering the Chicago, Maywood, and Charlotte sites. After she got all the necessary information, she continued to work on the project. She only had a brief lunch break at her workplace at about 12:30 p.m.

Around 2:00 p.m., she came across a technical problem which required her to log onto the project's information site in Chicago again. In late afternoon, she conducted another round of routine browsing of the Charlotte, Chicago, and Maywood sites. Because time is so limited for meeting the project's deadline, Pui-Fun did not go out for dinner on this day. Instead, her husband brought her dinner from a fast-food chain at about 6:30 p.m. She stayed at her workplace for the whole day and was off at about 12:00 midnight. Because company policy restricts employees' private use of the Internet at work, she rarely reads personal email messages or browses her favorite Web pages during work hours. She usually does so before her formal work hours begin or in the twenty minutes or so after she is formally off from work while waiting to be picked up by her husband. On this day, she browsed some newspaper and magazine Web pages hosted in Hong Kong while her husband was on the way to pick her up.

(b) Procedures. Although Pui-Fun's diary day is an extreme example, which only involves a very limited range of activities, it can still be used to implement and illustrate procedures for constructing the multi-scale 3D extensibility diagram. As a preliminary attempt to represent activities in both the physical world and cyberspace, the 3D space-time paths constructed in this paper only include her Web activities. Email messages received or sent by her on the diary day are not represented in the diagram since the time at which these messages were read cannot be determined from the email directory.

The first step is to determine the most appropriate spatial scales and to extract the relevant base maps from various digital sources. For the case of Pui-Fun, base maps of three spatial scales were prepared. First, a map of Franklin County, Ohio, and a regional map of 15 U.S. states in the northeastern part of the country were extracted from Wessex's First Street geographic database. Franklin County is the home county of Pui-Fun, whereas the U.S. region extracted will be used to locate the three American cities involved in her cyber-transactions – Chicago, Maywood, and Charlotte. At the global scale, the world map layer was derived from the digital map data that came with ArcView GIS (many high latitude regions and islands in the world map layer were eliminated to improve visual clarity). As the best projection at a particular scale depends largely on the specific objectives at hand (e.g., minimum distortion in shapes or accurate distance between locations), coordinates in these three map layers are in unprojected decimal degrees.

As Pui-Fun's cyber-transactions were all undertaken at her workplace, these three map layers were registered to this location. The regional and world maps were then transformed into scales that allow them to be displayed in sizes commensurate with that of Franklin County. Results of these transformations in two dimensions are shown in Figure 14.1, where the location of Pui-Fun's workplace is identified by the epicenter symbol, which is the same point no matter which of the three map scales is used. At the local level, the end points of the line connecting Pui-Fun's home and workplace shows where she lives and works in Franklin County. At the regional level, her cyber-activities on the diary day involved Web sites located in Chicago, Maywood, and Charlotte (as indicated by the dashed lines). At the global level, she visited Web sites hosted in Hong Kong in the People's Republic of China. After the map-scale transformation, these three 2D map layers are converted to 3D shape files and added to an ArcView 3D Analyst scene as 3D themes. After preparing these map layers, 3D shape files for Pui-Fun's space-time paths were generated using Avenue scripts and added to the 3D scene. These procedures created the multi-scale extensibility diagram shown in Figure 14.2.

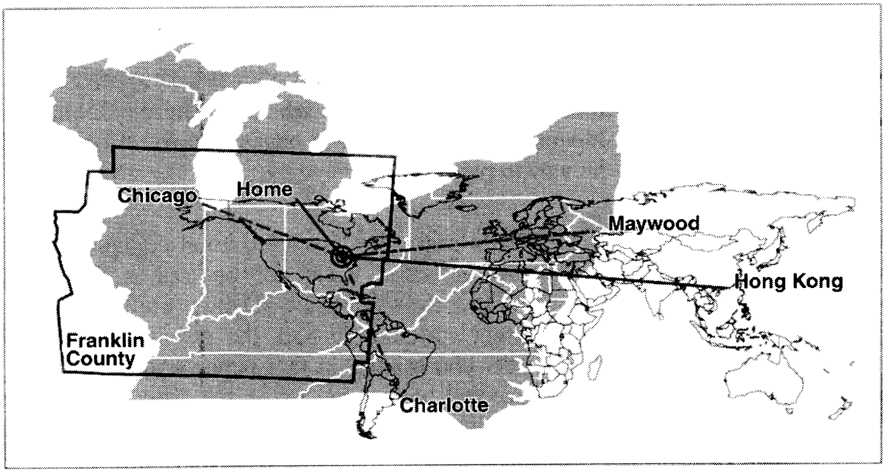

Figure 14.1. A two-dimensional representation of the three map layers after transformation.

(c) 3D Visualization. This multi-scale representation overcomes the limitations of the two methods discussed in the last section. Using this GIS-based extensibility diagram, the researcher can visualize all transactions at different spatial scales at the same time without need for multiple graphical windows (Figure 14.2). The visualization functions available in ArcView 3D Analyst also enable one to explore interactively with the 3D scene in a very flexible manner (e.g., the scene is visible in real-time while zooming in and out, or rotating). This allows for the selection of the best viewing angle and is a very helpful feature especially when visualizing very complex space-time paths. To focus only on one type of transaction or activity at a particular spatial scale, one can select the relevant themes for display while keeping the other themes turned off. Further, when the three sets of paths and base maps are displayed at the same time, they can be color coded to facilitate visualization. In the original color 3D scene, each segment of the space-time paths are represented using the same color as the relevant base map (e.g., blue for Franklin County and local activities), conveying a rather clear picture of the spatiality and temporal rhythm characterizing Pui-Fun's activities on the diary day. But, in the black-and-white version presented in Figure 14.2, spike lines are used to identify the location involved in each transaction.

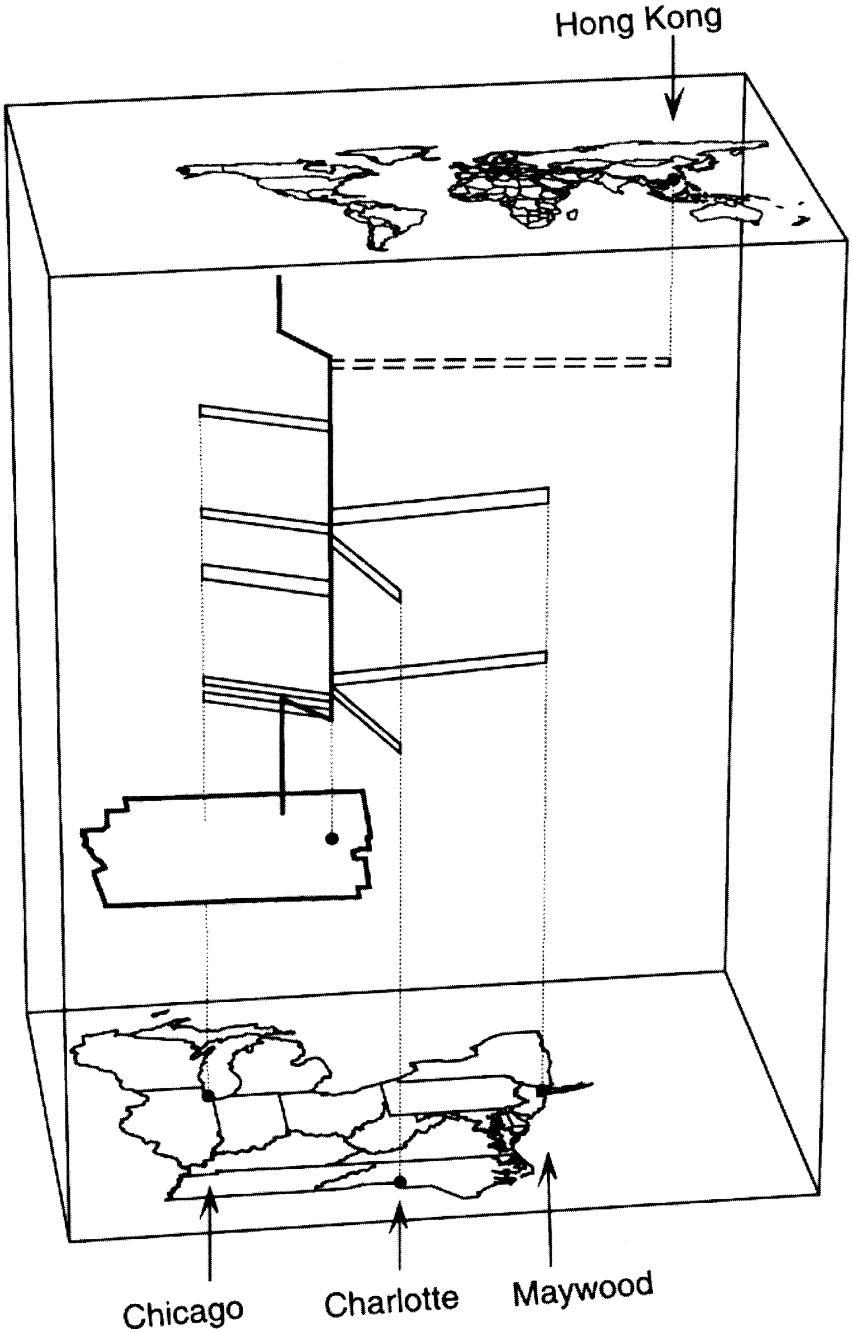

Figure 14.2. A multi-scale, 3D representation of the individual's space-time paths.

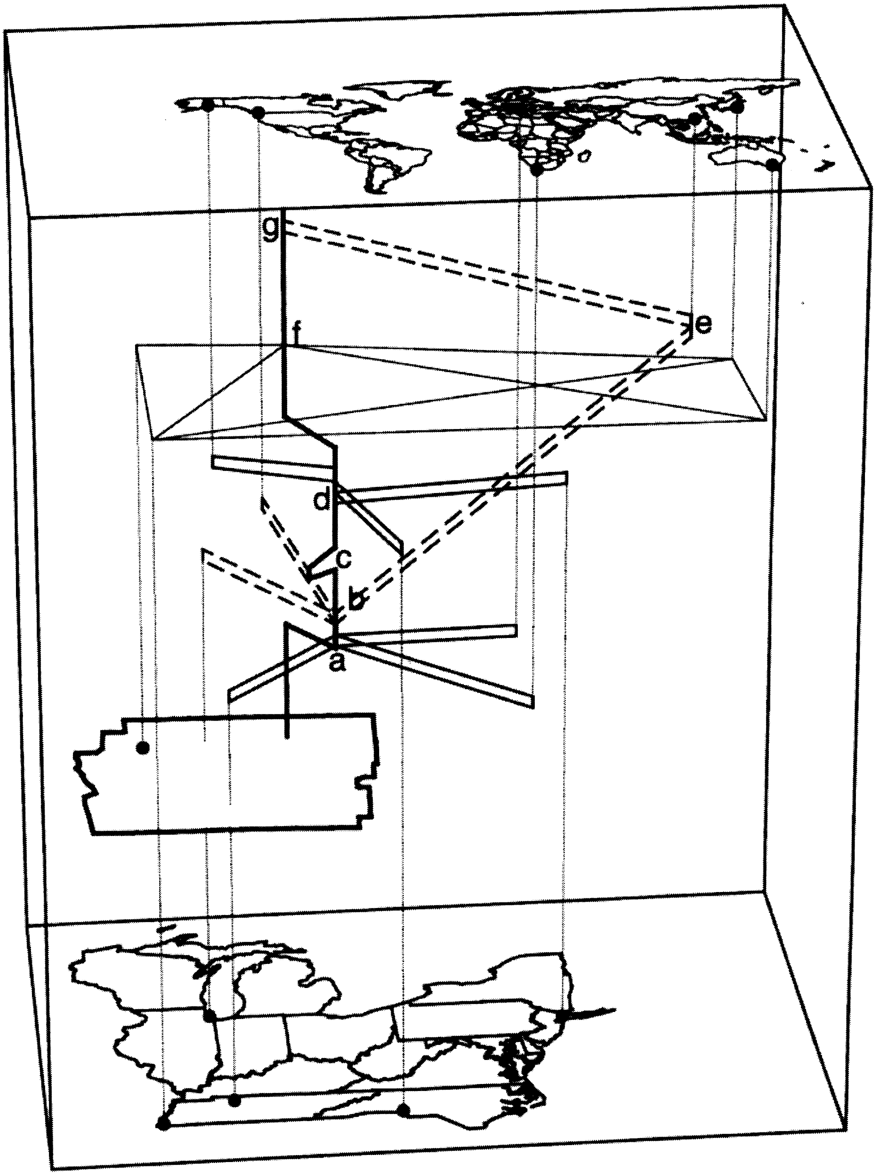

Figure 14.3. An extensibility diagram of a set of hypothetical activities.

Given the limited range of Pui-Fun's activities on the actual diary day, the potential of this GIS-based extensibility diagram is further explored using some hypothetical activities. The objective is to show how various types of transactions at different spatial scales can be represented. Using Pui-Fun as an example and partly following Adams' (1995) scheme, Figure 14.3 shows five types of activities undertaken on a particular day. On this day, Pui-Fun worked from 8:30 a.m. to 5:30 p.m., and had a one-hour lunch break at a nearby restaurant (c on the diagram). She subscribes to a Web-casting service where news items are continuously forwarded to her Web browser. On this day, she read some news about Yugoslavia, South Africa, and Nashville, TN (a on the diagram) before she started work. An hour later she sent an email message to three friends located in Hong Kong, Chicago, and Vancouver (b). The friend in Chicago read the email two hours later and the friend in Vancouver read the email five hours later. The friend in Hong Kong read the email 13 hours later and replied immediately (e). The reply message from this friend, however, was read at 2:00 a.m. at Pui-Fun's home (g). In the afternoon, Pui-Fun browsed Web pages hosted in New York, Charlotte, and Anchorage in Alaska (d). She was off from work at 5:30 p.m. and spent the evening at home. At 9:00 p.m. she started an ICQ (real-time chat) session with friends in Tokyo, Melbourne, Memphis TN, and Dublin OH (f on the diagram).

As shown in Figure 14.3, very complex interaction patterns in cyberspace can be represented using multiple and branching space-time paths. These include temporally coincidental (real-time chat) and temporally non-coincidental (e-mailing) interactions; one-way radial (Web browsing), two-way dyadic or radial (e-mailing), and multi-way (chat) interactions; in-coming (Web casting) and out-going (e-mailing) transactions (Adams 1998, Janelle 1995). The method is thus capable of capturing the spatial, temporal, and morphological complexities of a person's extensibility in cyberspace.

14.6 Conclusion and Discussion

Many characteristics of human extensibility can be represented using the multi-scale 3D GIS method presented in this paper. With appropriate time-space scaling, the extensibility diagram can reflect spatial relationships between different locations as a result of cyber-transactions. For example, the world can be as close as a few seconds away while it takes longer to reach one's next door neighbor. This kind of time-space inversion can be revealed and examined using this method. Further, although the focus of this paper is on the individual, the method itself can be used to represent interactions among many individuals. Thus, it allows for the study of social networks in space-time. The method, however, is limited by the capabilities of current GIS. For instance, current vector GIS can only represent objects as discrete entities with clear-cut boundaries, such as the straight-line representation of individual space-time paths. They cannot represent the fluidity of personal boundaries as fuzzy zones. It is also difficult to incorporate any qualitative information to account for the subjective experience of individuals in their everyday life. Future research on 3D GIS methods needs to explore how these limitations can be overcome.

There are other difficulties in implementing the method. First, since detailed data of an individual's activities in physical and cyberspace space are needed for constructing the 3D extensibility diagram, data availability will be a major issue. The problem is especially serious for transactions in cyberspace, as there are not only many different types of transactions to be recorded (e.g., e-mailing, Web browsing, Web casting, real-time chat, etc.), there is also no readily available means for recording these transactions. Data collected by commercially available server-side logging programs (used frequently by computer network administrators) are not adequate for this kind of study. Future research needs to investigate how to record these activities on the client side. This would involve a major difficulty regarding personal privacy: Will individuals be willing to disclose this kind of personal information in such detail?

Second, even when data about cyber-transactions are available, the location of a particular host on the Internet may be difficult to identify since IP addresses may not map onto geographical locations uniquely. Lastly, although individual space-time paths can be represented using this 3D GIS method, it renders the computation of space-time accessibility measures much more difficult. Given that cyber-transactions involve multiple spatial and temporal scales, and may include multiple and branching space-time paths, how can the space-time prism be identified? When fixed activities (such as work) may be ongoing with other flexible activities, which may involve far-away locations, how should space-time accessibility measures be computed? Each of these areas requires further research.

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