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Using Activity Theory to Identify Relevant Context Parameters

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Abstract: One of the most important aspects of ubiquitous computing is context-awareness. In this paper, we adopt an interactional perspective on context: something is context because it is used for adapting the interaction between human and the current system; activity is central to context; context differs in each occasion of the activity. Based on this understanding, this paper proposes an Activity Theory based method which attempts to answer the following questions: how to analyze activity for context-awareness, and how to identify relevant context parameters. This method includes two steps: by using Activity Theory's hierarchical structure of activity, an activity is decomposed into actions, which we take as units for identifying context parameters; by making an extension to the Activity Theory's framework we identify relevant context parameters for each action. Finally, this paper gives an outlook how this method can be used in designing context-aware pedestrian wayfinding services.

Keywords: Context-aware, Context modeling, Activity Theory, Relevance, Pedestrian wayfinding service

1 Introduction

Recent years have witnessed rapid advances in the enabling technologies for ubiquitous computing. Ubiquitous computing demands applications that are capable of recognizing and adapting to the highly dynamic environments and of placing fewer demands on user's attention (Henricksen et al. 2002). It is widely acknowledged that context-awareness in ubiquitous computing can meet these requirements. As one type of ubiquitous computing, in order to have a high usability, Location Based Services (LBS) should be also context-aware, and adapt to the dynamic environment.

The term context-aware computing was first introduced by Schilit et al. in 1994 (Schilit et al. 1994). Since then, numbers of definitions of the term context have been proposed. Basically the majority of existing definitions of the term context can be categorized into definition by synonyms which suffers from self-referencing in loops, and definition by examples which suffers from incompleteness (Zimmermann et al. 2007). Dey et al. define context as "any information that can be used to characterize the situation of entities" (Dey & Abowd 1999), which is used most widely in the current context-aware applications. However, in using "any information" the definition becomes too general (Zimmermann et al. 2007). The practical usefulness of such definitions is limited when developing some specific context-aware systems. An important view about context can be found in Dourish (Dourish 2004), which identified two views for context: representational and interactional. He argues that the correct focus for research is on interaction between objects and activities and not solely on the representation of objects (Chen & Atwood 2007). We agree with this perspective and also with

Winograd's point (Winograd 2001) that: something is context because it is used for adapting the interaction between human and applications.

When developing context-aware systems the developer must pre-determine what aspects of the world can be used as context. Often, researchers start with comprehensive definitions but operationalize much simpler concepts of context in their actual implementations. Such simplifications appear to be necessary when developing specific systems (Lueg 2002). These kinds of actual implementations always focus on context representation, such as using data structure (key-value, markup scheme, ontology-based models, etc.) to store the relevant context parameters, adding some metadata (reliability, spatial precision, etc.) to improve the quality of context (Henricksen et al. 2002). They choose some aspects of the world as their context parameters from their own views. What is missing, however, is a method about how to identify relevant context parameters. After all, this is a fundamental question for the developer, and has an important relationship to the usability of the systems. At the same time, while many authors acknowledge that activity is central to context (Schmidt 2002) (Reichenbacher 2004) (Dransch 2005) (Zipf & von Hunolstein 2003), little work has been done to develop methods to support modeling activities in context-aware systems.

This paper attempts to solve the two problems mentioned above. As activity is central to context, therefore we focus on analyzing activity. This will enable a better understanding of context and context-awareness (Kofod-Peterson & Cassens 2005), and help us to identify possible context parameters which are relevant to the activity at hand. Activity Theory (Engeström 1987) is one of the most popular theories for modeling activity. In this paper, we propose a method based on Activity Theory. With this method, it is possible to decide which context parameters should be used in context-aware systems.

The paper is arranged as follows. Section 2 describes our understanding of context. Section 3 introduces some basic concepts of Activity Theory, and proposes our Activity Theory based method to identify relevant context parameters. Section 4 shows how this method can be used in designing context-aware pedestrian wayfinding services. Finally, the conclusions and future work are presented.

2 What's Context?

For any research on context-aware computing, a fundamental question is "what is context". A better understanding of context will enable developers to identify what context to be used in their systems (Dey & Abowd 1999). We agree with Dourish's (Dourish 2004) and Winograd's (Winograd 2001) perspectives on context:

1) Something is context (parameter) because it is used for adapting the interaction between human and the current system; features of the world become context (parameters) through their use (Winograd 2001). For example, the humidity of the room is a context parameter only if the adaptation of the interaction between human and the current system depends on it, but otherwise it is just a feature of the world.

2) Context arises from the activity (Dourish 2004). It interacts and constraints activities happened within it (Chen & Atwood 2007). An entity's activity determines its current needs. Context-aware systems are developed to meet human's needs and then assist human activities.

3) Context is dynamic, and it is particular to each occasion of activity (Dourish 2004), thus context parameters may be different in different actions in an activity. We also propose that the abstraction levels of context parameters' values may be different from occasions of activity, e.g. the values of context *location* may be longitude/latitude pair or "outdoor" to different actions.

Because the world is infinitely rich, we can not model every feature of context. In the following, we use the term *context parameters* to refer to the possible features of context.

3 A Method based on Activity Theory (AT)

In this section, we concentrate on using AT to analyze human activity. This will help us to identify the possible environmental, social, and technological contexts which are involved in performing the activity.

3.1 Activity Theory

Modern Activity Theory is based on the works of Leont'ev (Leont'ev 1987) and Engeström (Engeström 1987). It is a descriptive tool that is useful for analyzing and understanding activity in general, independently of any specific field of application (Barthelmess & Anderson 2002).

Activity, as defined by AT, provides enough contextual information to make an analysis meaningful. Activity has a hierarchical structure. They are composed of goal-directed actions, which are performed consciously. Actions, in turn, consist of non-conscious operations (Kofod-Peterson & Cassens 2005). In AT (Fig.1), activities or actions are performed by *subjects*, motivated by a goal, transforming an *object* into an *outcome*. An *object* may be shared by a *community* of actors, that work together to reach a desired *outcome*. *Tool*, *rules* and *divisions of labour* mediate the relationship between *subjects*, *community* and *object* (Barthelmess & Anderson 2002). *Object* and *outcome*, which reflect activity's goal, are central to activity.

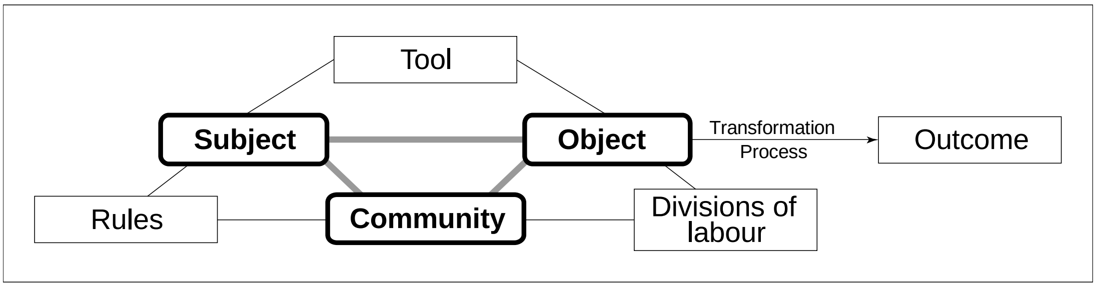

Fig. 1. Activity Theory's framework introduced by Engeström (Engeström 1987)

Although AT doesn't offer "ready-made techniques and procedures" (Engeström 1993), we can use AT's framework to identify key elements (*subjects, Tool, object, outcome, community, rules, and divisions of labour)* which influence the current human activity. Context-aware systems (tools) designed to facilitate and achieve human activity should also reflect these key elements. Therefore, AT can be used to identify possible context parameters.

Other works on the use of AT in identifying context are (Kofod-Peterson & Cassens 2005) (Kaenampornpan & O'Neill 2004). However, both of them don't consider that context differs in each occasion of activity. At the same time, as AT doesn't model the physical environment, such as location, light, sound, both of them also don't model the context parameters of the physical environment.

3.2 Using Activity Theory to Identify Relevant Context Parameters

In this section, we use AT's hierarchical structure of activity to decompose activity into actions, and then make an extension to the AT's framework, and use the extended framework to identify relevant context parameters for each action.

3.2.1 Action as a Unit of Analysis

In AT, activities are longer-term formations; their objects are transformed into outcome not at once but through a process that typically consists of several steps or phases (Nardi 1996). There is also a need for shorter-term processes: activities are composed of goal-directed actions, which are performed consciously; actions, in turn, consist of non-conscious operations (Kofod-Peterson & Cassens 2005). The activity is similar to the task which users are trying to accomplish, actions can be considered as steps of achieving it, and operations are procedures under each step. Context differs in each step (Chen & Atwood 2007).

At the activity level, we can identify the activities which the context-aware system should support. This is always shaped by the *"software requirements specifications"*. By this, we can restrict the world view of the system and make the task of developing a context model manageable. We can use the notion of actions to identify the different situations the system can encounter, which will help us to identify context parameters for the current action (Kofod-Peterson & Cassens 2005). Every action has a subgoal, and all the subgoals form the activity's overall goal. Operations under the same action share the same subgoal, and thus share the same context parameters. We want to take action as a unit for identifying context parameters.

It is possible to identify actions which constitute the current activity (from AT's point of view). The decomposition of activity can use the methods used in *task analysis*, such as Hierarchical Task Analysis (HTA). It is always performed by human-factors professionals in specific domain.

In order to facilitate and achieve human activity, context-aware systems (tools) should therefore know which action the user is engaged in at all times (Kofod-Peterson & Cassens 2005), and then adapt to the current action's relevant context parameters. The following section discusses about how to use the AT's framework to analyze each action, and identify relevant context parameters.

3.2.2 Using AT's Framework to Identify Relevant Context Parameters for each Action

As AT doesn't model the physical environment, however features of physical environment, such as location, weather, noise, humidity, also have an influence on human activity. Thus we make an extension to the AT's framework: the physical environment in which the activity happens is added to the framework. Fig. 2 shows the extended framework of Activity Theory.

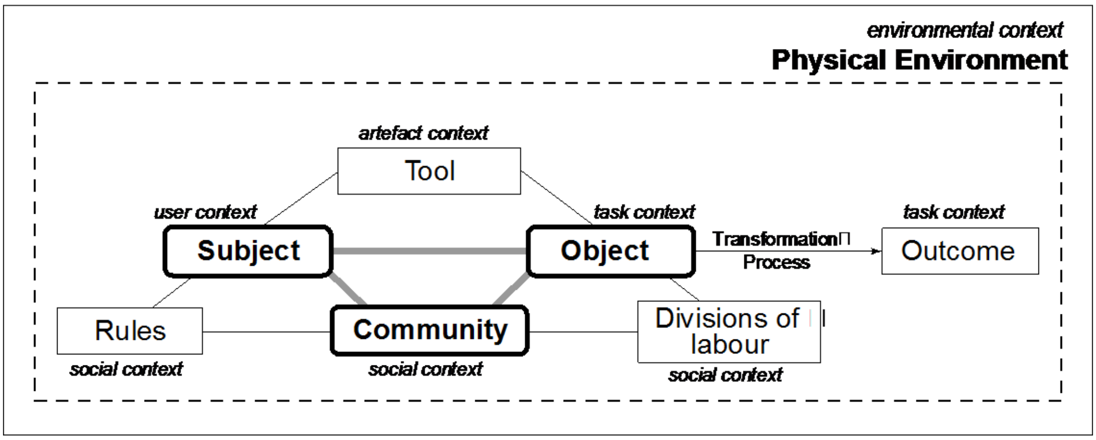

Fig. 2. The extended framework of Activity Theory (After Engeström (Engeström 1987))

The above extended framework covers the key elements which influence human action. Features (attributes) of these elements can be viewed as different types of context parameters which are relevant to the action. Therefore, we propose a possible mapping from the elements of AT to context categories (Table 1).

As mentioned in Activity Theory, history is an important factor to the action. History will become *subject*'s experience or knowledge. Tool can be viewed as transmission of human experiences for performing this activity or action, thus *tool* also reflects history. As a result, we don't want to take history explicitly. History will be represented in *user context* and *artifact context*.

Table 1. Mapping from the elements of AT to context categories

Elements of AT	Context category	Description of the context category
Subject	user context	Users' mental and physical information, such as preference, mood, skill, timetable, demographic information, and disabilities.
Object, Outcome	task context	This describes what action the user is engaged in, it includes the user's goals, tasks.
Community, Rules, Divisions of Labour	social context	This describes the social (especially organizational) aspects of the user, may include the information about people (in the community) who influence user's action or share the same object, norms, organizational rules and legislations the user should follow.
Tool	artefact context	Profiles of the tool and its availability, especially the information about systems and devices.
Physical environment	environmental context	This describes the information about the physical environment, such as location, time, weather, humidity, noise, and so on. It also includes the common legal rules (behavior) or legislations in this environment, such as navigation rules, pedestrian rules which will change according to the different environments (countries).

The above table can be viewed as the *possible context dimensions* which may have impacts on the context-aware systems. Since the world is infinitely rich, when we try to choose some context parameters to be used in our context-aware system, we should carefully consider the notion of "relevance". If some aspects of the world have significant impacts on the current context-aware computing usage, these aspects are relevant to the current context-aware system.

"Relevance" is always shaped by the goal (reflected by object and outcome) of the current action, and sometimes is additionally defined by *"software requirements specifications"*. The requirements of the goal are always defined by some *empirical results (such as user expectations and preferences)* on this goal, thus by focusing on these, we can identify some relevant context parameters which are common for this type of goal. When concentrating on *"software requirements specifications"*, we can identify some other relevant context parameters which are specific to the current system. For example, some *empirical results* on the topic of pedestrian wayfinding show that: when communicating the route information with map, way finders prefer "track up" oriented map to "north up" map. As a result, walking direction is commonly relevant to pedestrian wayfinding applications, and should be considered as a common relevant context parameter. The common relevant context parameters will be enriched with more empirical results coming out.

In the design process, the developers should:

1) Use the extended framework to identify the contents of each key element (such as *subject*, *community*, *tool*…, especially *object* and *outcome* which reflect the goal.) for every action;

2) For every action, identify each key element's relevant features (attributes) by analyzing the current action's goal (shaped by the empirical results on the corresponding topic) and *"software requirements specifications"*, and classify these relevant features (attributes) into related context category according to Table 1. Empirical results of the goal define the relevant context parameters which are common for this type of goal, while *"software requirements specifications"* define some other relevant context parameters which are specific to the current system.

At this moment, it is impossible to define a context model which will empower the system to be universally context-aware, meaning that it will be able to build its own context model on the fly (Kofod-Peterson & Cassens 2005). The developers may choose some of the context parameters to be used in their system based on *"software requirements specifications"* versus implementation costs.

4 Context-Aware Pedestrian Wayfinding Services

Technological advance in mobile devices and mobile communication triggered a move towards Location Based Services (LBS). In order to have a high usability, LBS should be also context-aware, and only provides the relevant information to users.

There are also some researches on context-awareness in Location Based Services (Reichenbacher 2004) (Dransch 2005) (Zipf & von Hunolstein 2003) (Sarjakoski & Nivala 2005). Reichenbacher (Reichenbacher 2004) provided a generic context model for mobile cartography which includes the dimensions of User, Activity, Situation, Information, System, and Meta-information, and also he discussed the process of adaptive visualization of geographic information. Nivala (Sarjakoski & Nivala 2005) also suggested a categorisation of contexts for mobile maps which includes computing (System), User (Purpose of use, User, Social, Cultural), Physical (Physical surroundings, Location, Orientation), Time, History (Navigation history). All these Context models (categories) can be viewed as possible context dimensions for mobile cartography. But as mentioned in the first section, there is little research on how to analysis activity and how to identify relevant context parameters for context-aware LBS.

As one of the most important applications in LBS, mobile pedestrian wayfinding services aim at providing navigation guidance through a mobile device in an unfamiliar environment. Pedestrian wayfinding services should be context-aware, and adapt to the dynamic environment. They are designed to assist people’s wayfinding activity. Since Activity Theory can help us to analysis human wayfinding and then identify key elements which affect the accomplishment of human wayfinding, we can use our Activity Theory – based method to identify the relevant context parameters for mobile pedestrian wayfinding services. This section shows how this suggested method can be used in designing such services.

1) Hierarchical structure of wayfinding activity

From the hierarchy of activity’s point of view, the activity is wayfinding, or route from origin to destination. According to (Downs & Stea 1977), wayfinding activity includes four processes: *orientation* (determining one’s position), *planning the route*, *keeping on the right track, discovering the destination*. The last two processes can be combined together as *moving from origin to destination*. They correspondingly relate to three modules in wayfinding services: positioning, route calculation, and route communication.

2) Using AT’s framework to identify relevant context parameters for each action

In this section, we use the method described in section 3.2.2 to analyze the above three actions. First, we use the extended framework to identify the contents of each key element for every action. If the acting person is performing a wayfinding activity with some other people, the element “*community*” will include all the people who have an influence on this activity, and the element “*rules*” contains the explicit or implicit regulations, norms and conventions related to each action, and the element “*divisions of labour*” is the member’s role in each action. To make it simple, we assume our example as individual wayfinding, where the acting person carries out the wayfinding activity mainly by the help of the wayfinding services, and he/she doesn’t need the help of pass-byers (such as other pedestrians). Therefore, it is unnecessary to consider the elements *community*, *rules* and *divisions of labour*. Table 2 shows the contents of key elements for each action.

Table 2. Contents of key elements for each action

	Orientation	Planning the route	Moving from origin to destination
Object, Outcome	Position of the user for outdoor application	Route plan meeting the requirements	Keeping on the right track: take correct directions at every decision point
Subject	The acting person	The acting person	The acting person
Tool	Wayfinding services, and positioning technologies	Wayfinding services	Wayfinding services, positioning technologies, environmental wayfinding signage, etc.
Physical	At the start point	At the start point	Along the route

Environment			

The next step is to identify each key element's relevant features by analyzing the goal of the current action and *"software requirements specifications"*, and classify them into related context category. In the following, we take the "*Moving from origin to destination*" action as an example. The goal of this action is "Keeping on the right track: take correct directions at every decision point". We can find some indispensable conceptions and functionalities from lots of empirical results on this topic (Gartner & Uhlirz 2005) (Zipf & Joest 2003), such as automatic scrolling (automatic adaptation of the presented map section to the position of the user), egocentric mapview (the map is always adapted to the user's direction of move), velocity dependence (the level of details of the map is adapted to the user's moving velocity), device dependence (the map is adapted to the profile of the device, such as size of display, color, etc.), etc. Since position of the user (environmental context), moving direction (*environmental context*), velocity (*environmental context*), size of the display (*artefact context*), color (*artefact context*) are used to implement the above functionalities, they can be considered as common relevant context parameters for the "*Moving from origin to destination*" action. In the meantime, if some functionalities such as "the content of the route map should be changed according to daytime / night time, summer / winter" are specified in the *"software requirements specifications"*, "daytime / night time" and "summer / winter" (*environmental context*) will be considered as specific relevant context parameters which are specific to the current system. Using the same method, the relevant context parameters (common and specific) for the other actions can be identified.

5 Conclusion and Future Work

In this paper, we adopt an interactional perspective on context: something is context because it is used for adapting the interaction between human and applications; activity is central to context; context differs in each occasion of the activity. Based on this perspective, we proposed a method using Activity Theory (AT) to identify relevant context parameters: first, by using AT's hierarchical structure of activity, an activity is decomposed into actions, which we take as units for identifying context parameters; second, we make an extension to the AT's framework, and use this extended framework to identify relevant context parameters for each action. Finally, a simple application of this method in designing context-aware pedestrian wayfinding services is outlined. By using this method, developers can effectively identify relevant context parameters for their context-aware systems.

Our next step is to develop some actual applications to evaluate this method. Furthermore, as relevance is very important in context modeling, we are also interested in using our extended Activity Theory framework to define different relevance.

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