Visualizing context

Jerry Mount and David Bennett
Department of Geography, The University of Iowa
jerry-mount@uiowa.edu
david-bennett@uiowa.edu

ABSTRACT: Context-aware systems are becoming more powerful with new developments in wireless and mobile connectivity, powerful portable computing devices, data from sensor networks and increasingly ubiquitous access to remote data repositories. Access to real-time databases and streaming information from remote sources increases the functionality and viability of analyses in ubiquitous computing. Increasing availability of data, however, is not necessarily the primary goal for context-aware systems. The greatest benefits will come by increasing the amount of ***useful*** information that can be distributed using ubiquitous/pervasive computing. For the purpose of this paper, context is defined as useful information derived from various types of environments that surround or situate a group or individual attempting to complete a specific task or goal. All elements of this individual/environment/task triplet are dynamic and, thus, context is a continually emerging set of relationships that provides the medium through which decisions are made and acted upon. Operating in concert with context is the purpose or goal of activities conducted by groups or individuals. The purpose defines the task and is therefore part of the contextual drivers of the system. Purpose or goal incorporates static and/or dynamic properties of their environments that are used to create viable options for decisions tailored to those groups or individuals. This implies that there are properties of groups or individuals that define relationships between themselves and the context of those decisions. For example, a person confined to a wheelchair must make decisions about navigating through space that account for limitations imposed by their disabilities. Personal knowledge about their capabilities can then be compared with the physical environment to determine what routes are acceptable based on factors like sidewalk slopes, weather conditions, and the availability of assistive technology like elevators. Although knowledge of an area gained through experience can be used to personally tailor routing decisions for certain areas, people often travel to locations that are unfamiliar and, thus, the determination of viable routes in new environments can be problematic. In this case, the user still has the same abilities or limitations, but the relationships between the user and the environment are unknown and viable routes are indeterminate until tested or knowledge is gained in some other way. In addition, the properties or state of the users of a spatial decision system, such as a network routing system, can also change through time and space. For example, a person can become fatigued while traversing a route so that the original acceptable path may not be preferred at a later time given changing properties or states of the user. The relationships between people and the context in which they operate are therefore complex and dynamic through space and time. The goal of context-aware systems is to address these dynamic relationships in order to provide services or decision support for its users.

Many questions develop quickly from discussions of context, however. What does context look like? Why is it important to consider? How can we visualize something that in some ways is apparent through all of our senses but in other ways is obscured by a lack of perfect knowledge? How do we account for the dynamic properties of context? Obviously, if we are modeling these phenomena we would have to parameterize things that we may know little about depending on the environment. However, ubiquitous computing can utilize information not readily perceived by users or is not available in a format designed for human consumption. An environment does not, therefore, have to be experienced by a user in order to be included in a decision process that results in a viable outcome. Models of the relationships between a group or individual and various types of environmental settings through space and time can be used to personalize decision making processes. By understanding the role of dynamic relationships between groups or individuals and the various environments through which they operate we can develop models that, in turn, can be used to visualize the dynamic processes involved in decision-making. This paper proposes ways to visualize the relationships between groups or individuals and the environments in which they operate.

Introduction

Context is an interesting subject. It is paradoxically readily apparent yet hard to define. In addition, there are many types of context that are discussed in the literature, including social, physical, emotional, and historical. But what exactly is context? Is there one big Context comprised of lots of little contexts or is context ultimately dependent on situation? Is it generalizable or representable? Is context something that can be incorporated into spatial analyses and, if so, what effect what would it have on knowledge produced or decisions made? The purpose of this paper is to provide insight into the concept of context in a computing environment and, in doing so, gain insight into how context can be used in spatial analyses and ways to visualize it

Definitions

Context is defined by Merriam-Webster's dictionary in two ways. The first defines context as components of a dialog that can help one understand the meaning of the dialog. A couple of things are evident in this definition, the first being that context is comprised of parts or components and the second is that these parts add meaning to the discourse. The second definition states that context is the "interrelated conditions in which something exists or occurs". This also indicates that context is a collection of things and that the conditions comprising context are related to one another. It may also be inferred that increased meaning emerges when the components of context are combined. So, to reiterate, context is composed of parts, the parts are related to each other, and context contributes to the construction of increased meaning.

There are, however, other definitions of context that have been developed in particular research domains that are applicable here. Computer science, for example, draws heavily on the concepts of context in ubiquitous and pervasive computing and human-computer interaction research. Ubiquitous computing, now commonly called pervasive computing, grew out of technological advances that allowed computing devices to become small and cheap enough to be distributed throughout the environment. The early works of Weiser (1991), Schilit (1993), and others led to a new shift in computer science research that originally sought to make the computing environment disappear into the natural and built environments yet become more powerful and ubiquitous. This combination of small and powerful devices led quickly to discussions that focused on the role of these devices and how to account for particular properties associated with specific locations. The nature and definition of context, as used by computer scientists, became a prominent topic in this new research area. Early definitions stated that context was a set of properties that help define the situation for a user, software, hardware, or all of these. Common features in most early definitions of context almost always included location and identity. Since the goal was to embed computing into the environment it was considered important to know where something was occurring and who was involved in these activities. It quickly became apparent that these bits of information did not capture all useful properties of an environment so researchers continued to expand the definition by adding particular properties that suited their purposes. These included properties of time and dates, physical measurements (temperature, humidity), and even emotional states (Dey and Abowd 1999). The examples used to illustrate context increased as more environmental and personal properties were discovered to be important. However, by the early 2000's, many researchers found that the definitions were too specific and tended to just be properties specific for an application. The following quotations illustrate various definitions of context that have evolved through time:

> "We have found two issues of crucial importance: location and scale. Little is more basic to human perception than physical juxtaposition, and so ubiquitous computers must know where they are." Weiser 1993:5.

> "Three important aspects of context are: where you are, who you are with, and what resources are nearby. Context encompasses more than just the user's location, because other things of interest are also mobile and changing. Context includes lighting, noise level, network connectivity, communication costs, communication bandwidth and even the social situation…" Schilit et al 1994: 85.

> "Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." Dey and Abowd 2000:4-5.

> "Instead, I want to propose an interactional model of context, in which the central concern with context is with the questions, ''how and why, in the course of their interactions, do people achieve and maintain a mutual understanding of the context for their actions?" Dourish 2004:22.

The evolving definitions of context seen in computer science were not developed in isolation. Although many of the early computer science definitions of context were focused on user and environmental properties that could easily be determined, it is apparent in the later definitions that researchers are drawing on knowledge domains outside of computer science. These domains include social sciences such as sociology, psychology, anthropology, linguistics and their sub-disciplines (Dourish 2004). The inclusion of alternate views of context are discussed later in the paper but it is obvious that context, and context-aware systems, have evolved into a more mature subject related to ubiquitous/pervasive computing.

Why is it important?

We suggest that context, and context-aware systems, will be an important part of the future of geographical information science (GISci). Although we haven't reached the level of ubiquitous technology embedded in the environment as envisioned by Weiser, we have made progress in computing environments that are not tied to the traditional locations. For example, devices such as laptops, tablets, personal digital assistants (PDAs), ultra-mobile computers, and even cell phones have developed into powerful computing systems that can be used in non-traditional computing environments. Data storage capabilities have also increased dramatically along with computing power. In addition, the development of long range wireless networks allows mobile computing systems access to data and information repositories in remote locations. Many of these mobile devices also have built-in sensors (e.g. cameras, temperature, and humidity) that can be used to collect data, as well as analyze and store data. Improvements in programming environments and operating systems further increase the capabilities of mobile devices. All of these improvements, coupled with decreasing costs of sensors, maturation of sensor networks, web-based frameworks for geospatial computing, and better access to increasingly better spatial and aspatial data demonstrate potential benefits for GISci. However, there are more than software or hardware considerations here. Pervasive computing seeks to provide specialized and individualized services based on properties of the environment and the user. The GISci community can take these concepts and apply them as geospatial services that are shaped by the context of the user. Context can be seen as a set of relationships between the person using the system, the task to be completed, and the environment.

In GISci, context-aware systems can be used to incorporate the individual or group perspective into spatial analyses. This allows the system to tailor spatial analyses to the needs or preferences of individuals or groups. Ironically, humans start with the ability to conduct experiential analyses of their environments from a first-person perspective; then we developed spatial analyses that exclude the normal human perspective. Through the use of context, we suggest that these perspectives are once again included in the processes of analysis and decision-making. Since decisions rely on situational properties, context would seem to be a natural fit with decision-making. There are variations in people concerning knowledge, experience, perspective, preferences and capabilities so it becomes important that context is included into spatial analyses when appropriate.

Background

Ubiquitous computing came out of a desire to take computing services out of traditional locations and embed them into the general environment (Weiser 1991). To some extent this has occurred but traditional computing environments still remain and will probably continue in the future. This is important because ubiquitous computing was not seen as merely mobile computing on laptops or portable computing devices but something that could change the formal relationship between place and computation. Wireless network devices, positioning devices, and increasingly powerful mobile computing devices have assisted in realizing some of Weiser's vision but the computer has not become hidden. Pervasive computing, as ubiquitous computing is now called, has become a more inclusive paradigm in computer science that embraces mobile computing and ubiquitous computing. Pervasive computing increases the need for context-aware systems that can react to changing environments, account for dynamic and individualized user conditions, and assist users in completing tasks. However, as stated previously, context itself is difficult to define and researchers have chosen many ways to try and capture the concept.

The main debate over the definition of context can be seen as a difference in paradigms according to Dourish (2004). The traditional view is that context is something to be modeled using mathematical and statistical techniques. This view relies on a positivist approach. The alternative is the phenomenological approach that looks to social construction of reality and individual and group experience as a basis for defining context. In this view context can be essentially anything but context is also dynamically determined.

Positivist view

Dourish identifies four main concepts within the positivist, or representational, view of context. The first is that context is information, observed or known a priori, that has been transformed into a useful format and that it is useable by a computational system. The second idea is that context can be defined by the software creator during the design phase. The third is that context remains stable throughout the task and that this information can be used in subsequent activities or tasks. The final concept is that context and activity can be considered to be two separate things. Dourish states that this might be the most important aspect of the positivist view but that this view is problematic. If the context and activity are separable then context can be determined without defining an activity. According to this assumption context is context regardless of the activity that is occurring in an environment.

Phenomenological view

As an alternative to the positivist view of context Dourish offers a more philosophical view by introducing the phenomenological perspective. In this approach context can be viewed as a set of relations between things in the environment, users and their activities. This implies that while anything can be context, not everything is relevant given specific relationships between the user, the task, and the environment. This view also proposes that context may not be determinable during the design phase but that it is a dynamic process based on the contextual relationships relevant to the task. This implies that context emerges with each new situation. Therefore, two people may be located at the same spatiotemporal spot, doing the same activity, yet different contexts are involved. Figure 1 is an example of this showing three users in the same location in space and time but each has a different view concerning properties of the area that can affect outcomes of their task. The last major concept in the phenomenological view is that context and activity are explicitly linked and therefore context does not occur without activity or task. Dourish (2004:22) states that “context arises from the activity” and that is created by the task.

Each view of context within computer science is understandable. The positivist view seeks to operationalize context for context-aware systems. Since many of the properties of interest were basic things like location and user-identity this view tends to focus on user specific properties. Much of the original ubiquitous computing research was focused on mundane uses of location and identity so early pioneers of context-aware systems were less concerned with the philosophical definitions of context. The definitions provided earlier show that researchers tended to define context with an ever-expanding list of properties that were useful for the project at hand.

Although we recognize that there are reasons why each view is attractive, one as functional or operational view and the other as an overarching philosophical view, there are ways to bridge the two by focusing on the relevant parts of context. We recognize that we cannot capture all properties of context but we can focus on those which are most important in spatial analyses.

The positivist view attempts to define context as information that can be used to alter the behavior of applications depending on the properties defined by the software designer. This structure is rigid and brittle and assumes that context may be knowable before a user initiates a task. Intuitively this is problematic as software designers may not be able to account for environmental properties they do not understand. In addition, there is the problem of uncertainty and dynamic processes that can confound the situation.

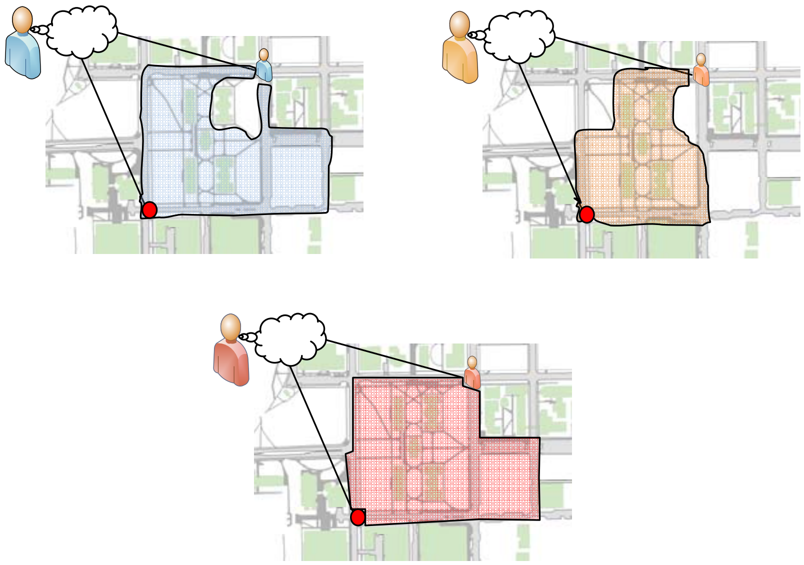

Figure 1 - Task specific context for multiple people

There are important features of the positivist view including the idea that context can be treated as information. Although we agree with Dourish that contexuality is a set of relationships between user, task and environment; operational information is important. For example, attempts to incorporate context into spatial analyses requires that contextual properties be defined and transformable into a useful format. Spatial analyses require measurable or attributable properties although the level of measurement (nominal, ordinal, interval, and ratio) can vary. In this case, a particular domain of knowledge has developed specific methods to compute a solution that requires information. The task dictates what information is necessary. Context can be transformed into information; not all context is however, applicable to all. For example, although it is possible to measure many parts of the environment, not all of these measurements influence a person running a spatial analyses (i.e., they are not relevant to the task). Context is, therefore, an emergent feature of the relationship between the three parts of user, task and environment. The tasks, and its parameters, function as a filter for context in the big sense. Figure 2 shows a simple conceptualization of context. From the relationship between task, user and environment comes task specific context. Since this paper addresses the nature of context within geospatial services it is important to bring the discussion back to this domain.

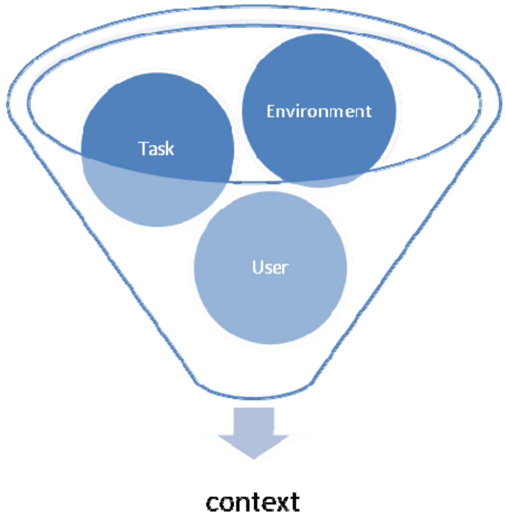

Figure 2 - Task specific context

Spatial services

Context can play an important role in tailoring geospatial services, such as routing, to the individual/task/environment triplet for which the routing solution is computed. There are at least three main benefits of using context in these services. The first is that context can be used to improve the efficiency and speed of spatial analyses by removing extraneous data from the analysis. This is mostly a data reduction process that insures that only relevant areas and criteria are included in the calculation. The second is that context can personalize a spatial analysis to a specific user. Not all spatial analyses can benefit from this but those that use individual or group perspectives are candidates. For example, routing services are a good example of a service that should incorporate context. Routing has all three components for building context – a task, a user, and an environment. The third benefit of context is that it incorporates dynamic processes that affect human activities into spatial analyses. Routing is interesting because each of the three components can be altered at any time; all have dynamic properties and, thus, context must be dynamic. Traditionally spatial analyses have ignored these dynamic properties. Incorporating dynamic context into spatial analyses is not an easy task, but it is crucial to the development of effective pervasive computing.

Summary on context

In this paper we attempt to walk a tightrope between the positivist view of context as information that is definable and transformable and the interactional, or phenomenological, view that acknowledges that context is more than what we can capture in an objective manner. We balance this high-wire act with the domain-specific knowledge and methods from Geography and GISci. These domains have developed methods for solving spatial problems and created a body of knowledge that provides insight into which properties or variables are most important. In our view, it is appropriate and necessary to transform context into information.

Our definition of context within this umbrella of spatial analyses is as follows:

> *Context is any transformed information that is pertinent to the task at hand. It is emergent based on the relationships among users, tasks and environment at a particular point in time. It is dynamic through space and time and must be measurable or attributable in all instances. Information that cannot, or does not, affect potential outcomes of decision processes or other analyses is not considered context for the current task.*

We are proposing that we can, and should, operationalize context in spatial analyses by transforming contextual relationships into usable information. It is important to recognize that context (in the big sense) is bigger than we can account for in algorithms and measurements. However, to understand and use context we need to reduce it and transform it to formats that we can understand, while recognizing that there is something more out there. Context is dynamic and the components used to define it vary through space and time. It is an emergent set, however, and should be viewed in terms of the task, individual, and environment of a particular activity. There are some parts of context that we cannot measure or transform into a useful format but GISci can assist by providing knowledge on the most important parts. The hardest part to including context into spatial analyses will is most likely be the evaluation and attribution of these subjective relationships between user and the environment. This discussion, however, is beyond the scope of this paper.

Examples

We use an example from a project in development in the Department of Geography at The University of Iowa to show how context can be visualized using traditional cartographic techniques. Context is used to incorporate user perspective into network routing analyses for the individual. These examples demonstrate that pervasive computing, through access to data repositories and spatial analyses, can be used to supplement user experience and knowledge of an area. In other words, users do not need perfect knowledge of an environment to make informed decisions. Context becomes a component of the decision-making process to offer viable route solutions for particular users.

In our campus routing example context is encoded into an edge-weighting scheme and assigned to network edges stored in a mutable graph. The graph is updated with current properties reflecting the user and the environment at each run time. New route solutions can be computed at each decision point along the path or at any time there are changes in the user, task or environment. The system is dynamic and designed to address the complex relationships between the three elements of context **-** the user, task and environment. Parameters of the task are also updatable at any time so if, for example, a user decides to go to a different location then the destination is altered. This potentially changes the context that emerges from the task, the environment, and the individual. The edge-weighting scheme modifies the impedance of edges according as a function of environmental properties, such as slope and distance, and user preferences and constraints. For example, if a person using the routing system is confined to a wheelchair then certain user/environment/task relationships are created. Wheelchairs have operating parameters designed to maintain safety of the user so network areas with characteristics that exceed these parameters should be excluded from the route solution since they cannot be traversed. This constraint could be overridden by the user, however, if the person has a way to account for the safety risks or chooses to ignore them. Our system allows people to define their own relationships at runtime so we don't have to develop categories of users based on their capabilities or limitations. In addition, people have a variety of preferences that can vary through space and time. Preferences include things like a desire to follow paths that are safe, wanting to minimize the effort required to reach a destination, a desire to avoid the use of elevators, or even find opportunities for scenic views along the route. Users can define environmental features that are attractive or repulsive and these can be used in the edge-weighting function as well. If a person is thirsty then the locations of water fountains could be used to modify adjacent edge-weights or those within certain proximity and therefore affect the route solution (i.e., the contextual relationship between the user, task and environment has been altered to reflect a desire by the user). After a person uses a water fountain they are less likely to need one in the near future and the contextual relationships can be altered to reflect this new situation.

Visualizing context

As suggested above, context reflects a set of dynamic relationships. As such, visualizations of context should demonstrate these complex interactions through space and time. One way to show context is through a series of time-steps that illustrate these relationships at a given place and time. Figure 3 shows a conceptual view of context following a user as they traverse a route solution. Context appears as circles of varying sizes to illustrate the dynamics of the relationships between user/task/environment. Figure 3 was included to demonstrate context as a moving kernel based on the triplet relationships at a space and time. Context will not be regularly shaped in most cases, however, and it would not be uncommon to see it jutting out to seemingly odd locations on the landscape. Context does not necessarily follow the rules of Euclidean space. For example, social networks can affect context by modifying the relationships between the user/task/environment but close proximity of the social driver is not necessary. A phone call or email from remote locations can affect local contextual relationships.

In addition, context could be visualized as a three-dimensional and/or volumetric entity that varies through space and time. Context could be illustrated as "blobs" that show the situation at a given space and time. The size and shape of the "blobs" could vary continuously along the path as context changes. Environmental properties like the presence of smoke, unpleasant aromas, temperature extremes, direct sunlight, and humidity are examples of three-dimensional features that could be included in context-aware spatial services. Figure 4 shows how context could be visualized for different users in the same location at the same time. The width of the tube indicates what parts of the environment are pulled into the spatial analysis for various users. This image is intended to be viewed as a path with context represented as the tubes that surround the medial axis. Although this image is not particularly effective it is intended as a conceptual view of context as exhibiting three-dimensional and temporal aspects.

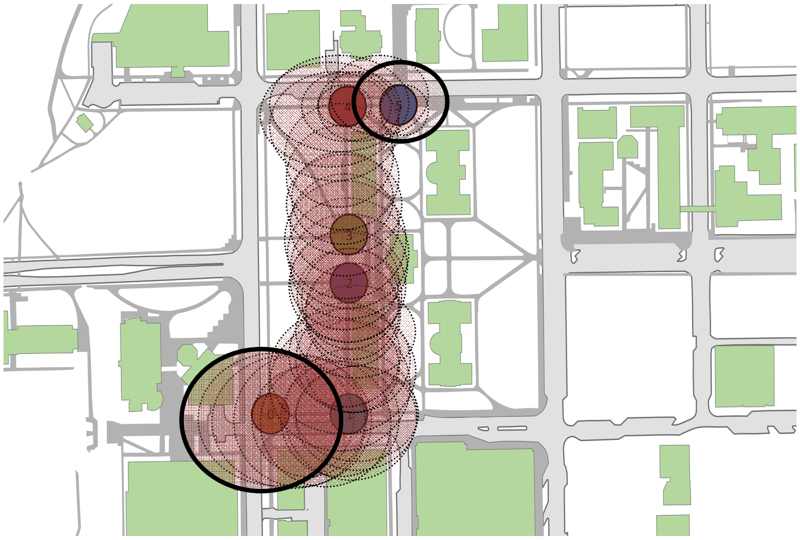

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Figure 3 - Conceptual view of context as moving kernel

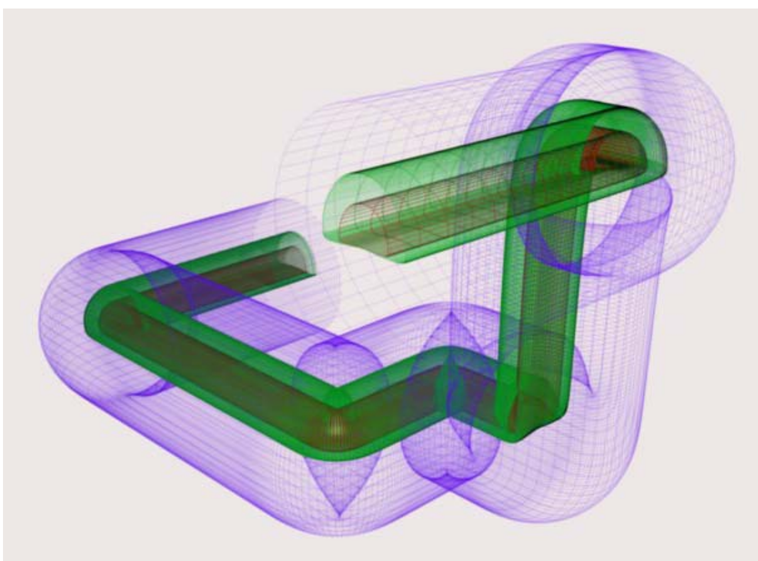

Figure 4 - Context as three-dimensional entity

So far we have presented conceptual images of context. We can, however, use real-world examples to show ways to visualize it.

Figure 5 shows a three-dimensional campus sidewalk and building network used in the remaining examples. This is the network that is modified through the edge-weighting scheme to produce the contextual representation of the environment used by the routing services. All following examples show routes using the same origin and destination. Deviations from the simple shortest-path (Figure 7a) are due to changes in the task, user or environment.

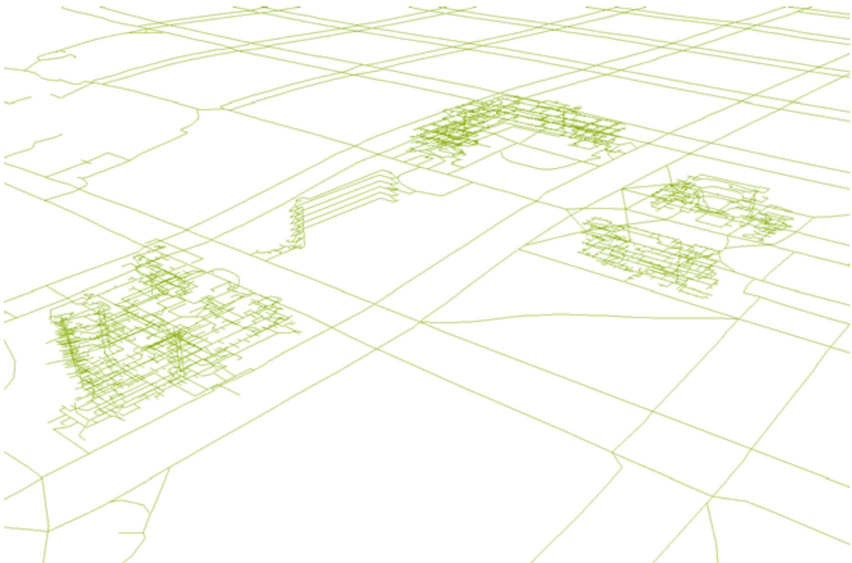

Figure 5 - Campus network

Figure 6 shows three route solutions with the same origin and destination but properties of the environment or the user have changed between runs. The task has remained constant. Figure 7a and 7b show the effects of user specified barriers on the route solution (e.g., segments of steep slope, ice or snow, or rough pavement that impede the movement of those who use wheelchairs). Figure 7a shows the shortest path between two locations on campus before barriers have come into effect. Figure 7b shows the route after barriers have enabled. Barriers, in this case, are spatio-temporal entities that block movement across the edge.

So far, these are all examples of context developed at runtime. Conditions in the user and the environment are held constant in these examples. In other word, the user and the environments have not changed after the initial route solution is computed. However, since context exhibits spatio-temporal effects these can be visualized as well.

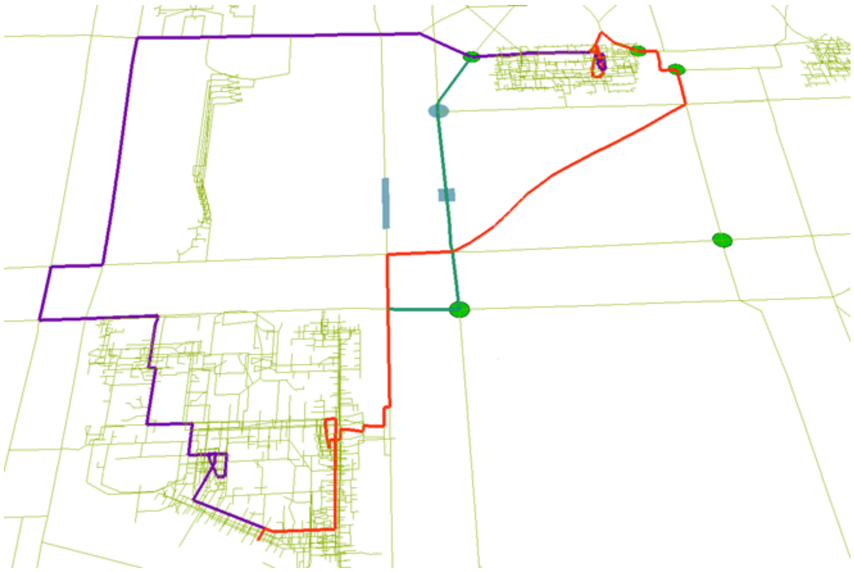

Figure 6 – Various route solutions

Figure 7a - Shortest path between 2 locations on campus

Figure 7b - Shortest path with barriers

To visualize the dynamic relationships of context **during** the task one can look at the changing graph weights at various times. If the shortest path is constantly recalculated at each node along the current path when users approach it then we can get a better view of the changing conditions through space and time. We used the Dijkstra shortest-path algorithm to determine the optimal paths between the origin and destination so there was a need to determine the base weights for each edge. This is user-definable so the system can accommodate particular user perceptions of the environment. For example, the slope length of each edge of the network could be used as the base weight. If there are no modifications to the context represented by edge weights then the shortest path would just use the slope length to compute the path. Other people might use time or a function based on several properties of the network. The default base edge weight in our system is slope length. Figures 8a-8d show changing properties of the network as a series of snapshots while a user is traversing a route solution. These snapshots show how the graph representing context is altered through time. Edge widths change as relationships between user/task/environment are changed. Figure 8d illustrates network barriers coming into effect and edges affected by the barriers are removed from consideration in the route solution.

A good way to view changing properties of context would be to compile time-series snapshots into a movie. Animations are a good way to show dynamic properties of users through time and space.

Figure 8a – Context step 1

Figure 8b – Context step 2

Figure 8c – Context step 3

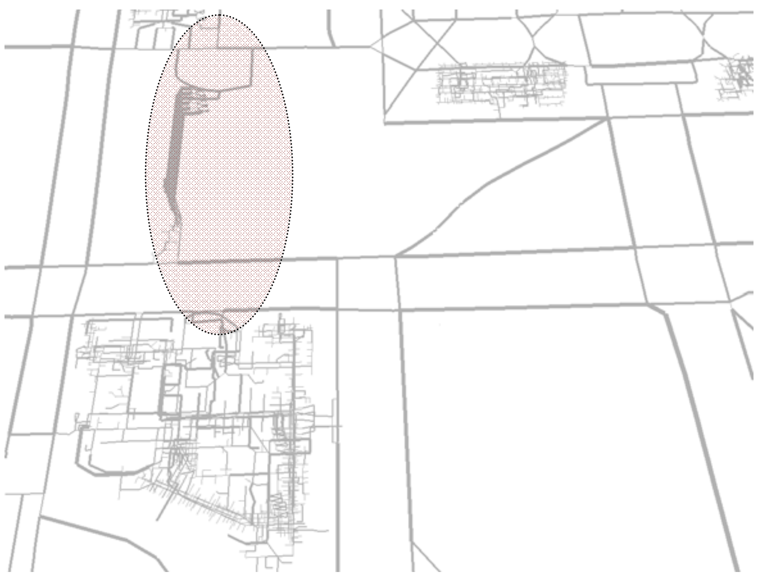

Figure 8d – Context step 4

Conclusions

This paper presents a case for defining and using context in pervasive computing environments. Context is an important part of spatial analyses but it is often implicitly defined and usually only in terms of environmental properties. Context, as we have defined, is a set of emergent relationships between computer users, tasks, and the environment. Users can tailor spatial analyses to their perceptions of the environment using context. Accommodations for preferences and needs can be addressed in this manner. Although we recognize that there are aspects of context that we cannot include in spatial analyses we argue that the body of knowledge developed by GISci can let us focus on the most important properties of context to provide viable spatial services.

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