Using Activity Theory to Model Context Awareness: a Qualitative Case Study

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Abstract

In this paper, we describe an approach to modelling context-aware systems starting on the knowledge level. We make use of ideas from Activity Theory to structure the general context model and to assess empirical data. We further on describe how the data-driven and the model-driven aspects of our approach are combined into a single knowledge model. We outline the design of an empirical study conducted to gather information about a concrete workplace environment. This information is then used to populate our context model. We describe also how the collected data can be used to validate our approach.

Introduction

The area of context-awareness in pervasive computing has gained considerable momentum over the last years. Not only in the number of researchers dealing with this issue, but the scenarios and visions have also grown more sophisticated. Originally, Weiser proposed the world of ubiquitous computing as a world populated with ordinary items augmented to assist people in their day to day activities (Weiser 1991).

Since then the complexity of the tasks that pervasive computing has to solve has steadily grown. The systems envisioned today are often pro-active and described as intelligent environments; or ambient intelligence. Examples of these systems are the Aura system in (Satyanarayanan 2001, p. 3), which, for example, is able to infer that sensitive information should not be presented at a talk, as unfamiliar faces are present. A similar example is available in (Ducatel *et al.* 2001, p. 4), where Maria's visa has been negotiated automatically, thus allowing her to walk right through immigrations when arriving at her foreign destination.

Just attempting to approach these visions is a daunting task. The degree of pro-activity, autonomous behaviour, and complicated reasoning abilities is staggering. However, one of the central issues when autonomous systems are to function in an environment is the ability to perceive and make sense of that environment. Systems as described in the above examples are situated (Brooks 1987) in the environment, and to a large degree inseparable from it (Gibson 1979).

The area of context awareness attempts to deal with the issues of modelling, representing, and to some degree reasoning about the environment. However, historically there has been a close connection between the concept of context and location, often they have been regarded as synonymous. This is not surprising, as we, the users, are mobile. However, one very important aspect of situations that has largely been ignored is activity. We believe that focusing on activities will allow us to gain a better understanding of context and context awareness.

Several interesting approaches to investigate activities have been proposed; such as Actor-Network Theory (Latour 1988), Situated Action (Suchman 1987) or the Locales Framework (Fitzpatrick 1998). Another fascinating starting point is Activity Theory, which is based on the works of Vygotsky and Leont'ev (Vygotsky 1978; Leont'ev 1978). In this paper, we propose the use of Activity Theory to model context and describe situations.

Most of the recent research in context aware systems has been largely technology driven. It is "...driven by what is technically feasible rather than by what might be helpful in a situation." (Lueg 2002b, p. 1) One main obstacle is the lack of a common understanding of what constitutes context. This lack of common understanding is by no means surprising, since no common theory on context understanding in humans seems to exist. Thus, it would be unreasonable to expect a common theory for artificial entities.

However, it is reasonable to assume that knowledge and reasoning play an important role when humans assess situations. Thus, it seems feasible to regard context in artificial systems from a knowledge level perspective (Newell 1982). This will give systems the advantage of reasoning about context, rather than relying on pattern matching only.

Furthermore, as IT systems are used by humans in social settings, it is viable to perform an analysis of context on the level of socio-technical systems (Lueg 2002a). In fact, the integration of intelligent systems into workplace environments marks a shift from mere tool usage to partnership between humans and intelligent artefacts.

This work is organised as follows: First, a short introduction to Activity Theory is given. Second, we describe the context model utilised in this work. This is followed by a demonstration on the use of Activity Theory to identify contextual information. Afterwards, we discuss which information is needed in order to design a system for a hospital ward scenario and how the data is gathered. The next section details how the context model is populated with domain knowledge and information about specific situations. Finally, a conclusion and outlook on future work is given.

Activity Theory

Activity Theory (AT) is a descriptive psychological framework helping to understand the unity of consciousness and activity. It is best described with a set of basic principles. These guiding principles include (Bannon & Bødker 1991):

- **Hierarchical structure of activity:** Activities (the topmost category) are composed of goal-directed actions. These actions are performed consciously. Actions, in turn, consist of non-conscious operations.
- **Object-orientedness:** Objective and socially or culturally defined properties. Our way of doing work is grounded in a praxis which is shared by our co-workers and determined by tradition. The way an artefact is used and the division of labour influence the design. Hence, artefacts pass on the specific praxis they are designed for.
- **Mediation:** Human activity is mediated by tools, language, etc. The artefacts as such are not the object of our activities, but appear already as socio-cultural entities.
- **Continuous Development:** Both the tools used and the activity itself are constantly reshaped. Tools reflect accumulated social knowledge, hence they transport social history back into the activity and to the user.
- **Distinction between internal and external activities:** In contrast to traditional cognitive psychology, Activity Theory emphasises that internal mental processes cannot be properly understood when separated from external activities, that is the interaction with the outside world.

A basic notion of Activity Theory is that the subject participating in an activity does so because he wants to achieve a certain goal. His interest is directed towards the object of an activity which he tries to use and modify to achieve an anticipated outcome. His interaction with this object is mediated by tools, creating the basic triangle of Subject, Object, and Mediating Artefact.

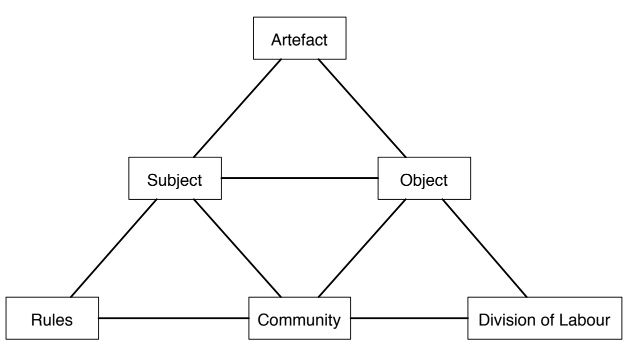

Figure 1: Cultural Historical Activity Theory (CHAT)

Since we consider social activities, the acting subject is part of a community. The relations between the acting subject and the community as well as between the community and the object are mediated by a set of rules and the division of labour (since the desired outcome is anticipated to be shared by the community, a solitary view on the relation between one subject and the object would miss important aspects).

The expanded model, including a community component and other mediators, is commonly referred to as Cultural Historical Activity Theory (CHAT). It is often depicted as the triangle shown in Figure 1.

Context Model

The context model utilised in this work assumes a subjective view on situations. This is in contrast to the prevailing view where context normally describes an objectively defined situation. We argue that any experience is personal, thus the choice of contextual parameters and their weight will also be personal.

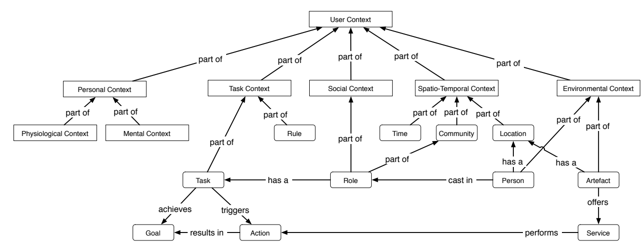

Figure 2: Context model

If we were to take this argument to the extreme, we could argue that not only the experiences are personal, but also the model and the representation. However, since our goal is to build artefacts that are useful and feasible to develop, we have chosen a pragmatic view on how to model context. The model is based on the definition given by Dey (Dey 2001):

> Context is the set of suitable environmental states and settings concerning a user, which are relevant for a situation sensitive application in the process of adapting the services and information offered to the user.

This definition does not explicitly state that context is regarded as knowledge. However, following the argument in the introduction, we argue that context must be viewed from a knowledge perspective. Concurrently, we support the view maintained by Brézillon and Pomerol that context is not a special kind of knowledge. They argue that the knowledge regarded as context is dependent on the circumstances: "…knowledge that can be qualified as 'contextual' depends on the context!" (Brézillon & Pomerol 1999, p.7)

Keeping to the pragmatic view on building artefacts, we impose a taxonomy on the context model during the design phase (Figure 2). This taxonomy incorporates the tradition in context aware systems, and the general concepts found in Activity Theory. The taxonomy divides context into five sub-categories (Kofod-Petersen & Mikalsen 2005):

1. **Environmental context:** This part captures the user's surrounding, such as things, services, people, and information accessed by the user.
2. **Personal context:** This part describes the mental and physical information about the user, such as mood, expertise and disabilities.

3. **Social context:** This describes the social aspects of the user, such as information about the different roles a user can assume.
4. **Task context:** the task context describes what the user is doing, it can describe the user's goals, tasks and activities.
5. **Spatio-temporal context:** This type of context is concerned with attributes like: time, location and the community present.

The context model is represented as a multi-relational semantic network. It is used within the CREEK framework for knowledge intensive Case-Based Reasoning (CBR) (Aamodt & Plaza 1994; Aamodt 2004). The model allows for the inference of relationships between concepts by construction of contextual dependent paths between them. One important feature is the ability to match two features that are syntactical different, by explaining why they are similar (Aamodt 1994; Jære, Aamodt, & Skalle 2002).

Activity Theory for Identifying Context

We have further on brought this established knowledge model from the domain of context aware computing together with our activity theoretic approach to context awareness in order to design a context model which is sound from a psychological perspective.

Our interest in Activity Theory for context awareness is two-fold. On one hand, we use an activity theoretic model to build and justify a general knowledge model for capturing context related knowledge. This is a top-down, or model driven, approach to capture the essential aspects on the knowledge level. On the other hand, we use the same activity theoretic model to design empirical studies in the same setting where we later want to deploy a context aware system. In this second phase, done in a bottom-up way, or data driven, the data gathered in this process is used to populate the knowledge model with domain- and situation-specific knowledge.

Since our system builds on the knowledge intensive Case-Based Reasoning (CBR) methodology (Aamodt 2004), the domain-specific knowledge gets incorporated into the general knowledge model of the system and the situation-specific knowledge takes the form of cases.

The top-down approach of building the knowledge model is described more thoroughly in (Kofod-Petersen & Cassens 2006), so we will only describe it shortly here and go into more detail on the data-driven part later in this paper.

The contextual knowledge we want to capture includes knowledge about the acting subjects, the objects towards which activities are directed, the information sources accessed, and the community as well as knowledge about the mediating components, like rules or tools. To this end, we have proposed a mapping from the basic structure of an activity into the taxonomy of contextual knowledge as depicted in Table 1. We can for example see that the personal context contains information we would associate with the acting subject itself.

We would like to point out that we do not think that a strict one to one mapping exists or is desirable at all. Our view on contextual knowledge is contextualised itself in the sense that different interpretations exist, and what is to be considered contextual information in one setting is part of the general knowledge model in another one. Likewise, the same piece of knowledge can be part of different categories based on the task at hand.

Table 1: Basic aspects of an activity and their relation to a taxonomy of contextual knowledge

CHAT aspect	Category
Subject	Personal Context
Object	Task Context
Community	Spatio-Temporal Context
Mediating Artefact	Environmental Context
Mediating Rules	Task Context
Mediating Division of Labour	Social Context

Other work on the use of AT in modelling context has been conducted e.g. by Kaenampornpan and O'Neill (Kaenampornpan & O'Neill 2004). The authors focus on modelling features of the world according to an activity theoretic model, but they do not carry out a knowledge level analysis of the activities. This is in contrast to our own approach, and we argue that our knowledge intensive approach has the advantage of giving the system the ability to reason about context so that it does not have to rely on pattern matching only. This is advantageous especially in situations where not all the important features are accessible by the system, for example because of limits of sensory input in mobile applications.

An interesting feature in Kaenampornpan and O'Neill's further work is the notion of history of context. The history is used to elicit a user's current goal (Kaenampornpan & O'Neill 2005). We do not explicitly address the problem of representing the user history in context models. The application area we are considering in this article features a set of relatively well defined situations, and information about the user's goal is included in the cases of the underlying CBR system.

Li and Landay (Li, Hong, & Landay 2004) propose an activity based design tool for context aware applications. In contrast to our proposal, the authors focus on supporting the designer of context aware applications with a rapid prototyping tool, not on the use of Activity Theory in the Context model itself.

Wiberg and Olsson (Wiberg & Olsson 1999) make also use of Activity Theory. The main issue here is the design of context aware tangible artefacts. The usage situation is well defined upfront and no reasoning about the context has to take place. This differs considerably from our own approach.

Gathering Data

We now have a well defined semantic network serving as a knowledge model which is sound both from an Activity Theory viewpoint and from the tradition of context-aware computing. The next step is to populate the model with data from real world situations.

The setting for our empirical study is supporting medical personnel at a hospital ward. The persons involved deal with different activities, like ward rounds, pre-ward round meetings, and different forms of examination. The staff has to access a large variety of different information systems. The main goal is to have a system which makes the information sources needed in different situations available pro-actively. To this end, the system must first identify the activity the system's user is involved in, identify his role, and then query the information sources which are likely to be accessed.

To gather data about this work processes, we have designed forms for a study which allow us to focus on different parts of an activity theoretic analysis of the work process. The forms had to meet certain requirements:

- It should be possible to clearly identify the different activities the users were involved in. Further on, the goal for each situation should be identified, even if the users did not explicitly state these goals. This would enable us to identify the different outcomes anticipated by the users, and eventually could help us building a model capturing the hierarchical structure of activities.
- The artefacts used should be identified, and different forms of use of these artefacts should be recorded. This would give us hints about the mediating role of artefacts. Special interest should be given to the use of infomation sources.
- The different entities involved in the activity as depicted in the basic triangle (see Figure 1) should, if observable, be described in order to be able to directly connect the data collected to the knowledge level model.
- By observing the praxis of using artefacts, deeper insight on externalisation of cognitive processes can be gained. Although this is not in the scope of our current work, a study design which takes this aspect into consideration could help us evaluating the capabilities an intelligent system would have to provide to its users in order to be seen as an intelligent partner.
- Although a truly intelligent system would be able to adapt itself to completely new situations, we consider the usage situation, e.g. with regard to the governing rules and the capabilities of the tools used, as being relatively constant. Therefore, our study design did not particularly deal with issues of continuous development.

At the same time, the resulting form could not be too extensive since it was to be filled out by a single person observing the activities. The end result was a form which captured essentially the following aspects:

- **Location:** The room where the situation occurred
- **User:** The user of the system
- **Role:** The role of the user
- **Present:** Other persons present
- **Role:** The role of each of the persons present
- **Patient:** The ID of the patient in question
- **Time:** The time of day
- **Source:** Information sources and targets
- **I/O:** The direction of the information flow
- **Information:** Type of information

The data was collected through a period of one month at the St. Olavs Hospital in Trondheim, Norway. A medical student followed several employees and recorded the situations that occurred throughout the days on the forms we had designed for this task.

Populating the Context Model

The context aware system we are describing in this article is realised within the CREEK framework for knowledge intensive CBR (Aamodt 2004). The knowledge components of CREEK are modelled as a semantic network. The semantic network for our context aware application integrates the following components:

1. The basic knowledge, which holds the generic concepts necessary for modelling the general domain and case knowledge. See (Aamodt 2004) for a more thorough description.
2. The general taxonomy as described in Section "Context Model".
3. General aspects of the activities, such as roles, artefacts, communities, and the relation between them as described in Section "Activity Theory for Identifying Context".
4. The adaptation of the generic model to the work environment at hand, in this case the hospital. The adaptation to each specific scenario consists itself of two different parts. The task is:
   (a) To enrich the context model with domain specific information, like which artefacts were used and which services they offered and consumed, and
   (b) to populate the context model by adding concrete situations (cases) that were observed.

Domain Specific Information

In order to adapt the generic context aware system we have described to a particular working environment, the tasks performed in this environment, the communities of labour existing, and the specific artefacts used, we have to enrich the knowledge model with specific information about the environment modelled. This enrichment includes: the different locations at the wards; the roles that employees, patients, and visitors assume; the classes of persons encountered in the wards; artefacts and services they offer and consume.

The empirical study performed was used to extract the necessary knowledge and model it in the CREEK framework. A typical example for this kind of knowledge would be the observation that we have two distinct types of health workers (nurses and physicians), and that there are different types of physicians (e.g. consulting physicians, temporary physicians, and assistant physicians). Further more, this physicians could assume different roles, like group leader or examiner. Another example would be that five distinct laboratories are used, and that an ECG was placed at specific locations.

This knowledge was extracted from the collected data and modelled manually into the system.

Situation Specific Information

The data set contains 360 situations, 197 for cardiology and 163 for gastroenterology. The empirical evaluation of the system's performance is done in two steps. First, a qualitative evaluation of the data from the cardiology ward was carried out in order to review the context model and the integration on the knowledge level. This work has been completed. Second, data from both wards will be used in an quantitative evaluation of the final system architecture. This second step has not been completed yet.

The data describing the context of situations includes some information which could easily be sensed through available hardware, like location and the users involved and the time of the situation occurring. Some of the other data might not be easily available, like the presence of a patient's relatives.

However, since we are mainly concerned with methodological issues in this paper, we have not addressed the more technical aspects of collecting and fusing sensory information yet.

For the quantitative evaluation, approximately half of the situations were fed into the system manually, thereby giving the system a set of initial cases to reason about. The second half was used to test whether the system could successfully classify situations and identify the correct information sources needed.

The 197 situations at the cardiology ward which have been incorporated into the systen are distributed as described in Table 2.

Table 2: Distribution of observed data for cardiology

Situation	AL7	AL9	AL14	OL9	Σ
Pre pre ward	5				5
Pre ward round	7	22	11	26	66
Ward round	7	21	11	26	65
Examination		8	2	9	19
Post work		8	9	13	30
Pre discharge			2	4	6
Heart meeting		1		1	2
Discharge meeting				4	4

Eight different types of situations have been identified in the data set. Four different physicians were observed, where three were assistant physicians (AL7, AL9, and AL14) and one was a consultant physician (OL9). Beside these, several nurses, patients, and relatives were present in different situations.

The first qualitative analysis has shown that the CBR system was able to successfully identify new situations based on the initial set of cases. Further on, based on the knowledge about the sequence of actions contained in the previously seen cases, the system was able to identify the correct sequence of actions needed in the ongoing activity.

Conclusion and Future Work

We have shown that context aware intelligent systems can benefit from the socio-technical analysis made possible by applying Activity Theory. Moreover, taking socio-technical aspects into account is a necessity when intelligent systems are not used as mere tools but are designed to be more of a partner in a work process. It is beneficial to be able to make use of a sound psychological framework when defining a knowledge model as well as when constructing guidelines for observations. Our approach described in this paper can be used to design studies in real world settings which can be used as starting points for the deployment of context aware systems.

We have outlined how the observational data can be integrated into a knowledge level model to form a coherent multi-relational semantic network, which allows for the perception of the environment, reasoning about context to identify situations, and problem-solving based on this understanding.

Based on the data for the cardiology ward, we have populated our existing general model with domain- and situation-specific knowledge. At the same time, we have focused on identifying generic solution strategies corresponding to the situations we have discovered.

After the context aware system has successfully identified the current context and the potential goals of the human actors, the knowledge contained in the specific cases together with the domain-specific knowledge about possible courses of action make it feasible to support the human activities by offering guidance and retrieve necessary information.

As for empirical validation, we have performed an initial qualitative assessment of the system's integrity, and tested the ability of our reasoning component to correctly identify new situations on a subset of the collected data. Our initial results indicate that a knowledge intensive approach to combine situational data with general and domain specific knowledge can be regarded as being very promising when tackling the intricate problem of identifying situations. The next step is to execute a full simulation of the system on all available data.

On the methodological side, we will use the results from our empirical work to further formalise the relationship between different aspects of an AT based analysis and the different knowledge containers we can utilise in our system. Equally important is the development of a methodological approach to study design and data assessment.

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