Activity Theory and Context-Awareness

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Abstract. A lot of research has been done in the area of context-aware computing. Even though, the term context seems often not to be well defined. We attribute this problem partly to the fact that research often focuses on syntactical and technical issues of contextuality and does not take a knowledge level perspective on context. When including the knowledge level, some sort of analysis is required on what aspects need to be modelled. In this paper, we propose the use of an Activity Theory (AT) based approach on modelling components, and outline how it can be combined with the AmbieSense context modelling framework we have proposed earlier.

1 Introduction

A major short fall of the research in context-aware systems, and in many other disciplines as well, is the lack of a common understanding of what context is, and perhaps more importantly, what it is not. This shortfall is a very natural one, since no common understanding of what context is and how it is used in the real world exists, it is no surprise that it is hard to agree on the artificial world that IT systems, most often, represent.

Most of the research today has been focused on the technical issues associated with context, and the syntactic relationships between different concepts. Not so much attention has been given to context from a knowledge level [1] perspective or an analysis of context on the level of socio-technical systems [2].

This is the main reason for the approach chosen here. It should be feasible to look at how we can use socio-technical theories to design context-aware systems to supply better services to a user, in a flexible and manageable way.

Context-aware IT Systems are usually designed for specific purposes and with specific tasks in mind where the system has to support human users. It is used by people with specific needs and qualifications, and it should preferably adapt to changes in these needs over time [3,4]. Althoff et al. [5] have introduced an organisational view of the Case-Based Reasoning (CBR) cycle for the purpose of business process modelling. For the purpose of this paper, we are looking at CBR systems embedded in such a work situation, but on a more general level.

This paper is organised as follows: first some background work on the use of context in cognition is covered. Secondly, the knowledge model, including context employed in this work is described. Thirdly, Activity Theory is briefly introduced. This is followed by an explanation of how Activity Theory can be utilised to model contextual information. Finally, some pointers for future work are presented.

2 Context in Cognition

The concept of context is a closely related to reasoning and cognition in humans. Even though, context might be important for reasoning in other animals, it is common knowledge that context is of huge importance in human reasoning.

Beside the more mechanical view on reasoning advocated by neuro-science, psychology and philosophy play important roles in understanding human cognition. It might not be obvious how computer science is related to knowledge about human cognition. However, many sub-fields in computer science are influenced by our knowledge about humans; and other animals.

The field of Artificial Intelligence has the most obvious relations to the study of reasoning in the real world, most prominently psychology and philosophy. Since AI and psychology are very closely related and context is an important aspect of human reasoning, it should come as no surprise that context also plays an important role in the understanding and implementation of artificial intelligence.

AI has historically been closely connected to formal logic. Formal logic is concerned with explicit representation of knowledge. This leads to the need to codify all facts that could be of importance. This strict view on objective truth is also known in certain directions within philosophy, where such a concept as knowledge as an objective truth exists. This comes as no surprise, since the father of logic Aristotle, believed that some subset of knowledge had that characteristic (Episteme). This view stands in stark contrast to the views advocated by people such as Polanyi, who argues that no such objective truth exists and all knowledge is a some point personal and hidden (tacit) [6].

Since context is an elusive type of knowledge, where it is hard to quantify what types of knowledge is useful in a certain situation, and possible why, it is obvious that it does not fit very well with the strict logical view on how to model the world. According to Ekbia and Maguitman [7] this has led to the fact that context has largely been ignored by the AI community.

The paper by Ekbia and Maguitman is not a recipe on how to incorporate contextual reasoning into logistic systems, rather an attempt to point out the deficiencies and suggest possible directions AI could take to include context. The work by Ekbia and Maguitman builds on the work by the American philosopher John Dewey.

According to Ekbia and Maguitman, Dewey distinguishes between two main categories of context: spatio and temporal context, together know as background context; and selective interest. The spatio context covers all contemporary parameters. The temporal context consists of both intellectual and existential context. The intellectual context is what we would normally label as background knowledge, such as tradition, mental habits, and science. Existential context is combined with the selective interest related to the notion of situation. A situation is in this work viewed as a confused, obscure, and conflicting thing, where a human reasoner attempts to make sense of this through the use of context. This view, by Dewey, on human context leads to the following suggestion by the pragmatic approach [7, p. 5]:

1. Context, most often, is not explicitly identifiable.
2. There are no sharp boundaries among contexts.
3. The logical aspects of thinking cannot be isolated from material considerations.
4. Behaviour and context are jointly recognisable.

Once these premises have been set, the authors show that the logical approach to (artificial) reasoning has not dealt with context in any consistent way. The underlying argument is that AI has been using an absolute separation between mind and nature, thus leading to the problems associated with the user of context. This view on the inseparability of mind and nature is also based on Dewey's work. This view is not unique for Dewey. In recent years this view has been proposed in robotics as situatedness by Brooks [8,9,10], and in ecological psychology by J. J. Gibson [11].

Through the discussion of different logical-based AI methods and systems, the authors argue that AI has not yet parted company with the limitations of logic with regards to context. Furthermore, they stress the point of intelligence being action-oriented; based on the notion of situations described above.

The notion of intelligence being action-oriented, thus making context a tool for selecting the correct action, is shared by many people within the computer science milieu. Most notably the work by Strat [12], where context is applied to select the most suitable algorithm for recognition in computer vision, and by Öztürk and Aamodt [13] who utilised context to improve the quality and efficiency of Case-Based Reasoning.

Strat [12] reports on the work done in computer vision to use contextual information in guiding the selection of algorithms in image understanding. It is common knowledge that when humans observe a scene they utilise a large amount of information (context) not captured in the particular image. At the same time, all image understanding algorithms uses some assumptions to function. Examples are algorithms that only work on binary images, or not being able to handle occlusions.

Strat defines three main categories of context: *physical*, being general information about the visual world independent of the conditions under which the image was taken; *photogrammetric*, which is the information related the acquisition of the image; and *computational*, being information about the internal state of the processing. The main idea in this work is to use context to guide the selection of the image-processing algorithms to use on particular images. This is very must in line with the ideas proposed by Ekbia and Maguitman, where intelligence is action-oriented, and context can be use to bring order to diffuse situations.

This action-orientated view on reasoning and use of context is also advocated by Öztürk and Aamodt [13], who demonstrate the use of context to improve the quality and efficiency of Case-Based Reasoning. They argue that the essential aspects of context are the notion of *relevance* and *focus*. To facilitate this improvement to Case-Based Reasoning a context model is constructed. This model builds on the work by Hewitt, where the notion of *intrinsic* and *extrinsic* context types are central. According to Hewitt, intrinsic context is information related to the target item in a reasoning process, and extrinsic is the information not directly related to the target item. This distinction is closely related to the concepts of *selective interest* and *background context* as described by Dewey. The authors refine the view by focusing on the intertwined relationship between the *agent* doing the reasoning, and the *characteristics* of the problem to be solved. This is exactly the approach recognised as being missing in AI by Ekbia and Maguitman.

The authors build a taxonomy of context categories based on this merger of the two different worlds of information (internal vs. external). Beside this categorisation, the authors impose the action, or task, oriented view on knowledge in general, and contextual knowledge in particular. The goal of an agent *focuses* the attention, and thereby the knowledge needed to execute tasks associated with the goal. The domain use in this paper is medical diagnostics, where a doctor attempts to diagnose a patient by the hypothesise-and-test strategy. The particular method of diagnostics in this Case-Based Reasoning system, is related to the strategy used by Strat. Though with the minor modification that Strat used contextual information to select the algorithms to use, whereas Öztürk and Aamodt have, prior to run-time, defined the main structure of a diagnostic situation, and only uses context to guide the sub-tasks in this process.

Zibetti et al. [14] focus on the problem of how agents understand situations based on the information they can perceive. This work is the only one that does not attempt to build an explicit ontology on contextual information prior to run-time. The idea is to build a (subjective) taxonomy of ever-complex situations solely based on what a particular agent gathers from the environment in general, and the behaviour of other agents in particular.

The implementation used to exemplify this approach contains a number of agents "living" in a two-dimensional world, where they try to make sense of the world by assessing the spatial changes to the environment. Obviously the acquisition of knowledge starting with a *tabula rasa* is a long and tedious task for any entity. To speed up the process the authors predefined some categories with which the system is instantiated.

All in all, this approach lies in between a complete bottom-up and the more top-down approaches described earlier.

3 The AmbieSense Context Model

The context model used in this work draws on the subjective view proposed above. This system proposes that the understanding of a given situation is based on a personal view. Thus, the CBR agent utilised to assess the situation is personal. However, to avoid the problem of a *tabula rasa* we have chosen a pragmatical view on how to model context and introduced a taxonomy that is based on the definition of context given by Dey [15], applying the following definition:

> 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.

Even though this definition from Dey do not explicitly state that context is viewed as knowledge, we adhere to the view advocated by Brézillon and Pomerol [16]; that context is not a special kind of knowledge. Hence, particular kinds of knowledge can be considered context in one setting and domain knowledge in another. Approaches from organisational psychology, such as Activity Theory, can assist system designers to identify the relevant pragmatic aspects.

We believe that this pragmatic definition of context allows application developers to efficiently rule out information that is not context in their particular application domain (or their context). At design time, developers can ask the question; is this information relevant for adapting our services and information? If the answer is no, the information is discarded as not being context, and excluded from the context model. This flexibility leads to an open context model that only defines the taxonomic structure in the design phase (see Fig. 1).

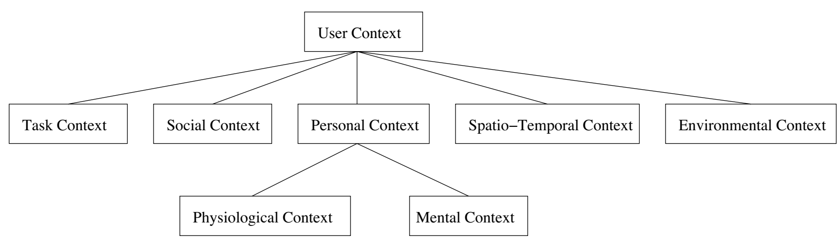

Fig. 1. User Context in the AmbieSense project

We argue a context model where context is not a special type of information. However, this view is not contradictory to a need to structuring our knowledge model with context in mind. Since we are focusing on applications utilising contextual information to improve services provided to users, we have chosen to structure our model around a taxonomy inherited from the context-aware tradition.

The context is divided into five sub-categories (a more thorough discussion can be found in [17] or [18]):

1. **Environmental context:** This part captures the users surroundings, such as things, services, light, people, and information accessed by the user.
2. **Personal context:** This part describes the mental and tuples physical information about the user, such as mood, expertise, disabilities and weight.
3. **Social context:** This describes the social aspects of the user, such as information about friends, relatives and colleagues.
4. **Task context:** the task context describe what the user is doing, it can describe the user's goals, tasks, activities, etc.
5. **Spatio-temporal context:** This type of context is concerned with attributes like: time, location and movement. The different aspects of the contexts are attribute-value tuples that are associated with the appropriate contexts.

The model depicted in Fig. 1 shows the top-level ontology. To enable the reasoning in the system this top-level structure is integrated with a more general domain ontology, which describes concepts of the domain (*e.g.*, Airport Hall, Gate, Restaurant, Newsstand) as well as more generic concepts (Task, Goal, Action, Physical Object) in a multi-relational semantic network. The model enables the system to infer relationships between concepts by constructing context-dependent paths between them. One important use of this is to be able to match two case features that are syntactically different, by explaining why they are similar [19,20].

A part of a domain model —in which the context model is integrated— is illustrated in Fig. 2.

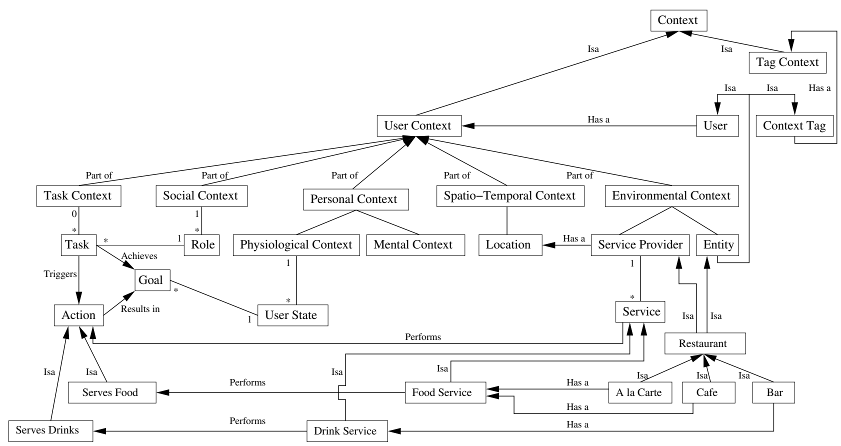

Fig. 2. Enriched Context Model

This work postulates that a goal or task exists in every situation. It would be futile to identify a situation unless there is some task connected to it – no matter how mundane. This is most obvious when dealing with users, where a situation implies that there is a problem that needs to be solved; such as the possible situation ”hungry user”, which implies the goal of *not hungry user*, leading to the task *provide food*, with a subtask *locate food*.

The problem we face now is to identify the tasks connected to a particular situation, the goals of the user, and the artefacts and information sources used. The different approaches outlined before do not deal with modelling as such. They primarily focus on how context can be represented and utilised. However, knowledge acquisition is an important part of knowledge intensive systems in general and context-aware systems in particular.

Activity Theory has proven itself as a useful tool in modelling and understanding interaction between humans and their use of artefacts in work place situations [21]. We believe that Activity Theory will prove itself just as useful when dealing with acquisition and modelling of knowledge in context-aware applications.

4 Activity Theory

In this section, we concentrate further the use of Activity Theory (AT) to support the modelling of context. We can use AT to analyse the use of technical artefacts as instruments for achieving a predefined goal in the work process as well as the role of social components, like the division of labour and community rules. This helps us to understand what pieces of knowledge are involved and the social and technological context used when solving a given problem.

First, we give a short summary of aspects of AT that are important for this work. See [22] for a short introduction to AT and [23,24] for deeper coverage. The theoretical foundations of AT in general can be found in the works of Vygotsky and Leont'ev [25,26,27]

Activity Theory is a descriptive tool to help understand the unity of consciousness and activity. Its focus lies on individual and collective work practise. One of its strengths is the ability to identify the role of material artefacts in the work process. An activity (Fig. 3) is composed of a subject, an object, and a mediating artefact or tool. A subject is a person or a group engaged in an activity. An object is held by the subject and motivates activity, giving it a specific direction.

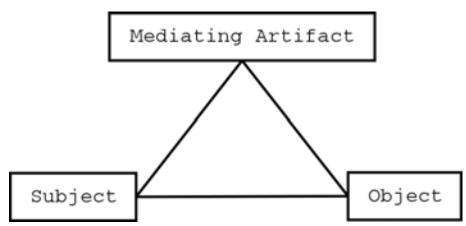

Fig. 3. Activity Theory: The basic triangle of Mediation.

Some basic properties of the AT are:

- **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 influences 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.

Taking a closer look on the hierarchical structure of activity, we can find the following levels:

– **Activity:** This is the topmost level. An individual activity is for example to check into a hotel, or to travel to another city to participate at a conference. Individual activities can be part of collective activities, e.g. when someone organises a workshop with some co-workers.
– **Actions:** Activities consist of a collections of actions. An action is performed consciously, the hotel check-in, for example, consists of actions like presenting the reservation, confirmation of room types, and handover of keys.
– **Operations:** Actions consist themselves of collections of non-conscious operations. To stay with our hotel example, writing your name on a sheet of paper or taking the keys are operations. That operations happen non-consciously does not mean that they are not accessible.

It is important to note that this hierarchical composition is not fixed over time. If an action fails, the operations comprising the action can get conceptualised, they become conscious operations and might become actions in the next attempt to reach the overall goal. This is referred to as a breakdown situation. In the same manner, actions can become automated when done many times and thus become operations. In this way, we gain the ability to model a change over time.

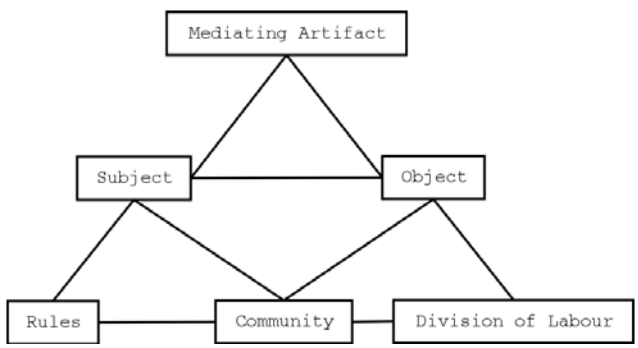

Fig. 4. Cultural Historical Activity Theory: Expanded triangle, incorporating the community and other mediators.

An expanded model of Activity Theory, Cultural Historical Activity Theory (CHAT), covers the fact that human work is done in a social and cultural context (compare e.g. [28,29]). The expanded model takes this aspect into account by adding a community component and other mediators, especially rules (an accumulation of knowledge about how to do something) and the division of labour (see Fig. 4).

In order to be able to model that several subjects can share the same object, we add the community to represent that a subject is embedded in a social context. Now we have relationships between subject and community and between object and community, respectively. These relationships are themselves mediated, with rules regarding to the subject and the division of labour regarding to the object.

This expanded model of AT is the starting point for our use of AT in the modelling of context for intelligent systems.

5 Activity Theory for the Identification of Context Components

The next step is to identify which aspects of an Activity Theory based analysis can help us to capture a knowledge level view of contextual knowledge that should be incorporated into an intelligent system. This contextual knowledge should include knowledge about the acting subjects, the objects towards which activities are directed and the community as well as knowledge about the mediating components, like rules or tools.

For example, we want the contextual knowledge to contain both information about the acting subject itself (like the weight or size) and the tools (like a particular software used in a software development process). To this end, we propose a mapping from the basic structure of an activity into the taxonomy of contextual knowledge as depicted in Table 1. We can see that the personal context contains information we would associate with the acting subject itself.

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

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.

The same holds for the AT based analysis itself: the same thing can be an object and a mediating artefacts from different perspectives and in different task settings. The mapping suggested here should lead the development process and allow the designer to focus on knowledge-level aspects instead of being lost in the modelling of details without being able to see the relationship between different aspects on a socio-technical system level.

As an example, let us consider a software development setting where a team is programming a piece of software for a client. The members of the team are all *subjects* in the development process. They form a *community* together with representatives for the client and other stake-holders. Each member of the team and personal from other divisions of the software company work together in a *division of labour*. The *object* at hand is the unfinished prototype, which has to be transformed into something that can be handed out to the client. The task is governed by a set of *rules*, some explicit like coding standards some implicit like what is often referred to as a working culture.

The programmers use a set of *mediating artefacts* (tools), like methods for analysis and design, programming tools, and documentation.

When we design a context-aware system for the support of this task, we include information about the different team members (*subjects*) in the *personal context*. Aspects regarding the special application he is working on (*objects*) are part of the *task context*, it will change when the same user engages in a different task (lets say he is looking for a restaurant). The *rules* are part of the *task context* since they are closely related to the task at hand – coding standards will not be helpful when trying to find a restaurant. We find the tool aspects (*mediating artefacts*) in the *environmental context* since access to the different tools is important for the ability of the user to use them. Knowledge about his co-workers and other stake-holders (*community*) are modelled in the *spatio-temporal context*. Finally, his interaction with other team members (*division of labour*) is found the *social context*.

Activity Theory is also capable of capturing changing contexts in break-down situations. Lets consider that a tool used in the development process, such as a compiler, stops working. The operation of evoking the compiler now becomes a conscious action for the debugging process. The focus of the programmer shifts away from the client software to the compiler. He will now be involved in a different task where he probably will have to work together with the system administrators for his work-station. In this sense other aspects of the activity, such as the community, change as well. It is clear that the contextual model should reflect these changes. The ability of Activity Theory to identify possible break-down situations makes it possible for the system designer to identify these possible shifts in situation and model the anticipated behaviour of the system.

6 Ongoing and Future Work

We have outlined how the design of context-aware systems can benefit from an analysis of the underlying socio-technical system. We have introduced a knowledge-level perspective on the modelling task, which makes it possible to identify aspects of knowledge that should be modelled into the system in order to support the user with contextual information. We have furthermore proposed a first mapping from an Activity Theory based analysis to different knowledge components of a context model. The basic aspects of our socio-technical model fits nicely to the taxonomy of context categories we have introduced before, thus making AT a prime candidate for further research.

The use of Activity Theory allows for system designers to develop the general models of activities and situations. General models are necessary to support the initial usage of the system. They are an important prerequisite for the Case-Based Reasoning system to integrate new situations; thereby adapting to the personal and subjective perspective of the individual user.

In Section 3 we have formulated the problem of identifying the tasks connected to a particular situation, the goals of the user, and the artefacts and information sources used. We argue that our Activity Theory based approach is capable of integrating these cognitive aspects into the modelling process.

The integration of an *a posteriori* method of analysis with design methodologies is always challenging. One advantage AT has is that it is process oriented, which corresponds to a view on systems design where the deployed system itself is not static and where the system is able to incorporate new knowledge over time [30]. Activity Theory has its blind spots, such as modelling the user interaction of the interface level. However, in this particular work we are not focusing on user interfaces; thus, these deficiencies do not affect this work directly. Still, one of our future goal is to combine AT with other theories into a framework of different methods supporting the systems design process [31].

Nevertheless, one of the next steps is to formalise the relationship between different elements of an AT based analysis and the knowledge contained in the different contextual aspects of our model. This more formalised relationship should be put to the test on a context modelling task, using an AT based analysis of a socio-technical system to support the design of a context-aware intelligent system.

We have recently initiate a project where everyday situations in health care are being observed and documented. These observations will be used to test the situation assessment capabilities of our system. We will use a modelling approach based on Cultural Historical Activity Theory. This will allow us to identify the different activities the medical staff is involved with and the artefacts and information sources used.

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