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Towards a Comprehensive Model of Context for Mobile and Wireless Computing

Peter Tarasewich
Northeastern University

TOWARDS A COMPREHENSIVE MODEL OF CONTEXT FOR MOBILE AND WIRELESS COMPUTING

Peter Tarasewich
College of Computer and Information Science
Northeastern University
tarase@ccs.neu.edu

Abstract

A key to the success of mobile applications is the proper use of context. This paper presents a model of context for mobile and wireless computing environments. The model consists of three categories of context – environment, participants, and activities – along with any interactions that may exist between and within the categories. Time is also incorporated into the model, allowing for a context history that can be used for predicting future context. The model can be used as a guide to the development of mobile applications and as a common reference point for present and future research studies in the area of mobile and ubiquitous computing.

Keywords: Context model, mobile, wireless, ubiquitous, time, m-commerce

Introduction

Wireless and mobile applications are having an increasingly profound impact on organizations and individuals. No longer confined to the office or home, people can use devices that they carry with them, along with wireless communications networks, to access the systems and data that they need. In many cases these systems are not just replacements for wired information systems, nor do they even provide similar functionality. Instead, they are planned, designed, and implemented with the unique characteristics of wireless communication and mobile client use in mind.

Context will weigh heavily in the use of mobile and wireless systems. Mobile tasks and technology use are significantly different than their stationary counterparts. People can now conceivably be anywhere at anytime and use mobile systems, which is not true with traditional (wired) applications since a physical network connection is often needed. Factors such as location will need to be considered for the usability of a mobile application or device, as will the dynamic nature of the environment within which it is used. For example, a mother could be walking down a street in an unfamiliar city trying to use a mobile application to find the location of an office for an appointment, while keeping track of her three children and processing the sights and sounds of vehicles and other pedestrians. System design that may be well suited to a relatively stable office or home environment will not necessarily work on a loading dock or in an automobile cruising down a highway.

The purpose of this paper is to present a model of context that can be used for mobile and wireless environments. The primary motivation for this paper comes from the observation that while there has been much recent work on defining context (e.g., Dey 2001), *time* is not well integrated into context models. Furthermore, while many authors agree that time must be considered when looking at context, most seem to look only at the past (i.e., history). This paper makes the argument that the future (i.e., forecasts and probabilities of events occurring) can also play a significant role in context and its application to pervasive and ubiquitous computing, and therefore must be an integral part of any comprehensive context model.

What Is Context?

Merriam-Webster defines *context* as "the circumstances surrounding an act or event." (Merriam-Webster 1974, p. 164). Synonyms for context include situation, perspective, and environment. Context is something that must be taken into account as part of the myriad of activities that a person performs on any given day. Before the introduction of mobile devices, computer applications only had to consider a fairly limited set of contextual concerns. These might include organizational culture and politics, user characteristics (e.g., age, education, skills), system goals and priorities, and the working environment (e.g., lighting, noise). But users performed tasks on computers that remained physically immobile, tied to a power source and usually another computer or network. Context concerns could be concretely taken into account during the design process and changed little, if at all, after system completion. With the advent of mobile and wireless devices, context is a less predictable influence on the actual design and use of computer systems. People are using systems in environments that are relatively unstable from one day to the next.

In mobile and pervasive computing, the notion of context is often equated simply with location, but as will be shown in this paper, the concept is much more complex. As stated by Van Laerhoven and Aidoo (2001), "the notion of context is very broad and incorporates lots of information, not just about the current location, but also about the current activity, or even the inner state of the person describing it. As a consequence, people can describe their contexts in different ways, even if they are in the same location doing the same things." (p. 46) Mobile application use can continuously vary because of changing circumstances and differing user needs and perceptions.

Location by itself can be a very complicated concept. Not only is absolute location important, but also location relative to other objects and people. Brumitt and Shafer (2001) emphasized the importance of physical relationships between things (e.g., walls can block a user's visibility). They suggest understanding "the location of the person, their physical relationship to the devices around them, and the various consequences of the current state of the world." (p. 43) Brumitt and Shafer defined this increased understanding of location-based information as *geometry-awareness*. In this viewpoint, context not only takes into account the user and his/her device, but all people, devices, and physical objects in proximity of the user.

Schilit, Adams, and Want (1994) were some of the first to write about the broader meaning of context, defining context-aware systems as adapting to "the location of use, the collection of nearby people, hosts, and accessible devices, as well as to changes to such things over time." (p. 85) *Context-aware* computing deals with mobile systems that can discover and use contextual information (Chen and Kotz 2000). Schilit, Adams, and Want further described the important aspects of context as "where you are, who you are with, and what resources are nearby." (p. 85) This expands context beyond location to include co-location as well as the available communications infrastructure.

Expanding upon these ideas, Schmidt, Beigl, and Gellersen (1999) presented a fairly complete working model for context in the domain of mobile computing. They proposed creating a feature space for context with two broad categories – human factors and the physical environment. Human factors is then subdivided further into information on the user, the user's social environment, and the user's tasks. Physical environment is broken down into location, infrastructure, and physical conditions. The model also includes history (changes in the feature space over time). Their model is shown in Figure 1, with examples for the six lower-level categories of context in Table 1.

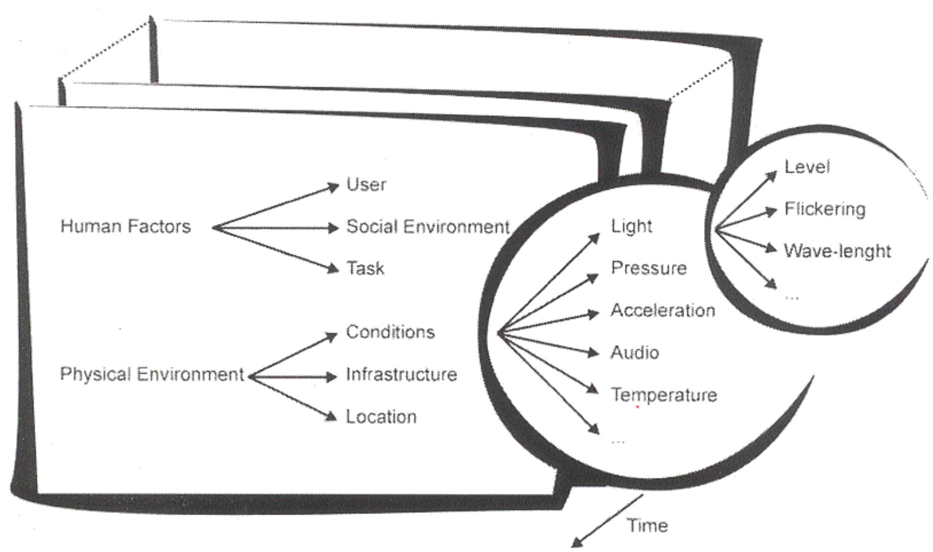

Figure 1. Context Model from Schmidt, Beigl, and Gellersen (1999)

Table 1. Examples of Context Model Lower Level Categories[a]

Information on the user	knowledge of habits, emotional state, biophysical conditions
User's social environment	co-location, social interaction, group dynamics
User's tasks	spontaneous activity, engaged tasks, general goals
Location	absolute position, relative position, co-location
Infrastructure	surrounding resources for computation, communications, task performance
Physical conditions	noise, light, pressure, acceleration, audio, temperature

[a]Schmidt, Beigl, and Gellersen (1999)

In separate research, Schmidt et al. (1999) proposed a similar context model but with three dimensions of environment, self, and activity (see Figure 2). While this model is more general than the one proposed in Schmidt, Beigl, and Gellersen (1999), each of the dimensions seems to address both human and environmental aspects of context. The environment dimension consists of physical and social aspects. Self consists of the device state, and the physiological and cognitive states of the user. The activity dimension encompasses the user's behavior and task. However, no mention of time is made in this model.

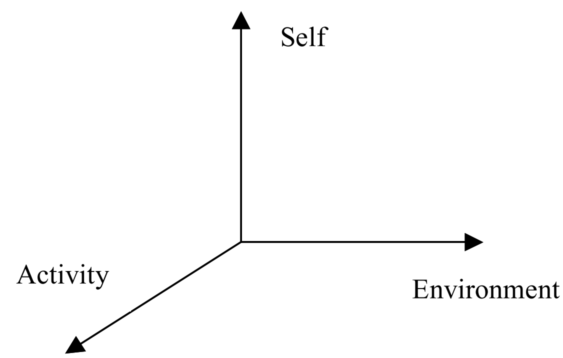

Figure 2. Three-Dimensional Context Model (Schmidt et al., 1999)

In their review of research on ubiquitous computing, Abowd and Mynatt (2000) presented "five W's" as a minimal set of necessary context information:

- Who – the user and other people in the environment
- What –human activity perception and interpretation
- Where – location and the perceived path of the user
- When – time as an index and elapsed time
- Why – reason a person is doing something

Abowd and Mynatt further state that the notion of "when" needs to be expanded to include the understanding of relative changes in time in order to help interpret human activity, including violations of perceived patterns (deviations from established routines). They also recognize the difficulty in determining "why" a user is doing something, but suggest that measuring the affective state of the user may be a starting point.

Collecting, storing, and using the types of context information described thus far is a complicated task. The accuracy of context information will vary based on the collection method(s) used. There is also the question of possible interaction between the different dimensions of context. Henricksen, Indulska, and Rakotonirainy (2002) described a context model for pervasive computing that addresses the need to measure context information quality and accurately define the relationships among context information. Furthermore, they emphasize the importance of the temporal aspects of context, including activities planned for the future. Context information is also characterized as being static (e.g., date of birth) or dynamic.

While many researchers are struggling to comprehensively define the complexities of context, Dey (2001) advocates a more general approach. He says that context is "all about the whole situation relevant to an application and its set of users." Dey further explains context as "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." (p. 5) His purpose in advocating such a general definition of context is to create a situation in which things that are important in a given situation at a given moment are considered context, and everything else is not context. But while it is true that the importance of different aspects of context changes from situation to situation, it may be confusing to eliminate aspects of context one moment and bring them back the next. While Dey does not explicitly consider time in this definition of context, he does consider the importance of time in earlier work (Dey 1998; Dey 2000).

Context-Awareness

If we take a model of context, measure the relevant context factors, and use that information to improve the functionality or usability of mobile applications, we end up with context-aware systems. Context-aware systems assist the user based on knowledge of the environment (Pascoe, Ryan, and Morse 2000). Such systems provide relevant information and/or services to the user, depending on the user's task (Dey 2001). Van Laerhoven and Aidoo (2001) stressed that context awareness should be adaptive, given that contexts depend heavily on both the user and application. There is a growing amount of research on context-aware computing, much of which concerns the construction and testing of prototype systems that use context information to create improved systems or ones that could not exist without taking context into account.

Some context-aware research has been focused on simplifying or improving the user interface. Chevrest et al. (2001) discussed three ways in which context can be used to simplify the user's interaction with an interactive system. These are:

- Reducing the need for input/action by the user
- Reducing the quantity of information that has to be processed by the user or increasing the quality of the information presented
- Reducing the complexity of rules constituting the user's mental model of the system

Researchers have begun formulating alternative interaction methods that begin to address the needs of mobility. For example, Pascoe, Ryan, and Morse (1999) discussed a context-aware application called "stick-e notes," which allows users to type messages on a mobile device and virtually attach it to their current location. Contexts other than location can also be used, such as time of day, temperature, and weather conditions. The format of the notes is not limited to plain text, and the notes reappear if the user approaches the same location again.

One way to address the issue of usability in a dynamic environment is to design devices that derive input indirectly from the user. Schmidt (2000) discussed a vision of mobile computing where devices can "see, hear, and feel." Devices act according to the situational context in which they are used. Schmidt sees a shift from explicit interaction with devices (e.g., using speech input) to *implicit interaction*, where the actions performed by the user are not necessarily directed at the device but are understood as input by the device. For example, a device might turn on automatically when grasped by a user, and power down after being left alone for a certain length of time.

Devices might also receive input from their surroundings rather than from the user. Addlesee et al. (2001) are investigating systems that react to changes in the environment according to a user's preferences. They use the term *sentient computing* because the applications appear to share the user's perception of the environment. They created a device called a "Bat" which determines its 3-dimensional location within a building in real time. These devices can be carried by users or attached to equipment.

Time

Time present and time past
Are both perhaps present in time future,
And time future contained in time past.

–T. S. Eliot, 1935

This section discusses the role of time in context when looking at the mobile information systems environment. Time is continuous, without a recorded beginning or known end. Time is important to context because the different pieces of context exist, not absolutely, but at a given moment in time. For example, a user may be at a certain location now, but may be somewhere else a minute from now. There is a historical record of context, and a context that will exist in the future. The importance of context can vary over time, based on its distance from the present (either into the past or future). For example, the co-location of people five minutes ago may be more important that the people who were in that same location five days ago. The impact of changes in context over time can also vary relative to the situation at hand (i.e., time may be more important in some circumstances than in others). For the purposes of this model, we categorize time by past, present, and future, and recognize that context changes (or, at least, can change) over time. That is, context exists according to a timeline.

Separate from the timeline side of context, there is the *time-related* side of context. This includes concepts such as time-of-day (e.g., morning, noon, and night), day-of-the-week, months, and seasons. These are not so much a direct part of context as conditions that are related to (or play a part in) other parts of the context model. For example, at night we might assume that it is relatively dark outside. But the level of darkness will vary with the absolute location being referred to. When it is morning in one part of the world, it is night in another. Darkness is also affected by weather conditions such as cloudiness. As another example, the day-of-the-week may determine when certain activities take place. Businesses may be open on weekdays but not on weekends. Seasons may also give us information about events, but again this varies based on location (e.g., it is summer in North American when it is winter in Australia).

While the use of context implies time in the present sense, some of the research reviewed in Section 2 specifically addresses time in its definitions and models of context. Schilit, Adams, and Want (1994) and Schmidt, Beigl, and Gellersen (1999) refer to changes in context of time, or history. Abowd and Mynatt (2000) add that relative changes in time are important to context-aware applications, saying that they can be used to help understand or interpret human activity (e.g., short visits could indicate a lack of interest at a museum exhibit). Chen and Kotz (2000) expand upon the Schilit, Adams, and Want definition of context by adding a distinct category of *time context*, which considers "time of a day, week, month, and season of the year." They also emphasize the potential importance of a context history for certain applications.

But these models all refer to the historical aspects of time, neglecting to explicitly consider the future. While context values cannot be precisely determined for time periods that have not yet occurred, forecasting models and methods can be used to predict values for the various factors of context. For example, weather conditions are routinely forecasted for various physical locations. As with many forecasting models, those for weather prediction rely heavily on historical data, and carry with them probabilities for accuracy. Weather predictions, when used in conjunction with predictions of locations, can be used to support effective decision-making. For instance, tourists planning activities during a vacation might be advised to schedule outdoor events when it expected to be warm and sunny rather than cold and rainy. As another example, a traveler might be advised to change a schedule due to impending weather conditions that could shut down the airport of a connecting flight.

However, we do not mean to say that people are ignoring the future completely in work related to context and computing. Henricksen, Indulska, and Rakotonirainy (2002) do state the importance of both the past and present when describing context, but their model looks primarily at associating time periods with activities (e.g., the time of a future appointment). Work by Vertegaal (2002) on attentive computing discusses the use of measures and models to determine the future state of a user's attention. Katsiri (2002) uses the location and past behavior of users to estimate the probability of a situation occurring in the future. Garlan et al. (2002) illustrate the benefits of forecasting in several of the scenarios described in their context-awareness work on Project Aura. Their futuristic scenario clearly illustrates the potential of a proactive system:

> Fred is in his office, frantically preparing for a meeting at which he will give a presentation and a software demonstration. The meeting room is a 10-minute walk across campus. It is time to leave, but Fred is not quite ready. He grabs his PalmXXII wireless handheld computer and walks out the door. Aura transfers his work from his desktop to his handheld, and lets him make final edits using voice commands during his walk. Aura infers where Fred is going from his calendar and the campus location tracking service. It downloads the presentation and the demonstration to the projection computer and warms up the projector. Fred finishes his edits just before he enters the meeting room. As he walks in, Aura transfers his final changes to the projection computer. As the presentation proceeds, Fred is about to display a slide with highly sensitive budget information. Aura senses that this might be a mistake: the room's face detection system and recognition capability indicates that there are some unfamiliar faces present. It therefore warns Fred. (p. 23)

The success of context-aware systems and attentive interfaces lies with their ability to accurately use available context information to assist the user in performing a task. While most of the current research in context and its related areas focuses on the user's present situation (and to a lesser degree, the past), it seems that even larger potential benefits exist when the future is routinely considered. With this in mind, a comprehensive model of context should explicitly consider the past, present, and future. It should also recognize the time-related components of context such as time of day, day of the week, and the seasons. The model presented in the following section attempts to address these points.

A Model of Context

We now present a model for context in mobile environments that builds upon the research presented in the previous sections. We first define three broad categories of context: environment, participants, and activities. This classification follows the Schmidt et al. (1999) model, except that their we have reclassified "users" as "participants" to emphasize that while the user is the focus of an information system, there are others that can be part of a given context. Additionally, the model includes any interactions or relationships that may exist between participants, activities, and the environment. This includes the user's social environment (consistent with Schmidt, Beigl, and Gellersen (1999)). The model is illustrated graphically in Figure 3.

Time is treated in two different ways for the purposes of this model. The three categories are all considered over a timeline of past, present, and future. This allows for a record of past context, which can be used for comparison to the current context, or for predicting future context. The time-related side of context (e.g., season, time-of-day) is treated as a set of relationships between absolute time (along a timeline) and other context characteristics. For example, any point in time has associated with it a value for a day-of-the-week, depending on location. A day-of-the-week may be related to specific user expectations, group dynamics, activities, and events. These time-related concepts are incorporated into the model as interactions.

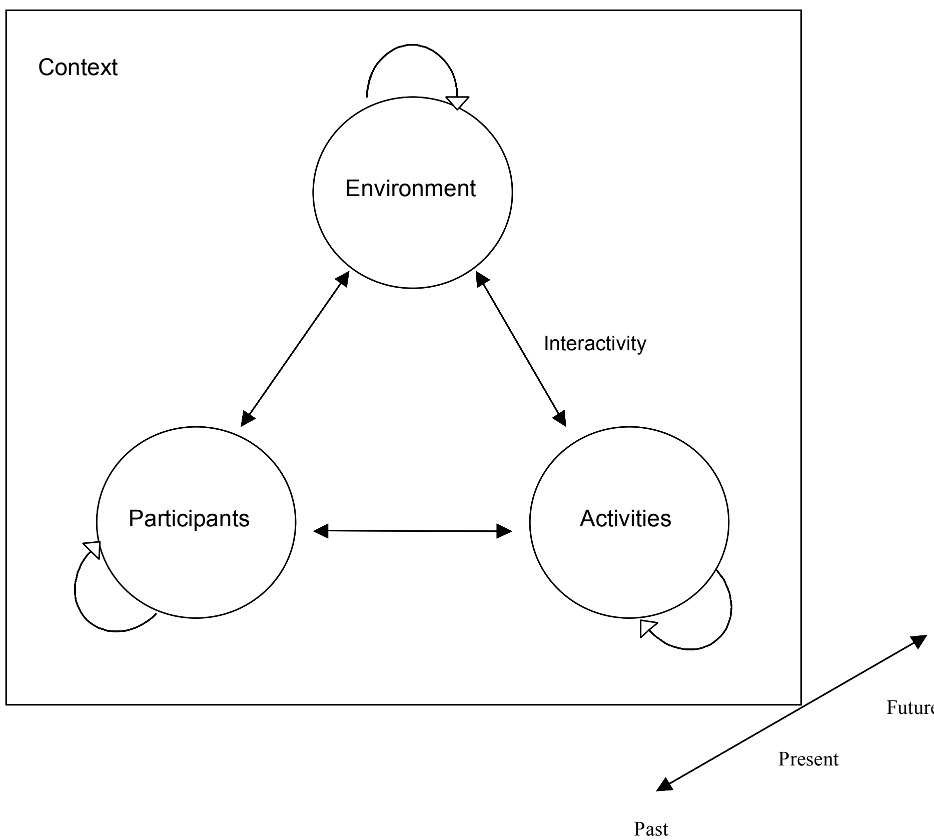

Figure 3. Graphical Representation of Context Model

All of this results in a "three-dimensional" model with the dimensions of environment, participants, and activities. These categories broadly group together the context factors that deal with the user(s), their activities, and the surrounding environment. This is a user-centered approach that is meant to facilitate the design and analysis of applications in a mobile or ubiquitous environment. The interactions between the categories recognize the relationships between and within the three dimensions, and addresses concerns expressed by Brumitt and Shafer (2001) and Henricksen, Indulska, and Rakotonirainy (2002). Incorporating a timeline emphasizes the possibility of tracking values for any context factor and using them in the determination of current or future context situations.

The model assumes that any characteristic (subcategory) can be active or inactive at any given moment for any given situation. While the model presented here does try to include all the *possible* pieces of context that influence a mobile information systems and its use, it seems reasonable to assume that all of these factors may not need to be taken into account for a given application or situation. There may also be a fuzzy scale to this ("degrees of activeness") rather than a binary condition.

Present

This section looks at the three categories of context in the present time. The "environment" category contains context factors that are outside of the control of the user(s) or other participants. The "participants" category includes the status of the user(s) or other participants. The "activities" category covers user, participant, and environmental activities. "Interactions" deal with those characteristics that pertain to interactions and relationships between individuals, their activities, and the environment. Table 2 summarizes some of the characteristics discussed below.

Table 2. Representative Characteristics for the Context Model (Present Time)

Category	Representative Characteristics
Environment	Location, Orientation (of objects) Physical properties Brightness and noise levels Availability, quality (of devices and communications)
Participants	Location, Orientation Personal properties (e.g., age, gender, education, preferences) Mental state Physical health Expectations
Activities	Tasks and goals (of participants) Events in the environment (e.g., weather)
Interactions	Co-location Group dynamics Social situations Participant/environment relationships (e.g., worker/workplace) Season, time-of-day, day-of-the-week

Environment Category

Characteristics of context that fall under the environment category include the location (absolute location) of objects such as interaction devices, vehicles, buildings, trees, roads, and bodies of water. Related to position is the orientation of an object in the environment (Privantha et al. 2001). That is, it may be important to not only know where an object is, but what direction it is facing or pointing. Physical properties of these objects can also be classified as environmental characteristics of context. For example, the object of interest may be an oak tree that is 30 feet tall.

Other characteristics in this category deal with the state and status of devices and other objects that the user or other participants may directly interact with. Interaction devices might include PDA's and cell phones. The state of a device might be working (versus broken) or on (versus off). The status of a device might be "waiting for the user to press a button." The state and status of objects such as vehicles and buildings would be considered under this category as well.

Physical aspects of the environment include conditions such as brightness, temperature, pressure, and noise level. Communications infrastructure and interaction devices are also grouped under environment. This includes communications availability (e.g., Bluetooth, cellular, wi-fi), device availability (e.g., cell phone, PDA, telematics), and quality (e.g., bandwidth and stability) (Schmidt, Beigl, and Gellersen 1999).

Participants Category

The participants category looks at the different states and status of the user(s) and other participants. This includes the physiological, emotional, and cognitive states of individuals, as well as their locations and orientations. The status of an individual consists of the person's recent experiences, or what the person is waiting for (or expects to happen next). This category allows for multiple users of a single device (e.g., a group of teenagers sharing an SMS message on one cell phone), multiple concurrent users of a system (e.g., computer supported cooperative work applications), and participants in the environment other than the user(s) (e.g., colleagues in a meeting).

Personal properties of participants are also classified under this category. Personal properties include age, gender, educational background, profession, preferences, skills, and physical capabilities (Jameson 2001).

Activities Category

This category includes the tasks, goals, activities, and behaviors of the user(s) and other participants. Classifying these as being either spontaneous or planned may be useful for context-aware applications. Environmental activities, such as weather (e.g., rain or snow) are also included here.

Interactions

Interactions classify the characteristics of context that deal with the interactions and relationships between participants, activities, and the environment. There are variants of absolute position that can be important in context-aware computing, such as the position of objects or participants relative to each other in the environment. This information can be used to determine the co-location of participants, objects, and activities. It may also be useful to consider the semantic position (the position within a larger context) of the user and other participants. For example, the user may be seated in the first chair at the table of conference room A in building 2N.

This part of the model also deals with behavioral issues that concern the user(s) and other participants, such as social situations and group dynamics. Examples of social situations include a group of close friends having dinner, strangers conversing on a city street, and employees in a project meeting. Group dynamics looks at how the people in given situation act or are expected to act based on historical encounters or know data about the people involved. For example, an employee staff meeting may involve a manager and his/her employees. In this case, it might be acceptable for the manager to receive a cell phone call, but not the employees.

There are potentially important relationships that may exist between the environment, participants, and their activities. Some fundamental relationships that exist between participants and the environment include those between workers and workplace, and students and campus. An example of a relationship that exists between activities and the environment is that between a performance and a theater.

Interactions also include the set of relationships that exist between time and other context characteristics. These include time-related concepts such as season, time-of-day, and day-of-the-week. Any point in time has associated with it a value for these different concepts, but the values also depend on location. A particular time-related concept may be related to specific user expectations, group dynamics, activities, and events. For example, shoppers may expect stores to be open weekdays, but not weekends, except during holiday shopping in November and December.

Past

There is a history for all of the context characteristics discussed in the section above on present context. Data on the values of these characteristics can be kept when it is possible (and reasonable) to do so. This data can be used with forecasting models to help determine future values of the same and related characteristics (as discussed below under future context). When actual measured historical data is not available, users, participants, and developers of information systems can provide estimates.

There are many challenges in keeping a context history that can be used with context-aware applications. One is determining the granularity (e.g., each second, each minute, hourly, daily) of the data that is captured and stored. The answer to this will most likely vary not only with the data collected but the purpose it is used for. Storage, processing, and communications limitations will need to be taken into account. There is also the question of determining how much historical data to keep, and the related question of how far back data can be traversed before it becomes irrelevant.

Future

Each of the context characteristics discussed in the section on present context can conceivably have a predicted value for any future point in time. The values will be estimated based on forecasting methods and/or models that use past values. The values will also have some associated accuracy or probability of occurrence associated with them. As discussed in Section 4, the expectations of future events or conditions can play a large part in the decision making process. Common prediction models include weather forecasting, traffic conditions, sports event outcomes, health conditions (e.g., diseases), natural disaster occurrences (e.g., earthquake, volcano eruptions, flooding), economic performance (e.g., stock and bond prices), air quality, and sales forecasting.

The future is far from certain, and predicting the future is a difficult task at best. In addition to the challenges of keeping a context history discussed in the section on past context above, there are the challenges in formulating accurate forecasting models. There are also the issues of how and when to implement such models, and how much faith to put in any decisions based on such models (i.e., the risk involved). While the potential benefits to implementing such forecasting models into mobile information systems and pervasive systems are very large, as with all decisions made with the help of technology, the final decision should be under the control of the user.

Discussion

This paper presents a model for context that can be used to guide the development of mobile applications and research in the area of ubiquitous computing. The model's classification scheme differentiates itself from previous models of context in the literature, as does its emphasis on the use and importance of time. A context model such as this might be useful as a common reference point for present and future research studies in the area of mobile and ubiquitous computing.

Our model can foster a better understanding of the affects of context on the use of m-commerce applications. While many activities compete for a user's attention on the Web, with wired e-commerce the environment *outside* of the Web is fairly stable from day to day. Most offices and homes function with a good amount of predictability, even if they do experience a great amount of activity. Relatively consistent amounts of attention can be devoted to performing tasks on the computer. On the other hand, with m-commerce, there can be a significant number of additional people, objects, and activities vying for a user's attention aside from the application itself. Furthermore, since devices are completely mobile, this outside environment can change rapidly from moment to moment. An m-commerce application may not be the focal point of the user's current activities, as the user may be trying to juggle interaction with a mobile device along with other elements in the environment (e.g., riding a bicycle with friends on a busy street while receiving directions from a navigation system). The amount of attention that a user can give to a mobile application will vary over time, and a user's priorities can also change unpredictably. Thus, the circumstances under which m-commerce applications are used can be significantly different than those for their desktop e-commerce counterparts.

The real world provides additional challenges to the design of m-commerce applications. Users have to deal with a large diversity of devices (phones, handhelds, telematics) that continue to shrink in size and weight. Changing environmental conditions (e.g., brightness, noise levels, weather) can also affect the use of mobile devices. There are potential benefits in storing sensitive data (e.g., medical, personal, and financial information) on mobile devices for use by m-commerce applications, but the mobility of devices increases the risk of losing the device and its data. Potential safety issues also appear when the location and activities of the user can vary widely. For example, when designing m-commerce systems for automobiles, serious consequences can result if the application diverts too much attention from the primary task of driving. Finally, m-commerce and its technologies bring new social concerns to the spotlight. Ringing mobile phones and key tapping users are already unappreciated by many people in public locations such as theaters and restaurants. Mobility of devices and applications raises the issue of their appropriateness of use under certain circumstances. Researchers have begun to address these challenges through innovative use of technologies, but more work is needed (Tarasewich 2003).

The true power of a context model for mobile applications may come from its use in supporting decision processes. Real world decisions become very complex as they take into account factors such as time, location, and co-location. A mobile application might plan out an optimal sightseeing route for tourists in an unfamiliar city based on the locations of desired sights. But the usefulness of the application increases if it takes into account times that buildings are open, special events that may be happening, and weather forecasts (especially for outdoor activities).

The complexities of context must be taken into account during the design and use of mobile applications to achieve long-term success. Design guidelines and usability methods that work with wired systems will not necessarily work with wireless systems. Systems must function well even as environmental conditions, circumstances, and user priorities change. Developers need to understand people and how they interact with their surroundings. Realistically, all context characteristics presented in our model will not be relevant (or important) to a mobile application or its user at a given time. But applications that do account for those context characteristics that are relevant will benefit from increased functionality and usability.

There are, however, limitations to our context model. The model does not deal with the question of *why* a person is performing a task or activity. It may be that reasons behind actions could be inferred from the actions themselves combined with the values of other context characteristics, or with their historical values. Furthermore, this model does not address how to capture, or the problems with capturing, values for the different context characteristics. Future work also needs to address privacy and distribution of context information (Henricksen, Indulska, and Rakotonirainy 2002).

In addition, our model does not try to differentiate the importance of the different context characteristics, beyond stating that they may or may not apply for a given situation. It also does distinguish those context characteristics that can be derived from other characteristics from those that must be measured. Dey (2000) mentions particular types of context (location, identity, time, and activity) which are relatively important compared to others, and discusses how they can act as indices into other sources of contextual information. It may be useful to classify characteristics into categories of "absolute" (e.g., location, orientation, time, and identification) and "derived" (e.g., co-location, season, and group dynamics).

The author is moving forward to address these limitations and other important issues. Our model needs to be validated by applying it to various context-aware applications. The relationships and interactions between (and within) the environment, participant, and activities categories need to be refined and validated as well. Future research will study context-aware computing that takes into account future time (i.e., forecasting).

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