# Modeling context in information seeking

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## INTRODUCTION

Context plays an important role in a number of domains where reasoning intervenes as in understanding, interpretation, diagnosis, etc. The reason is that reasoning activities heavily rely on a background (or experience) that is generally not made explicit and that gives a contextual dimension to knowledge. On the Web in December 1996, AltaVista gave more than 710000 pages containing the word *context*, when *concept* gives only 639000 references. A clear definition of this word stays to be found. There are several formal definitions of this concept (references are given in Brézillon, 1996): a set of preferences and/or beliefs, an infinite and only partially known collection of assumptions, a list of attributes, the product of an interpretation, possible worlds, assumptions under which a statement is true or false. One faces the same situation at the programming level: a collection of context schemas; a path in information retrieval; slots in object-oriented languages; a special, buffer-like data structure; a window on the screen; buttons which are functional customisable and shareable; an interpreter which controls the system's activity; the characteristics of the situation and the goals of the knowledge use; or entities (things or events) related in a certain way that permits to listen what is said and what is not said. Context is often assimilated at a set of restrictions (e.g., pre-conditions) that limit access to parts of the applications.

The first works considering context explicitly are in Natural Language. Researchers in this domain focus on the linguistic context, sometimes associated with other types of contexts as: semantic context, cognitive context, physical and perceptual context, and social context (Bunt, 1997).

In Artificial Intelligence, the lack of explicit representation of context is one of the reasons of the failures of many Knowledge-Based Systems (KBSs). For instance, Brézillon & Pomerol (1996; 1997) point out that knowledge, which is acquired from human experts, has a high contextual component. This contextual component is generally not acquired with the knowledge because knowledge engineers asked what experts' solution is, not how they reach it. However, context has already been used by researchers in AI as de Kleer (1987) in ATMS, McDermott (1982) in X1/RCON, Laird and col. (1987) in SOAR, Hendrix (1975) for the partition of semantic networks, Guha (1991) in the CYC project.

Several theoretical approaches consider explicitly or not context. Context has been modeled on the basis of the Situation Theory (Barewise and Perry, 1983). Situation theory is a unified mathematical theory of meaning and information content that is applied to specific areas of language, computation and cognition. The theory provides a system of abstract objects that make it possible to describe the meaning of both expressions and mental states in terms of the information they carry about the external world. Surav and Akman (1995) approach context as an amalgamation of grounding situation and the rules that govern the relations within the context. They represent a context by a situation type that supports two types of infons: parameter free infons to state the facts and the usual bindings. Parametric infons (which corresponds to parametric conditionals) aim at capture the if-then relations and axioms within the context. In Computer-Human Interaction, Nardi (1992) presents a study of context from a comparison of the activity theory (Leont'ev, 1974), the situation action models (Lave, 1988) and the distributed cognition (Flor & Hutchins, 1991).

The hypothesis of our work is that making context explicit, acquiring knowledge incrementally and explaining in context must be considered as intrinsic aspects of any problem solving, as information seeking, in which the user has a crucial role to play. Since 1995, several scientific events deal specifically with context, and a number of works consider context explicitly from the modelling of domain knowledge to programming languages. The modeling, representation and use of context appear to be the challenge of the coming years, especially when we now face very complex problems, large knowledge bases and multimedia.

We work on an application for the subway trafic control in case of incident. As one operator said: "When an incident is announced, I first look at the context in which the incident occurs. I mean the position of the other trains on the line, the period of the day, the available means, etc." Our goal is to design and to develop an incident manager able to tackle the problem of the context representation to exploit it in incident seeking and incident comparison with an occurring incident. In the latter case, we have to compare different incidents in a same context, and a same incident in different contexts. We aim at support the operator to select the best strategy. However, the system will be used after for other purposes as training or statistics.

The paper is structured hereafter in the following way. Section 2 describes the diversity of interpretations of the context notion, and the variety of representations in Section 3. Section 4 presents a framework in which this diversity makes sense and illustrates a context representation at the level of the





knowledge representation in a real-world application, and Section 5 concludes by a more general discussion.

## DIVERSITY OF INTERPRETATIONS OF CONTEXT

In any discussion about context, most of the time is spent in trying to establish what context is, how it can be defined, and how it can be distinguished from other notions as situation and viewpoint. The lack of consensus appears when one considers the nature of context either as static or dynamic, discrete or continuous, implicit or explicit, knowledge or process.

The meaning of this notion depends on a cognitive science versus an engineering (or system building) point of view, the practice viewpoint versus the theory one (Brézillon and Abu-Hakima, 1995). The cognitive science view is that context is used to model interactions and situations, and human behavior is the key for extracting a model. The engineering view is that context is useful in representing and reasoning about a restricted state space within which a problem can be solved. The identification of these two viewpoints permits to understand the contrasted views found in the literature.

According to the engineering viewpoint, the context is static and considered at the level of the knowledge representation and of the reasoning on this knowledge. As a consequence, static contexts do not change, and the interest is on context management and crossing contexts. Static contexts are attached to the domain knowledge and thus described in knowledge bases. The static part of the context is what may be coded at the design time. If it is (relatively) easy to represent the static aspect of context, the dynamic aspect of context must be considered during its use, say, a problem solving. Thus, one must account for both the static aspect (knowledge that remains constant throughout the interaction) and the dynamic aspect (knowledge that changes throughout interaction) of context.

Creating a context from existing contexts, as proposed by McCarthy (1993), this entails the possibility to establish a hierarchy of discrete contexts where a formula relating two contexts involving contextual assumptions is itself in a context. The interest of a context hierarchy is that, working on an object in one context, something may be derived about that object in another context. The two contexts may use different vocabularies, and the treatment of the object may be easier in one context than another. All works in knowledge representation consider a set of discrete contexts, and the effort relies on the crossing of contexts. Conversely, researchers in Cognitive Science prefer to speak about a continuous context. Without rejecting the possibility of discrete contexts, they consider that the context of interest is the interaction context because it is the unique context that may be perceived. The interaction context evolves continuously by elaboration and shift according to knowledge pieces introduced by an agent to be shared with the other. Context acts as a filter that defines, at a given time, what knowledge pieces must be taken into account (explicit knowledge) from those that are not necessary or already shared (implicit knowledge). A context is considered as a structure, a frame of reference, that permits not to say all the things in a story. For example, "At his birthday's party, Patrick blew up the candles." It is not said here there was a birthday cake because it is clear for everybody. Note that this frame of reference is supposed to be shared effectively.

Along the Engineering viewpoint, McCarthy (1993) said that for using knowledge across contexts, one needs a process of (partial) decontextualization, permitting one to abstract a piece of knowledge from contexts into a more general context that cover the initial contexts. Conversely, Edmondson and Meech (1993) suggest that the concept of "context" would be most preferably understood as a process of contextualization. Context then may typically be viewed as the environment of communication that enables the intended meaning to be ascribed by the recipient of the data. They give the example of a pilot in a cockpit, facing hundreds of captors. Few data provided by captors are transformed by the pilot into information, according to the current context (e.g., a flight in normal conditions).

The gap between the Engineering and Cognitive Science viewpoints appears to be only superficial because the two sides of the gap do not address the same types of context. Indeed, each viewpoint can bring something to, and benefit of, the other viewpoint. One is at the level of the knowledge representation and the reasoning (e.g., to focus the attention of the reasoner). The other is more concerned by the exchanges of information during human-machine interaction. The most interesting results from these observations are:

(1) Context is something surrounding an item (e.g., the task at hand or the interaction) and giving a meaning to this item. Context cannot be considered out of its use. Giving a meaning to an item, context acts then more on the relationships between items than on items themselves. Considered as a shared knowledge space that is explored and exploited by participants in the interaction, context includes elements from the domain (e.g., instantiated objects and constraints), the users (e.g., their goals), their environment (e.g., organizational knowledge), their interaction with a system (e.g., transaction history).

(2) There are different types of context with respect to what we consider (knowledge, reasoning, interaction, and each agent in its socio-organizational environment) and to the domain we are in. All these contexts are interdependent.

(3) There are different representations of the context depending if context is considered either as knowledge or as a process of contextualization. Context as knowledge implies that we must distinguish between contextualized knowledge (the knowledge effectively used at a given time) and contextual knowledge (the knowledge constraining the contextualized knowledge)





(Brézillon *et al.*, 1998). Considering context as a process--a viewpoint close to the previous one--implies a distinction between knowledge, information and data. Data become information through the contextualization process on the basis of the available knowledge at the time of the observation.

We now develop the last point.

## DIVERSITY OF CONTEXT REPRESENTATIONS

In Artificial Intelligence, context was first introduced in a logicist framework by McCarthy in his 1971 Turing Award talk (McCarthy, 1993). He defined context as generalization of collections of assumptions, and formalized them as first class objects (formal objects). The basic relation ist(c,p) asserts that the proposition p is true in the context c, where c is meant to capture all that is not explicit in p that is required to make p a meaningful statement representing what it is intended to state. Formula ist(c,p) is always asserted within a context, i.e., something like ist(c', ist(c,p)): c': ist (c, p). However, the bulk of the effort in building a context-based system lies in writing the axioms (lifting rules) describing and interrelating contexts.

Giunchiglia and his team focus on the reasoning and the way to cross contexts with bridging rules (Giunchiglia, 1993). Their strong stance is that "contextual reasoning is local reasoning." Expressing reasoning through context use may allow the exploitation of various forms of reasoning within distinct contexts, such as nonmonotonic reasoning, reasoning about situations, approximate reasoning, etc.

Some important results emerge of the logic approach. First, a context is always relative to another context. As a consequence, context has an infinite dimension and cannot be described completely. Second, when several contexts occur in a discussion, there is a common context above all of them into which all terms and predicates can be lifted.

In a rule-based representation (and others), context has been considered generally implicitly, at least without using this word. For example, MYCIN used screening clauses to control the firing of rules (Clancey, 1983). (Screening clauses acted as pre-conditions in other programming languages.) For example, consider the following rule of MYCIN:

IF

1. The infection, which requires therapy, is meningitis,
2. Only circumstantial evidence is available for this case,
3. The type of meningitis is bacterial,
4. The age of the patient is greater than 17 years old, and
5. The patient is an alcoholic,

THEN

There is evidence that the organisms which might be causing the infection, are diplococcus-pneumoniae (.3) or e.coli (.2).

The rule contains different types of knowledge (strategic knowledge, causal knowledge, etc.). The clause 4 had been added to control the interaction with the user. The clause acts as a screening clause and implies that the use of the rule is restricted to the context of adults. Such knowledge does not intervene directly in the problem solving, just constrains it.

Ezhkova (1989) considers context as a semantic background and defines it on the basis of the concept of contextual system. A contextual system has two types of memory: a long-term memory (a primary database and a base of contexts) and a short-term memory (intracontext knowledge processing and intercontext knowledge processing). An algebra of contexts is proposed to involve contraction, extension, immersion, coupling and intersection of contexts. Contexts are then stored or dynamically generated. Turner (1995) uses a similar approach for autonomous underwater vehicles for which he uses a set of elementary contexts that are combined according to the problem at hand. Such positions are a first step towards a compromise between the Engineering and Cognitive Science viewpoints.

On the one hand, context is the set of properties that are associated with an entity according to the environment in which the entity is. Context provides humans with a much greater control over the knowledge. Context permits to define which knowledge should be considered, what are its conditions of activation and limits of validity and when to use it at a given time. One of the primary reason for introducing contexts is to simplify the construction and the exploitation of the knowledge base. Context is mainly considered as a way to cluster knowledge for search efficiency, for representing counter-factual or hypothetical situations, for circumscribing the effects of particular actions to particular situations, and for directing an agent's focus of attention to salient features of a situation. Walther *et al.* (1992) use this approach in PROTEGE II. Their system associates each method with an ontology that defines the context of that method. All external interaction between the method and the world during the method assembly are a mapping of knowledge between the method's context ontology and the ontologies of the methods with which it is interacting.

On the other hand, context is considered as a property of the interactions among agents, as opposed to context as a fixed property of a particular problem or application domain. Context can be thought of as a kind of expert system that would be expert in 'predicting' what the user would likely want/need to do next because of its knowledge of what had happened to either that user or other users with the same goals/needs. However, interaction and context constrain each other: context activates behavior potential that in turn modifies the context of interaction.





## THE USE OF CONTEXT

### A framework for the different views on context

The different definitions of context can be discussed through the following model inspired from the general structure of an information processing system proposed by Newell and Simon (1972):

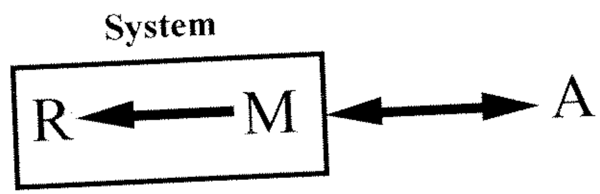


Figure 1: A framework for the different types of context

In this model, the system is supposed to interact with an agent called A. In our applications, the agent is an operator, but A may represent a human being, a computer system or any combination of them. The system itself is composed of a mechanism (M) for reasoning and a repository (R). The repository R may contain knowledge, data, information, domain and task models, ontologies, etc. R is supposed to be under the control of M that manages items in the repository, introduces and retrieves items from it.

According to this model, five types of context may be pointed out at the level of each entity R, M, A, and the two arrows. For example, the context of information retrieval is at the level of the simple arrow and the interaction context is at the level of the double arrow. Note that we do not consider here other contexts as the organisational context in which the user is. More complex contexts, and, indeed, it is the case of information seeking, are combinations of several elementary contexts (e.g., contexts of R and M in information seeking).

This model permits to point out that opposite views on context presented in the previous section concern different items. For example, discrete, static and decontextualization aspects of contexts intervene mainly at the level of R, when continuous, dynamic and contextualization aspects are at the level of the double arrow. As a consequence, the five types of context are different and must be represented differently.

We give in the following subsection a representation of context at the level of the interaction level, and at the knowledge-representation level in the next subsection.

### Context at the interaction level

At the interaction level, context must be made explicit to permit the sharing of knowledge with the other. For example, when I say to a person: "I heard a lion roars in my office this morning." It is self-explanatory for a person that knows me. If the person is surprised (e.g., the person may suppose that I am speaking of my boss), I will explain by introducing different knowledge pieces to share with the other: "I work in a university near a zoo that I can see from the window of my office. There are lions in the part of the zoo that is close to the University. I often hear lions roar. It was just the case this morning." Thus, knowledge pieces are structured in a well-defined way for both participants in the interaction. Once a part of the interaction context only contains such knowledge pieces that are shared, the structured pieces are then compiled in a single knowledge piece by both participants. Note that I give the minimal number of knowledge pieces to share the initial utterance. For instance, I don't say that the window of my office was opened, there was no trafic in the street, etc.

The movement of the knowledge pieces during this explanation across contexts from the following example drawn from this example is shown in Figure 2.

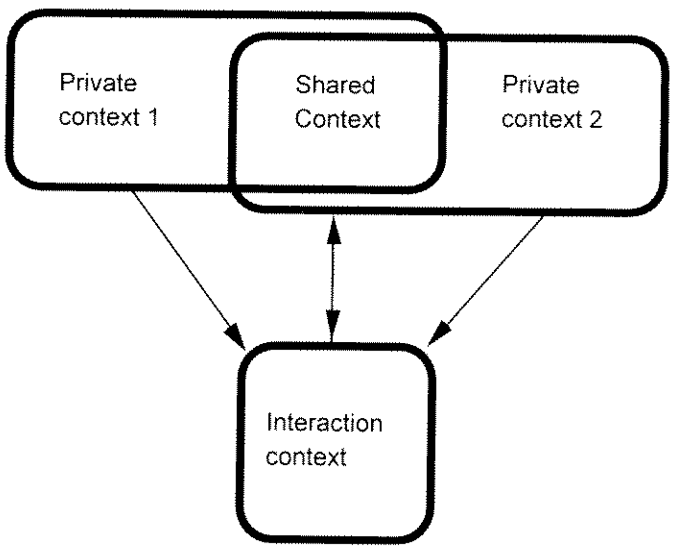


Figure 2: A representation of the interaction context





Say that "private context 1" is my private context and "private context 2" is the private context of the other person. The shared and interaction contexts belong to both of us. The interaction context contains pieces of knowledge in the focus of attention at a given moment. This begins by my first utterance "I heard a lion roar in my office this morning." These pieces have to be structured (i.e., explained) by both of us by establishing a link between the utterance and our respective background. Once we agree--i.e., I provide needed pieces of knowledge related to my first utterance, the whole pieces are integrated in an accepted knowledge structure--the knowledge structure belongs to the shared context. Thus, the shared context contains all pieces of knowledge that have been discussed and accepted by us. Note that the shared context also contains more general knowledge (e.g., the window was opened because the weather was fine).

### Context at the knowledge-representation level

One can consider three types of knowledge with respect to a given step of a problem solving: (1) pieces of knowledge that are directly used for the problem solving, (2) knowledge pieces that are not directly used in the problem solving but constrained it, and (3) knowledge pieces that have nothing to do with the problem-solving step. We called respectively these three types of knowledge: contextualized knowledge, contextual knowledge and external (or inert) knowledge.

Contextualized knowledge is knowledge that is explicitly considered at a given step of a problem solving, when contextual knowledge intervenes implicitly by only constraining problem solving. For example, operators that ensure the monitoring of the distribution of water in Paris had noted that there was a peak in the water consumption late each evening. The peak was reproducible every day but not predictable because not exactly at the same time. After an inquiry, they discovered that people use water for domestic needs (drink a glass of water, wash dishes, pour water on flowers, go to the toilets, etc.) during the advertisements introduced in the TV movie. The introduction of advertisements in the movie depends on the organization of the movie scenario. Such a knowledge (the time at which appear the advertisements at the TV) has a contextual nature for the water distribution. Contextual knowledge constrains a given step of the problem solving without intervening in it explicitly (water distribution is not dependent of advertisements).

This is a definition of context at one problem-solving step. At the following step, the nature of knowledge pieces changes: a piece of contextual knowledge may become either contextualized knowledge or inert knowledge. Conversely, a piece of contextualized knowledge may become either contextual knowledge or inert knowledge. (Other properties of the definition are presented in the next sections.) Thus, if contexts at the level of problem-solving steps constitute a set of discrete contexts, there is a unique context at the level of the problem solving itself that evolves continuously along the solving.

In (Brézillon *et al.*, 1997), we present an application for the subway in Paris. The goal is to support the operator who is responsible of a subway line when an incident occurs. The Figure 3 gives a very partial view of the solving of the incident "Ill traveller in a train." Incidents are represented by ovals and steps of the incident solving by rectangular boxes (e.g., "Alarm signal").

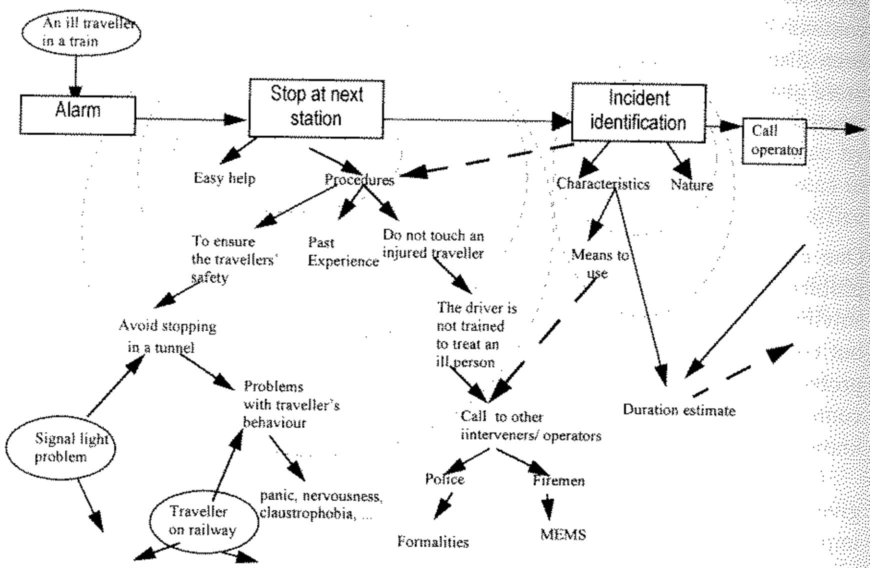


Figure 3: Context-based representation of the incident "Ill traveler in a subway"

Consider the step "Stop at the next station." This step, which contains contextualized knowledge not represented here, is imposed on the driver because, for example, this corresponds to procedures. Procedures arise from operators' experience with similar incidents. For example, travellers' security is better ensured in station than in a tunnel. At a deeper level, the driver has to avoid to stop the train a long time in a tunnel because some travellers may have behaviour's troubles as claustrophobia and leave the train to go on the railway (and thus may generate another type of incident as "Traveller on railway").

All the pieces of contextual knowledge are not at the same distance from the contextualized knowledge "Stop at the next station." For instance, "Procedures" is a contextual knowledge that is close to the incident-solving step, when "Avoid





stopping in a tunnel" is another piece of contextual knowledge that is far from the same step. However, both of them make this step necessary. Such a kind of distance permits us to order pieces of contextual knowledge in layers around a step like skins of an onion. We call this the onion metaphor. Layers of contextual knowledge are represented by stippled circles in Figure 3. Tichener (cited in (Jansen, 1995)) also introduces the notion of a situation surrounding the organism as one of the roots of context. Tichener's definition implies that context is not part of the actual chunk of knowledge but forms a layer, or a set of layers, around the knowledge.

Our context modelling along the onion metaphor reveals several interesting results:

(1) A step takes a meaning in a given context. Contextual knowledge does not intervene directly at this step but constrains it. For the step "Stop at the next station," the contextual knowledge "Easy help" is not the reason for stopping the train at the station. However, it intervenes in its realization.

(2) Pieces of contextual knowledge may be partially ordered. If we consider the step "Stop at the next station," we observe that some knowledge pieces of its context (e.g., "Easy help") are closer to the step than other (e.g., "Do not touch an injured traveler") because the constraints applied on the step are more direct. This permits to establish a kind of distance between contextual knowledge pieces with respect to the contextualized knowledge.

(3) Contextual knowledge itself takes a meaning in a context. The piece of contextual knowledge "Procedures" of the step "Stop at the next station" has its own context with elements as "Past experience" and "Do not touch an injured traveler." Recursively, one can link knowledge pieces together by layers. This result is a concrete example of McCarthy's claims (1993) about the definition of a context in an outer context and the infinite dimension of context.

(4) Pieces of contextual knowledge relate incidents together. With an association between a number of contextual-knowledge pieces, it appears that there is a relationship between a given incident and others. Figure 3 shows how such a relationship is established between "Stop at the next station" and other incidents as "Signal light problem" through contextual knowledge. Establishing such an incident net accounts for the occurrence in real-life conditions of combinations of incidents that seem apparently not related (e.g., "Ill traveler in a train" and "Signal light problem"). Common contextual components (or pieces of knowledge) of two contexts are highlighted by dotted, bold arrows in the Figure.

## DISCUSSION

Context plays an important role in human-machine interaction, and making it explicit permits to generate relevant explanation, acquire knowledge incrementally in its use context, learn in a context-sensitive way. This permits to make effective a kind of "cognitive coupling" between the human and the machine.

Context is always relative to another outer context in a recursive way. As a consequence, context cannot be fully modeled and represented, although, one often assimilates the context of something at a set of restrictions (e.g., pre-conditions) that limit access to parts of this something. We also need to position context at the level of the knowledge and its representation, at the level of the reasoning mechanism, or at the level of the human-machine interaction. All these types of contexts are interdependent. For example, the way in which a user defines its request (concerning the interaction context) depends on the conceptual schema of the interrogated database (part of the context at the level of the knowledge representation).

From our study, context is considered as a structure, a frame of reference, a shared knowledge space, a process of contextualization, etc. Whatever the nature of context, one must speak about context with respect to its use with something (interaction context, task context, etc.). The first thing to do is to explore the relationships between context and knowledge. A piece of knowledge may be contextual or contextualized according to the step of the problem solving where we are. Contextualized knowledge (i.e., operational knowledge) is knowledge that is explicitly considered in the problem solving. Context appears as a dynamic extension of knowledge and must be considered at the level of the knowledge.

Aamodt (1993) proposes a situation-specific knowledge acquisition that captures a collection of previously solved cases, and combined with generalised domain knowledge in the form of a densely connected semantic network. Another alternative is to modify the knowledge modeling approaches of knowledge acquisition by adding any technique supporting specification change (Menzies, 1996). In the two cases, the key idea is rapid, incremental knowledge acquisition in the context of use. This supposes that a system may learn continuously by updating its knowledge base after each new problem has been solved. However, the acquisition of knowledge in context is still a challenge.

Knowledge elaboration is also made complex because contextual knowledge is often under a highly compiled expression. As quoted by Clancey (1991), even what we take to be a highly stable behavior, such as reciting a phone number, is highly contextual. You establish this context by sitting in front of a phone. Such a situated knowledge is not acquired with the classical tools prior its use. In Clancey's example, one generally develops automatisms that authorize to deal the phone number without formulating it. For instance, one only "sees" the sequence of physical positions that the finger must have on the phone keyboard. It is rather difficult to acquire such a knowledge that may be expressed in a representation formalism not known by the machine. This situation is close to





the situation study by researchers in psychology. These researchers observe that we naturally organize our memories for past events into episodes, and the location of the episode, who was there, what was going on, and what happened before or after, are all strong cues for recall.

Representing context stays a hard problem. Representing context is possible, and indeed made since a long time. The deep problem is a real modeling of context.

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