Revisiting Hägerstrand's Time-Geographic Framework for Individual Activities in the Age of Instant Access

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1. Introduction

Individual human activity takes place in a particular space-time context. Space and time therefore are two major factors that constrain an individual from carrying out certain activities (Golledge and Stimson, 1997). Torsten Hägerstrand (1970) proposed a framework to examine the relationships between various constraints and human activities in a space-time context, known as *time geography*. Adopting an integrated space-time system, time geography uses the concept of a *space-time path* to describe an individual's trajectory in physical space over time, and the concept of a *space-time prism* to depict the extent in physical space and time that is accessible to an individual under certain constraints. With these concepts, the framework provides an effective approach to studying human activities in a space-time context. Researchers have frequently used the framework to study spatial and temporal characteristics of human activities in physical space (Lenntorp, 1976; Carlstein *et al.*, 1978; Parkes and Thrift, 1980; Carlstein, 1982; Ellegård, 1999).

In recent decades, our society experienced rapid developments of information and communication technologies (ICT), such as the Internet, cellular phones, and wireless-enabled personal digital assistants (PDA). ICT enable a different space, which can connect us electronically and transmit information more efficiently than physical space. This space has been named *virtual space* or *cyberspace* in the literature (Janelle and Hodge, 2000). With the help of ICT, people now enjoy new freedom in space and time to carry out activities and interact with others. For example, using cellular phones, we are no longer constrained to the fixed locations of landline phone services. We can now purchase air tickets or search for literature on the Internet regardless of the open hours of travel agencies and libraries. The new freedom can alter how people carry out their activities and how they interact with others, and may eventually lead to changes in spatial and temporal characteristics of human activities. Therefore, it is crucial to gain a better understanding of spatio-temporal characteristics of human activities in the Age of Instant Access.

Hägerstrand's time geography provides an effective framework to study spatial and temporal characteristics of human activities under various constraints. However, the original time-geographic framework focused mainly on human activities in physical space. Therefore, the framework falls short of providing a complete view of human activities with their space-time constraints in the Age of Instant Access. Efforts are needed to extend the current time-geographic framework to deal with activities in both physical and virtual spaces. In this paper, we will re-visit the basic concepts of Hägerstrand's time geography and propose an extended time-geographic framework to examine the spatial and temporal characteristics of human activities in both physical and virtual spaces.

2. Research Backgrounds

2.1. Time geography

Originally proposed by Torsten Hägerstrand (1970), time geography was developed to study the relationships between human activities and various constraints in a space-time context (Golledge and Stimson, 1997; Miller, 2004b). Hägerstrand and his colleagues argued that time should not be considered only as an external factor when we examine human activities. Time, as essential as space, should be included explicitly in the process of examination. Treating time as a term equal to space, the framework adopts a three-dimensional orthogonal coordinate system, with time as the third dimension added to a two-dimensional spatial plane. The space dimensions are used to measure location changes of objects, while the time dimension is used to order the sequence of events and to synchronize human activities.

Time geography assumes that an individual's activities are limited by various constraints (Hägerstrand, 1970). Three types of constraints that can impact an individual's ability to conduct activities in space and time are defined in time geography: *capability constraints*, *authority constraints*, and *coupling constraints* (Golledge and Stimson, 1997). Physiological necessities (e.g., sleeping, eating) and available resources (e.g., auto ownership) that can constrain a person from participating in activities are recognized as *capability constraints*. *Authority constraints* reflect general rules or laws that limit a person's access to either spatial locations (e.g., a military area) or time periods (e.g., a store's open hours). *Coupling constraints* are spatial and temporal requirements that allow an individual to bundle with others to conduct certain activities (e.g., having a meeting at a conference center at 3pm). Capability constraints emphasize characteristics of a single individual and authority constraints focus on impacts of physical or social environments on an individual. On the other hand, coupling constraints deal with interactions among multiple persons. Because people are social beings, interaction is an important element of most daily activities. Coupling constraints directly define the requirements in space and time that allow people to interact with each other. Capability constraints and authority constraints indirectly determine whether two individuals can couple; they limit the movements of an individual and control whether each individual is able to be present at a certain location during a certain time period. These three types of constraints control the spatio-temporal patterns of people's movements (Golledge and Stimson, 1997).

Time geography has two basic concepts, known as *space-time path* and *space-time prism*, to portray human activities with their spatial and temporal characteristics in an integrated space-time system (Hägerstrand, 1970). A *space-time path* is the trajectory of an individual's movements in physical space over time (Figure 1a). A space-time path can be considered as a linear feature in the 3D space-time system, which provides a continuous representation of the history of an individual's locations in space. A *space-time prism* depicts the extent in space and time that can be accessed by an individual under a specific set of constraints (Lenntorp, 1976). A prism forms a continuous space in the orthogonal space-time coordinate system defined in time geography (Figure 1b). Transportation serves as a means to trade time for space since movements in physical space take time (Miller and Shaw, 2001). Given a location and a time period, a person can stay at the location for the entire time duration. If s/he wants to move to a new location, the physical movement uses time and the time available for activities at the new location is shortened accordingly. If we project a space-time prism onto a 2D plane, the result will be a region, which is known as *potential path area* (shown as shaded area in Figure 1b). The shape of a space-time path or a space-time prism is conditioned by the three types of constraints defined in the framework.

2.2. Virtual space, virtual activities, and tele-presence

With a virtual space enabled by ICT, activities available to an individual are not necessarily located within the physical proximity of the individual. The electronic linkages in virtual space can replace transportation in some situations to help people participate in activities remotely. This new mode is known as *tele-presence*, which is different from the conventional *physical presence*.

Human beings are considered as agents who can sense their environment and interact with each other (Janelle, 1973). Without the help of any appliance, the sensing capability of a person can only reach a limited range, which is usually within the physical proximity of the person. Therefore, an individual needs to travel and make a physical presence before s/he can efficiently sense a particular environment (i.e., participate in an activity) or communicate with another individual (i.e., interact with others). The agency and sensation of people are significantly extended with the extensive use of ICT in our daily lives (Adams, 1995, 2000; Kwan, 2000). With the help of ICT, an individual can reach out far beyond his/her physical proximity and participate in an activity through tele-presence. Activities carried out through tele-presence do not depend exclusively on travel as in the case of physical presence. Therefore, once people gain access to virtual space, they can conduct activities through tele-presence while they are still physically separated from the activity locations or other participants. Thus, the opportunities of accessible activities to an individual are greatly expanded with virtual space and tele-presence. An individual can conduct activities through physical presence in physical space or through tele-presence in virtual space. We will use *physical activities* and *virtual activities* respectively to describe the activities conducted in the two spaces.

Researchers have studied different types of communication methods based on their spatial and temporal characteristics (Janelle, 1995, 2004; Harvey and Macnab, 2000; Miller, 2005). Four types of methods have been identified to classify communications with physical presence and tele-presence (Table 1). Conventional face-to-face meetings require participants to be at the same location during the same time period. This communication mode that requires coincidence in both space and time is classified as *Synchronous Physical presence* (SP). Post-it notes or bulletin boards require people visit the same location, although perhaps at different times, to complete the information exchange. This type of communication, which requires coincidence in space but not in time, is called *Asynchronous Physical presence* (AP). With the use of ICT, people are no longer required to be present at the same physical location for communication. *Synchronous Tele-presence* (ST) only requires coincidence in time (e.g., two friends at different locations sending instant messages over the Internet). Finally, *Asynchronous Tele-presence* (AT) is free from coincidence requirements in either space or time. E-mail between people belongs to this type of communication. This classification system can also be applied to describe different types of human activities and interactions based on their spatial and temporal requirements. Prior to the wide adoption of ICT, human activities used to be carried out mainly in physical space through either SP or AP mode. With tele-presence enabled by ICT, ST and AT modes have become increasingly used for interactions that are changing the ways people interact with each other and altering their spatio-temporal activity patterns.

3. An Extended Time-geographical Framework for Physical and Virtual Activities

3.1. Relationships of physical space and virtual space

Physical space and virtual space have different characteristics, although both can work as stages for people to carry out activities. Negroponte (1995) views physical space as a material world made of atoms and virtual space as a world composed of bits of information. While physical space can work as a container for both physical materials and information, virtual space is specialized to carry the flow of information efficiently. As activities in physical space are distributed at different locations, travel is usually involved for an individual to conduct activities (Hanson, 1995). Therefore, an individual has to manage and balance the time spent for travel and activity, so that s/he is able to transport and participate in activities. However, activities in virtual space allow people to be involved through tele-presence. When tele-presence is used, an individual can save time on physical movements and gain greater flexibility to arrange activities.

Research has shown that activities in physical space and virtual space can influence each other (Salomon, 1986; Shen, 1998; Batty and Miller, 2000). Various impacts of virtual interactions on physical activities, such as substitution, modification, and complementarity, have been observed. However, to understand and model the relationships between the two spaces remains a research challenge. We have seen that the significance of distance in our daily activities has been reduced by the use of virtual activities. With the help of ICT, people can participate in activities or interact with others while they are at different places; therefore, virtual space gives people increased flexibility to conduct activities. However, speculations about "the death of distance" (Cairncross, 1997) are debatable because virtual space access channels are not available ubiquitously in physical space. Physical location is still important as it controls where individuals can access virtual space. Therefore, it becomes a necessary condition that an individual is located at a place with virtual space access channels so that s/he can access virtual space and conduct virtual activities. For example, an individual may need to travel to an Internet Café to receive and send e-mails. Furthermore, an individual who has access to virtual space can retrieve information, and the information can affect the individual's travel decisions and behaviors, which in turn may change transportation distribution in physical space and time.

This study proposes a conceptual model to portray the roles of the two spaces in containing human activities (Figure 2). Both physical and virtual spaces can be considered relatively independent because each has its own specific characteristics. Transportation can help people move around in physical space, while ICT are the means for people to navigate in virtual space. The two spaces are not totally separated from each other; they have intersections and they influence each other through the intersections. Two aspects of the intersections are identified in this study. On the one hand, physical space provides access channels to virtual space, as virtual space is built on information and communication infrastructures that reside in physical space. Thus, if an individual wants to perform virtual activities, s/he has to reach these access channels in physical space. Consequently, movements in physical space may be required to help the individual find the access channels and connect to virtual space. In the meantime, virtual space can feed information back to physical space. The information can be retrieved from virtual space and has impacts on physical activity patterns through decisions made by individuals participating in virtual activities.

According to the proposed conceptual model, physical space plays two roles in supporting human activities: it is a *carrier of physical activities* and it is a *connector for virtual activities*. Being a carrier of activities is the conventional role that physical space plays in supporting physical activities. Therefore, the space-time prism concept of Hägerstrand's time geography can efficiently depict the relationship of activities with their space-time constraints. For virtual activities, on the other hand, physical space works as a connector to provide people virtual space access channels and support virtual activities by hosting ICT infrastructures and facilities. This role of physical space is not addressed in Hägerstrand's time-geographic framework. Therefore, the time-geographic framework must be extended to handle the new role of physical space in supporting human activities. The three types of constraints (i.e., capability, authority, and coupling) for human activities in Hägerstrand's time-geographic framework need to be re-visited and the concepts of space-time paths and prisms need to be adjusted to deal with the different roles of physical space.

3.2. Re-visiting the three types of constraints for human activities

ICT have become widely adopted in our daily lives; therefore, constraints addressed in time geography need to be extended to handle both physical and virtual activities. Although researchers have noticed that different constraints apply to virtual activities, limited efforts have been made in identifying them in a similar structure used for physical activities in time geography. Harvey and Macnab (2000) studied the constraints of personal communications through the Internet, emphasizing new capability constraints and temporal coincidence of coupling constraints. Their study provides a good foundation to examine constraints for virtual activities using an approach similar to that for physical activities in time geography. Based on the proposed conceptual model for relationships of physical and virtual spaces, this study re-visits the three types of constraints for human activities and extends their scope to cover both physical and virtual spaces.

3.2.1. Capability constraints

Capability constraints include human capabilities and characteristics of infrastructures or facilities that can limit activity participations. Physiological necessities of a human being, such as sleeping and eating, have been classified as this type of constraint. Both physical and virtual activities are constrained by these physiological necessities. Personal capabilities, which are skills and resources owned by an individual, are another subset of constraints under this type. Physical space acts as a carrier for physical activities. Therefore, auto ownership (resource) and driving skill (skill) determine the travel capability of an individual in physical space, which in turn determines activity opportunities in physical space. However, for virtual activities, physical space works as a connector to access virtual space. Therefore, the subscription of ICT services (e.g., dial-up connection or subscription of cellular phone service) and ownership of appropriate devices (e.g., computers with network card or cellular phones) can impact the performance of virtual activities. Without these resources, an individual is excluded from the intersection of the two spaces and from conducting virtual activities. In addition, capabilities of navigating in virtual space can also limit an individual's involvement in a virtual activity. For example, an individual needs basic computer and Internet knowledge to surf the Internet, and an individual must know a particular language in order to browse a web site developed in that language. In addition, speed limits (e.g., 45 mph for a local road segment) for roads and road capacity are examples of capability constraints for physical activities. Similarily, bandwidth for Internet connection (e.g., 56KB/s for a dial-up connection) and the coverage range of a cellular phone transmission tower are examples for virtual activities. In other words, characteristics of facilities can indirectly influence an individual's capability to conduct an activity.

3.2.2. Authority constraints

In time geography, authority constraints are defined as general rules or laws that limit the performance of activities at certain locations and/or time periods. As three domains (i.e., physical space, virtual space, and their intersection) have been classified in this study, the contents of authority constraints are examined for each of these three domains.

In physical space, certain locations are only accessible to specific groups of people. For example, a military base usually prohibits public visits, and private property only allows access by the owner(s) and persons with permission. Also, most service facilities have limited open hours. If an individual wants to visit a facility in person, s/he has to be there during the posted open hours, such as the open hours of a library. Restrictions of both physical location and time period can limit the access of a particular location to individuals and constrain the performance of activities at that location.

Virtual space has similar authority constraints as those of physical space. Although most resources on the Internet are free and available around the clock, some web sites do require membership and have limited hours of operation. For example, an on-line class registration web site of a university requires students to log onto the web site with their user names and correct passwords to browse their class registration information, and these functions may be available only during certain time periods due to administrative reasons. Also, similar situations occur for telephone services. If a person does not accept roaming service on her/his cellular phone, when s/he is at a place that is only covered by another company's service, s/he will not be able to access the network.

The intersection of physical and virtual spaces indicates that physical space provides access channels to virtual space. Because physical locations that host connection facilities to virtual space can be affected by the same situations discussed above, performance of virtual activities therefore is conditioned by constraints in the intersection. When an individual does not have a permission to visit a location hosting virtual space access channels or does not visit the location during its open hours, the individual cannot connect to virtual space and conduct virtual activities. Therefore, spatial and temporal authority constraints at those locations will restrict activities in virtual space.

3.2.3. Coupling constraints

Coupling constraints focus on spatio-temporal relationships of multiple individuals. In order to participate in certain activities, individuals have to interact with others through certain modes. Conventional coupling constraints require all participants to be physically present at the same location during the same time period to conduct an activity. With tele-presence, people now can communicate and interact with each other through any of the four interaction modes (i.e., SP, AP, ST, and AT). Therefore, people can be bundled for activities in different spatial and temporal contexts rather than only in the situation of co-location in both space and time.

Both SP and AP interaction modes require the physical presence of the participants. SP interactions such as face-to-face meetings have been the major focus in Hägerstrand's time geography to examine coupling constraints. In order to conduct SP interactions, participants must be physically present in the same location during the same time period. Consequently, participants share a *co-existence* relationship in space and time. AP interactions, such as a bulletin board, requires participants to be physically present in the same location. The participants however do not have to be there at the same time. Therefore, individuals involved in an AP interaction share a relationship of *co-location in space*.

Tele-presence has been considered as a means to overcome the barrier of physical distance. It allows people from different locations to join the same virtual activity. Of the four interaction modes, ST and AT interactions take advantage of tele-presence. ST interactions can bring people from different locations together to conduct an activity, such as a videoconference or a session of instant messaging, but they require participants to access virtual space during the same time period. People bundled through this mode will have a *co-location in time* relationship. AT interactions relax constraints of both space and time. Participants of AT interactions do not need to be at the same location or be present at the same time. E-mails and web pages are good examples of this type of interaction. By conducting AT interactions, participants can have a relationship of *no co-location in either space or time*.

Although tele-presence gives more freedom in space for people to conduct activities, its realization in the real world needs the support of physical space as presented modeled in the conceptual model (see Figure 2). In order to conduct activities involving tele-presence, an individual is required to access virtual space from where s/he is located and be connected through the entire duration of this activity. Although the existence of virtual space provides more choices and greater freedom in space and time to conduct activities, researchers realize that the cliché that virtual space "enable[s] people to interact with anyone, anywhere, at any time and in any place" is a "crude vision" of the emerging phenomena rather than a precise description (Batty and Miller, 2000, p. 138). After re-visiting the three types of constraints for human activities, we can see that capability constraints and authority constraints still apply to individuals in determining ifthey can conduct activities in virtual space; coupling constraints can control if individuals are able to interact with each other through tele-presence.

Table 2 sums up the contents of the three types of constraints for physical and virtual activities. The three types of constraints work together to determine which activities in physical and virtual spaces can be carried out by individuals. With the above discussions, we can see that at the present time physical location still plays an important role in controlling human activities, even for those activities conducted in virtual space.

3.3. Extended concepts of space-time paths and prisms for physical and virtual activities

3.3.1. Space-time paths with physical and virtual activities

A conventional space-time path represents only physical proximities around an individual in space and time. With tele-presence, an individual can reach out far beyond his/her physical proximity, and the conventional space-time path concept cannot portray individuals' characteristics in the Age of Instant Access. Janelle (1973) considers an individual as an extensible agent, who can take advantage of technologies (e.g., transportation and communications) to overcome the distance friction in physical space. ICT have enhanced our capability to extend over physical space and strengthen the connections and interactions among individuals across the distance (Wiberg, 2005). Adams (2000, p. 218) portrayed communications as linkages created through space and time by a person to relate to others, and considered "these connections as *part of* people rather than *between* people." Using CAD diagrams, Adams displayed a person's communications as arms reaching out in space and time from that person. Adopting the same idea, Kwan (2000) visualized virtual activities as extended links from an individual's space-time path in a multi-scale 3D GIS environment. The concept of human extensibility and the effort to represent this concept provides a good foundation for the representation of space-time paths with both physical and virtual activities in this study.

A space-time path is considered to be the container of all activities performed by a person because all activities take place at certain locations and time periods, and each of them occupies a portion of the space-time path. Activities can be located on a space-time path based on their time references. Although both physical and virtual activities are segments on space-time paths, they have different action spaces. While physical activities impact only the physical proximity of a space-time path, virtual activities can extend to distant locations. Virtual activities can only take place at ICT-enabled locations, such as at an Internet Café or within a cellular phone service area. Figure 3 shows the conceptual representation of an extended space-time path. Extended links from space-time paths are used to represent virtual activities, which indicate the extent of these activities over distance. For example, the symbols for activities of (b) instant messaging, (e) e-mailing, and (f) calling through a cellular phone in Figure 3 represent these virtual activities. Because some virtual activities may experience delays in time, extended links may not always be horizontal, but tilted as the one for e-mail activity. Also, as tele-presence often involves multi-tasking, an activity like calling through a cellular phone can overlap with a driving activity, which indicates that an individual makes a phone call through a cellular phone during driving.

3.3.2. Adjusted space-time prisms for potential virtual activities

A space-time prism describes the potential space and time available to a person for potential activities under certain circumstances. As mentioned in section 3.1, physical space serves two different roles: the carrier of physical activities and the connector for virtual activities. For physical activities, the space-time prism concept in Hägerstrand's time geography provides an effective approach to identifying potential activity opportunities in physical space and has been widely adopted in research (Hägerstrand, 1970; Lenntorp, 1976; Miller, 1991, 2004a; Kim and Kwan, 2003). For virtual activities, the concept needs to be adapted to consider that physical space serves as the connector for virtual activities.

When people conduct virtual activities, they have to be able to connect to virtual space. As virtual space access channels are not ubiquitous in physical space, physical presence at a location with access channels becomes a necessary condition for people to conduct virtual activities. Subsequently, physical movements undertaken to reach the access channels become a prerequisite for most virtual activities. Based on this discussion, we can see that the performance of activities in virtual space is still controlled by constraints in physical space and time. Therefore, the definition of an *adjusted space-time prism* for virtual activities can be described as the opportunities in physical space that allow an individual to connect to virtual space and carry out virtual activities under a set of constraints. In other words, the identification of potential virtual activities is a process of locating virtual space access channels in physical space under certain space-time constraints.

Based on the definition of an adjusted space-time prism in this study, the prism can be achieved by intersecting a conventional space-time prism with *space-time life paths* of virtual space access channels in physical space. In this study, the term *space-time life path* is used to describe the existence of a virtual space access channel in space and time. Unlike a space-time path, which portrays an individual's trajectory, a space-time life path represents a virtual space connection service with a specific space-time extent. A space-time life path is attained by extruding a virtual space access channel along time dimension according to its operational hours. Therefore, it represents the time period during which individuals can access virtual space from that specific location.

Two types of virtual space access channels, *wired access channels* and *wireless access channels*, are identified in this study according to their connection methods to virtual space. *Wired access channels* provide connections to virtual space at fixed portals, such as fixed phone lines and wired Internet ports. This type of virtual space access channel usually resides at fixed locations and can be considered a point-like geographic feature. *Wireless access channels* can offer connections to virtual space in continuous regions. An individual with suitable ICT devices can access virtual space from any location within the region. A cellular phone service area or a wireless network coverage area is a typical example of this type of access channels.

Two types of adjusted space-time prisms for virtual activities can be derived based on these two types of virtual space access channels. Figure 4a shows the adjusted space-time prism for virtual activities with wired access channels. The conventional space-time prism demarcates the space-time extent that an individual can reach under the given constraints. Three wired access channels are located at different locations (f_1, f_2, and f_3). Their space-time life paths are represented as space-time life lines, which are shown as thick dashed lines in Figure 4a. While both f_1 and f_3 have 24-hour access to virtual space, f_2 provides access only after a certain time. The space-time life lines of f_1 and f_2 intersect with the conventional space-time prism and their intersections are shown as thick solid lines in Figure 4a. The thick solid lines indicate that the person has opportunities to reach these two locations, to access virtual space, and to conduct virtual activities. The time window for accessing virtual space at each location is indicated by the length of the line segment, with its ends marking starting and ending times. Therefore, the adjusted space-time prism with wired access becomes a collection of vertical line segments in the 3D coordinate system. Figure 4b demonstrates the case of wireless access channels. As wireless access channels are regions in the physical space, their space-time life paths are represented as cylinders in the 3D system. Figure 4b shows one wireless access region whose space-time life cylinder intersects with the conventional space-time prism. The intersection of the conventional space-time prism and the space-time life cylinder depicts the opportunities in space and time that can be accessed by the person to connect to virtual space for virtual activities. The adjusted space-time prism for virtual activities with wireless access differs from the result of wired access in that it has a continuous extent in space and time. A person can keep accessing virtual space while moving around within those confines.

4. Human Interactions and Spatio-temporal Relationships of Space-time Paths and Prisms

The extended concepts of space-time path and prism provide representations for observed and potential human activities in both physical and virtual spaces for a single individual. As social beings, people cannot avoid communicating and interacting with each other, and most human activities involve multiple individuals. With physical presence and tele-presence, people can interact with one another through one of the four interaction modes (SP, AP, ST, and AT) discussed in section 2.2. Participants involved in an interaction via each mode share a specific spatio-temporal relationship. These spatio-temporal relationships of individuals can be represented through their extended space-time paths. Also, these spatio-temporal patterns can be used to identify potential human interactions in different modes with the extended concept of space-time prisms.

When the four types of human interactions are represented with extended space-time paths, different patterns can be recognized according to their spatio-temporal relationships (Figure 5). As an SP interaction normally involves physical activities, it can be represented by the physical proximity of the participants' space-time paths. The requirements for participants to be at the same location (L) during the same time period (from T_1 to T_2) result in an overlapping segment of space-time paths and create a co-existence relationship as shown in Figure 5a. An AP interaction is represented by sequential visits of different participants at the same location (L) (Figure 5b). Each space-time path has a segment occupying the same location (L) in different time periods. This leads to a co-location in space relationship. As both ST and AT interactions involve virtual activities, extended space-time paths are used to represent their relationships. In an ST interaction, participants located at different places interact with each other in virtual space within the same time period. Their space-time paths share a co-location in time relationship as displayed in Figure 5c. The block in the figure represents interactions between the participants across virtual space; the horizontal lines indicate the synchronization in time (the same duration from T_1 to T_2). An AT interaction further removes the requirement on time synchronization. A person can initiate a communication by sending a message out from location L_1 at time T_1, while the receiver can pick up the message at location L_2 at time T_2 to complete the communication. As shown in Figure 5d, a link is used to connect the two space-time paths representing the relationship of an AT interaction between them. The ends of the link indicate when and where the interaction was initiated and picked up. Due to the asynchronous character of this type of interaction, the link is a tilted line in the space-time system. This shows a relationship of no co-location in either space or time between the individuals.

These spatio-temporal relationships with their prisms can be used to examine the opportunities for potential interactions among people because different types of human interactions require different spatio-temporal relationships of their participants. As SP and AP interactions take place in physical space only, conventional space-time prisms are sufficient to investigate the potential interactions among individuals. If the conventional space-time prisms of two individuals overlap as shown in Figure 6a, it indicates that the individuals can reach the same location during a common time window (i.e., co-existence); therefore, they can carry out potential SP interactions. The overlap (shown as shaded area in Figure 6a) depicts the extent in space and time for the opportunities of potential SP interactions among the individuals. Figure 6b shows that two individuals will be able to reach the same locations during different time periods (i.e., co-location in space). Such situations provide opportunities for individuals to carry out AP interactions. The shaded areas of prisms in Figure 6b demarcate the space-time extent for each individual to conduct potential AP interactions at the locations. Both ST and AT interactions involve activities in virtual space. Therefore, adjusted space-time prisms are used to examine opportunities of these interactions. The gray areas of the space-time prisms in Figure 6c and 6d indicate the space-time extents that allow individuals to access virtual space. ST interactions require participants to access virtual space at the same time (i.e., co-location in time). If the two prisms for virtual activities overlap along the time dimension as shown in Figure 6c, the individuals will have opportunities to conduct ST interactions. The shaded areas within the prisms for virtual activities depict the opportunities in space and time that allow ST interactions among individuals. AT interactions do not require coincidence in either space or time (i.e., no co-location in either space or time). As long as participants have access to virtual space and the receiver of an AT interaction has access to virtual space at a later time than the initiator, they will be able to conduct AT interactions. Figure 6d shows the situation for potential AT interactions, which indicates that the receiver's adjusted space-time prism needs to last beyond the earliest boundary of the initiator's prism along the time dimension in order to pick up the incoming message. These spatio-temporal relationships of prisms provide an approach to exploring potential human interactions in both physical and virtual spaces.

5. Conclusions

The existence of virtual space enabled by ICT enhances our ability to access information, conduct daily activities, and interact with others. In this paper, we re-visit Hägerstrand's time geography and propose an extended time-geographic framework to examine individual activities with their spatial and temporal characteristics in the Age of Instant Access. Based on a conceptual model of the relationships of physical space and virtual space, this study identifies space-time constraints applied to virtual activities. Considering human beings as extensible agents, the concept of space-time path is extended to represent both physical and virtual activities. Using extended space-time paths, the spatio-temporal characteristics of the four different interaction modes (i.e., SP, AP, ST, and AT) are represented and visualized as four types of spatio-temporal relationships (i.e., co-existence, co-location in space, co-location in time, and no co-location in either space or time). Moreover, the concept of space-time prism for virtual activities is developed to illustrate opportunities for potential human activities. Two forms of prisms for virtual activities are constructed based on different types of virtual space access channels, which are wired connections and wireless connections. With this extended concept of prism, potential human interactions via the four different interaction modes can be determined by identifying the four spatio-temporal relationships.

The proposed extended time-geographic framework can be used to facilitate the investigation of spatial and temporal aspects of individuals' activities in physical and virtual spaces. The extended space-time path concept, which is capable of representing both physical and virtual activities, provides an effective approach of describing various activities carried out by an individual in the Age of Instant Access. Based on this representation, analysis of spatio-temporal relationships among multiple individuals can be readily implemented in a geographic information system environment (Yu, forthcoming). The identified spatio-temporal relationships with extended space-time paths then can be used to identify possible interactions among people. With a well-documented empirical dataset of individual activities, this extended framework can help researchers explore spatio-temporal patterns of human activities due to the impacts of ICT. The extended concept of space-time prism for virtual activities offers a method to study the extensible action space available to an individual through virtual space. This concept can be used to examine the potential activities carried out by an individual in both physical and virtual spaces. The four spatio-temporal relationships for adjusted space-time prisms can help evaluate potential interactions among interested population through either physical presence or tele-presence. With these extensions, the proposed time-geographic framework is capable of handling both physical and virtual activities in a space-time context and can provide a useful mode for examining individual activities in the Age of Instant Access.

Reference

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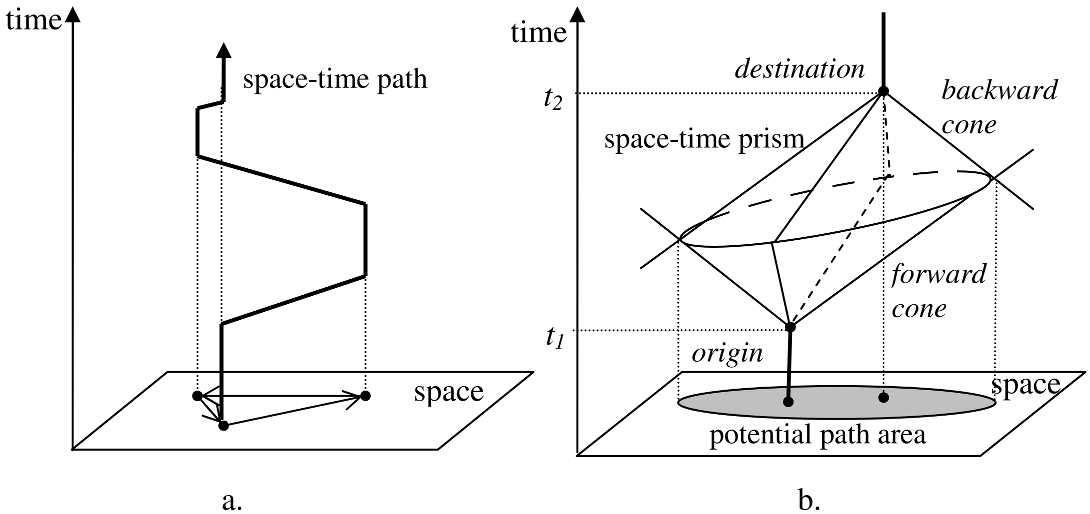


Figure 1. Space-time path and space-time prism.

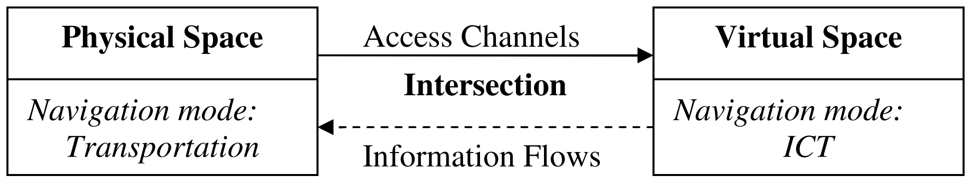


Figure 2. A conceptual model of physical space and virtual space.

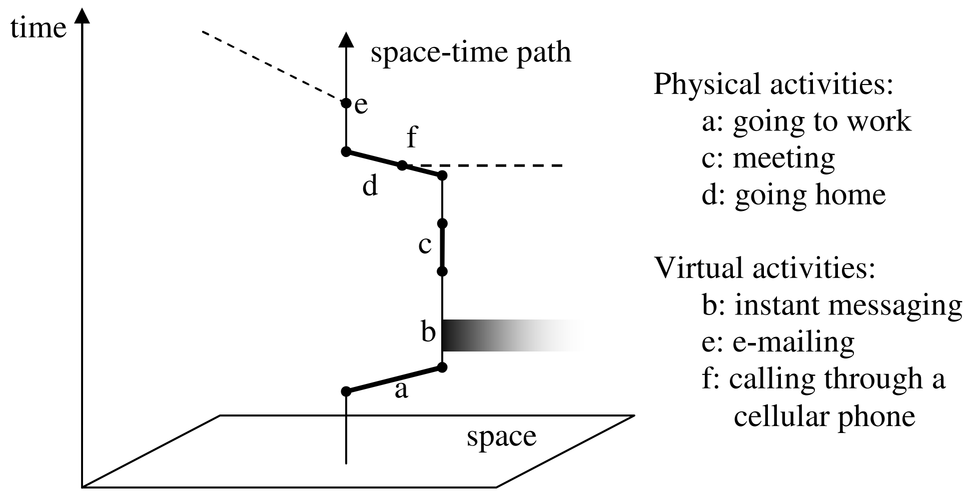
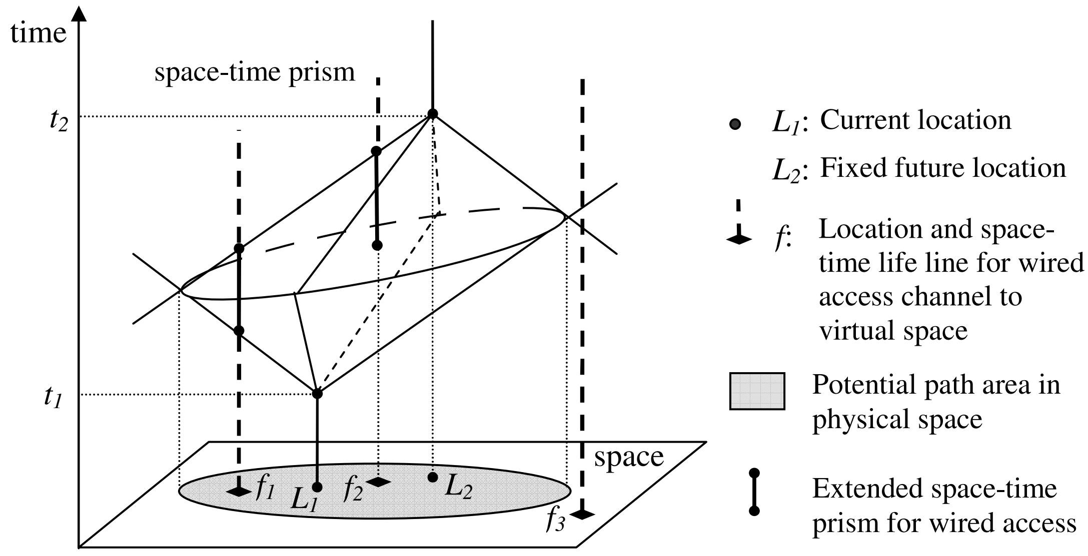
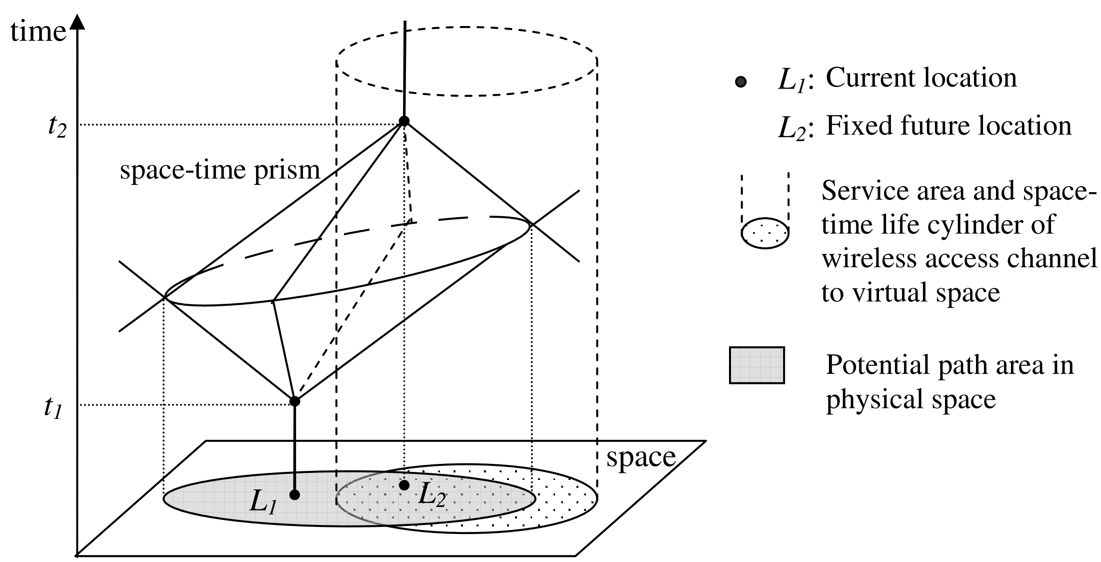


Figure 3. An extended space-time path with physical and virtual activities.

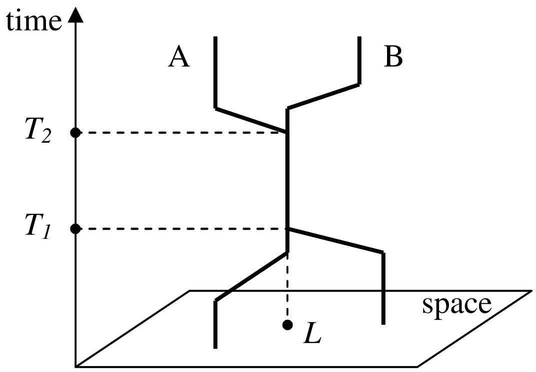


a. A space-time prism for virtual activities with wired access channels

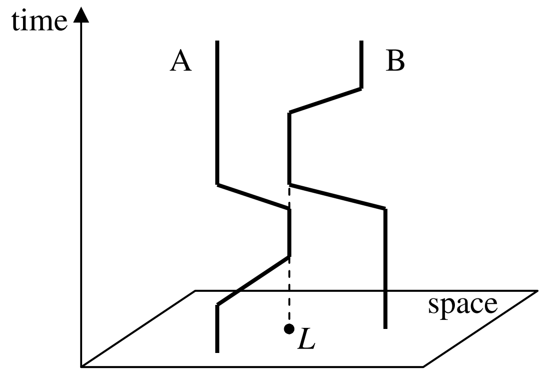


b. A space-time prism for virtual activities with wireless access channels

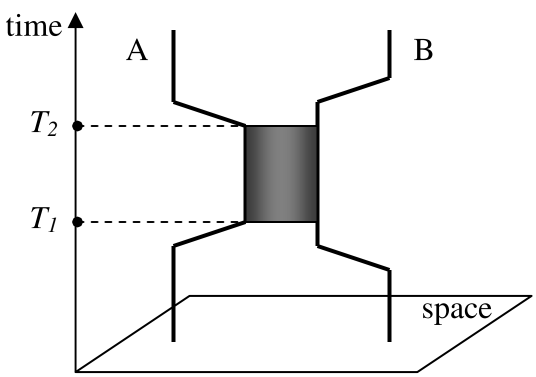
Figure 4. Adjusted space-time prisms for virtual activities.



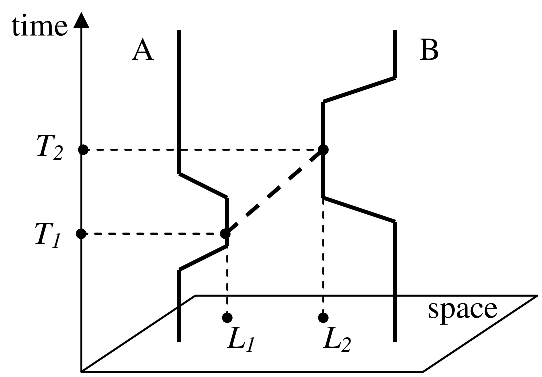
a. Co-existence



b. Co-location in space



c. Co-location in time



d. No co-location in either space or time

Figure 5. Spatio-temporal relationships of human interactions.

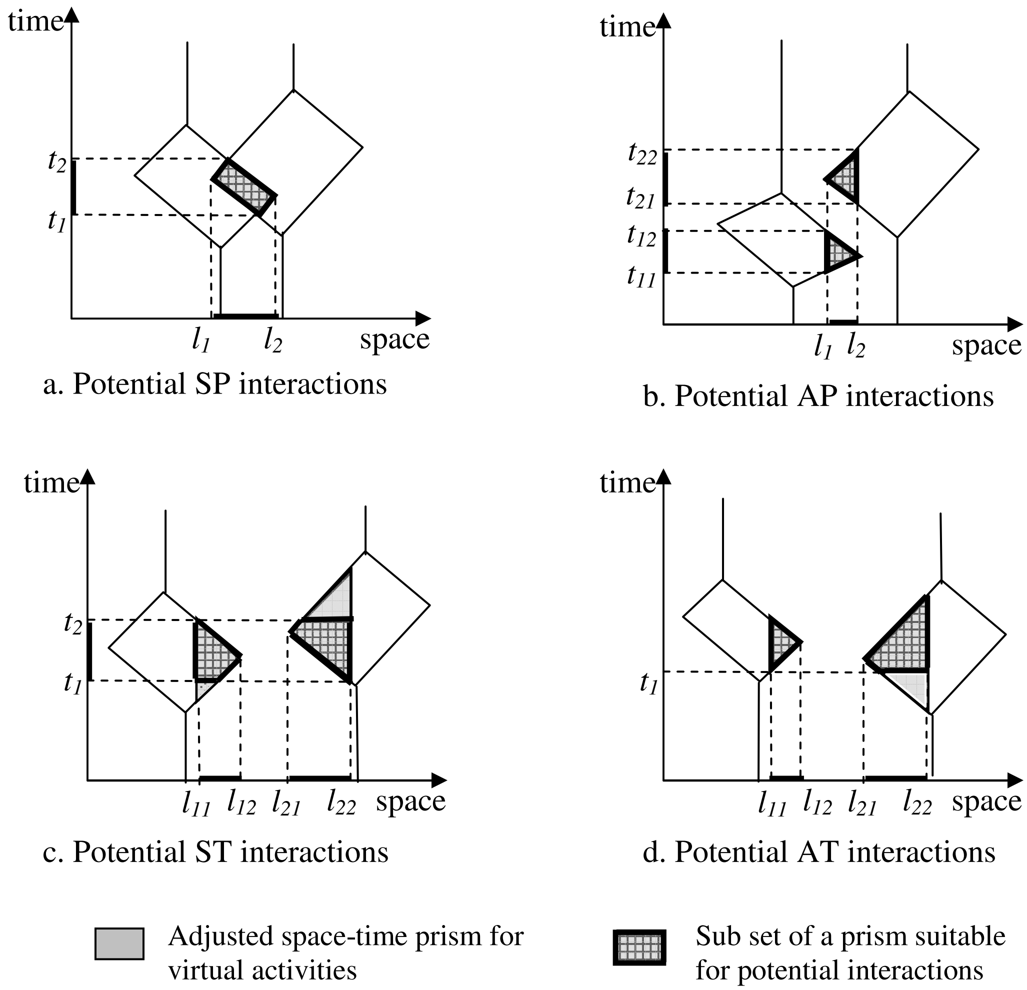


Figure 6. Spatio-temporal relationships of prisms and potential interactions.

Table 1. Communication modes based on their spatial and temporal constraints
(Adapted from Miller, 2005)

Temporal / **Spatial**	*Synchronous*	*Asynchronous*
Physical presence	**SP** Face to face (F2F) meetings	**AP** Post-it® notes Traditional hospital charts
Tele-presence	**ST** Telephone calls On-line chat rooms Teleconferences	**AT** E-mails Web pages

Table 2. Constraints for human activities in physical and virtual spaces

Constraints	*Contents*
Capability constraints	Human capabilities and characteristics of infrastructures or facilities that can support the conduction of human activities. • Physiological necessities: sleeping, eating, etc. • Individual capabilities: o In physical space: auto ownership, driving skills, etc. o For intersection: accesses to virtual space – wired accesses (e.g., Internet ports, fixed phone lines, etc) and wireless accesses (e.g., cellular phones, wireless Internet ports, etc). o In virtual space: computer skills, language ability to browse foreign web sites, etc. • Characteristics of environment: types of roads, speed limit, band width of the Internet connections, etc.
Authority constraints	General rules or laws that limit the performance of activities at certain locations and/or time periods. o In physical space: military area, shopping mall open hours, etc. o For intersection: student computer labs in a university, open hours of an Internet café, etc. o In virtual space: membership controlled web sites, business hours for web services, etc.
Coupling constraints	Spatial and temporal requirements for people to interact with each other through either physical presence or tele-presence. • Co-existence (co-location in both space and time): synchronous physical presence (SP), e.g., face-to-face meeting, etc. • Co-location in space: asynchronous physical presence (AP), e.g., fridge note, post message board, etc. • Co-location in time: synchronous tele-presence (ST), e.g., instant messaging, videoconference, etc. • No co-location in either space or time: asynchronous tele-presence (AT), e.g., email, voice mail, etc.