Context Representation and Usage for the Semantic Web: A State of the Art

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Abstract

The aim of this paper is to review the most important research initiatives concerning context in computer science. Context aspects are a key issue for many research communities like artificial intelligence, real time systems or mobile computing, because it relates information processing and communication to aspects of the situations in which such processing occurs. The overview addresses the ways context is defined and understood in various computer science fields and tries to estimate the role of context in the novel scenario of the Semantic Web, by studying the particularities of this setting, compared to the Artificial Intelligence or Natural Language Processing ones, and the consequences of these particularities in resolving the key questions concerning contextual aspects.

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1 Introduction

The aim of this paper is to review the most important research initiatives concerning context in computer science. Context aspects are a key issue for many research communities like artificial intelligence, real time systems or mobile computing, because it relates information processing and communication to aspects of the situations in which such processing occurs [Akman, Brezillon1, Brezillon2, McCarthy]. Due to its interdisciplinary nature context has also received a special attention in domains like philosophy and cognitive psychology, which often offer a theoretical basis for more formal or technical approaches in computer science [Akman, Surav]. Nevertheless this paper focuses on the context and context- sensitive applications as in computer science and presents briefly theories of other domains to underline their influences in the area of information systems. Philosophical or cognition theories of context are beyond the scope of this paper and deserve special considerations.

The overview addresses the ways context is defined and understood in various computer science fields. We focus on the interpretation of context as a kind of knowledge within a knowledge base or information system, which primarily gives meaning to ambiguous concepts or situations. Further on, we argue that context should be formalized by means of a knowledge representation language in order to be processed automatically and exchanged among context-sensitive applications. Context modeling and representation are strongly influenced by the way the system defines which knowledge is contextual or not.
Provided that context is coded in a machine readable form, the next step addresses the concrete usage of context in knowledge processes. In certain research communities [Hörnig], the study of contextual effects or influences is considered more important than the problem related to the fuzzy nature of context.
Finally we try to estimate the role of context in the novel scenario of the Semantic Web, by studying the particularities of this setting, compared to the Artificial Intelligence or Natural Language Processing ones, and the consequences of these particularities in resolving the key questions concerning contextual aspects.

2 Defining and Understanding Context

What is Context?

“A kind of conceptual garbage can”
(Clark, Carlson in [Clark])

Although the importance of context and contextual reasoning has been often emphasized in different research communities, there is no common definition for this

concept. The problem of defining context still remains unsolved though intensively analyzed in the past decades. Previous definitions of “context” have emerged in cognitive psychology, philosophy and also in particular areas of computer science, especially when dealing with natural language processing or automatic reasoning. However, since these definitions have proved to be hardly applicable in other computer science domains, numerous context-aware applications define context by enumeration of examples or by choosing synonyms for context.

The term “context” is frequently employed in descriptions and analyses of applications in both computer science and cognition, but its meaning is mostly left to the reader’s understanding and its usage is implicit and intuitive. This situation reflects the situation within various research communities, but also a more general understanding with respect to context. Humans dispose of this concept automatically in most situations of every-day life, understand tacitly its meaning, but in the same time find hard to elucidate it. Therefore, before adopting a suitable “scientific” definition of “context”, we will look at how dictionaries explain its meaning for standard usage and how researchers have attempted to solve this problem in their own work.

According to the Merriam- Webster’s Collegiate Dictionary [Merriam], this term usually has two primary meanings:

> the parts of a discourse that surround a word or passage and can throw light on its meaning or
> the interrelated conditions in which something exists or occurs .

The Dictionary of Philosophy adopts the following definition:

The sum of all meanings (associations, ideas, assumptions, preconceptions, etc.) that:

> are intimately related to a thing
> provide the origins for, and
> influence our attitudes, perspectives, judgments, and knowledge of that thing.

Coming back to computer science, we find the following definition in the Free Online Dictionary of Computing: “context is that which surrounds and gives meaning to something else”.

These definitions, without claiming to tap the full potential of the underlying concept, represent quite well the way people think about “context” apart from any scientific consideration. Besides, the Merriam- Webster definition reflects the main directions artificial intelligence research, adopted when dealing with context: it can be either a situation in the general sense of the term, a part of knowledge or both of them. Situations deal with problem-related or environmental aspects. Work in these directions is influenced by the situation theory of Barwise ([Barwise]). Rule-based systems associate assumptions and content to each context, represent them explicitly as classes or concepts and provide operations of comparing, merging them. This is mainly the position adopted by [McCarthy, Guha, Giunchiglia]. The Cyc approach [Cyc] holds a typical view in various artificial intelligence projects,

especially in the rule-based systems community, with respect to this subject and defines “context” as:

> a general theory of some topic
> a basis for problem solving

Real time systems and recently mobile computing use context as information about the environment. Data is gathered from special sensors and used to refine the behavior of the system or in case of mobile applications to improve the quality of push/pull information services. We deal in the setting with implicit and incomplete representations of context. The applications define context by enumerating information sources, which could be useful to improve their service package and develop procedures to integrate them in the application logics. A primary concern of context-awareness in mobile computing is the awareness of the physical environment surrounding users and their mobile devices. A whole class of mobile applications based usually on global positioning addresses the concern of location dependence. Beyond location, context-awareness may include user preferences and device capabilities, as in the CC/PP format from W3C [CC/PP]. A similar position is argued by [Schilit], who defines “context” as “the collection of nearby people and objects, as well as changes to those objects over time”. Advanced context models cover also user’s attention level, emotional state, activity or role in a specific task. Both in real time systems and mobile applications we assist to a change of perspective when dealing about context. Context is not any more a matter of knowledge representation or knowledge processing, but information about a concrete environment of a person, device, computer network ([Myrhaug]) and the main focus is placed more on the acquisition and processing of context information than on a clear definition of the concept ([Chen, Want]).

Context at the Knowledge Level

It is generally accepted that context represents a key knowledge source in various research fields of computer science. Also, it is important to specify the meaning of context as “a kind of knowledge” and to explore the way context affects knowledge-intensive processes. Therefore many research projects are confronted with the problem of formalizing context under the knowledge representation perspective ([McCarthy]). Two directions can be identified in this matter. An earlier trend was to consider context as a “wholistic phenomenon” ([Öztürk]) and to study its effects on processes in a uniform way. On the other hand, given the fuzzy nature of context and the difficulty to find a broadly accepted definition for it, researchers identified different *types* of context elements with varying roles in knowledge processes and focused on the discovery of these generic types and their characteristics.

When identifying types of context we can differentiate between the logic-based approaches in the AI, and the approaches in cognitive psychology. The latter study contextual effects in relatively simple tasks like learning, memorizing or retrieval. For example, Baddeley suggests a distinction between interactive and independent context types [Baddeley], while Dewey divides context in background information and selective interests [Ekbia]. In most of the approaches the central distinction are the effects the knowledge, considered to be contextual, has on (mental or non-mental)

processes. Models offered by cognitive psychology are also used in Artificial Intelligence approaches:

“The common wisdom is that psychology provides a specification of intelligence, and AI provides tools to implement this specification” ([Fisher]).

The issue of contextuality is explored in the AI in correlation with reasoning. Reasoning is usually performed on a subset of the global knowledge base and the notion of context should substantiate this idea of localization [Giunchiglia]. Apart from the logical or formal perspective, the same disputes found in cognition are transferred in Artificial Intelligence. Context is a (partial) theory of the world [McCarthy, Giunchiglia] or a specific situation [Akman]. Since contexts are logically formalized theories, one can define operations and relations between them (e.g. specialization). Types of context are also reconsidered. Lenat mentions 12 dimensions of context space for the re-organization of the Cyc knowledge base [Lenat].

Concurrently, researchers in cognitive psychology elaborated features or characteristics a type of knowledge should fulfill in order to be identified as “context knowledge”. Clark and Carlson established 20 years before six “essentials”, which in their opinion correspond to most of them [Clark]:

> Context is information in the sense of “information processing”, meaning that is covers knowledge, opinions and presumptions of a human being.
> Context is information a certain person disposes of.
> Context covers only the relevant information with respect to a certain task or process.
> Context covers not only task-relevant information, but it is limited to a certain situation.
> Context covers only available information with respect to points 1 to 4.
> Context information interacts with the task or process to be considered.

The described properties are adopted in numerous research approaches concerning context, but are also permanent subject of discussion. Context is associated usually with processes or with persons. The distinction or the limits of the two categories is sometimes not clearly specified. A similar problematic debates whether context is related to a “state of the mind” or a “situation”, whereas newest approaches combine both of them. In Natural Language Processing one speaks about the context of an act of communication or the content of the message in a context [Gale, Hörnig, Iwanska] (Figure 1).

Conclusion

We presented several approaches to context definition and interpretation as a kind of knowledge. Even though each of them emphasizes important aspects of this concept, there is no universally accepted definition for it and every context-sensitive domain or application system seems to find itself over and over in the position to assemble its own view of context, which suits the particularities of the given situation. Every kind of information may theoretically pose as context. Therefore, most of the context definitions in research projects are either intentional or tailored to a specific task, or hold a much too specific view of context, which can not be applied in other domains

or for different tasks without major changes. Moreover, definitions seem to be incomplete. In many cases a context-aware system starts with some common context definition and adds or eliminates some facts. In areas like mobile computing research efforts usually elude an explicit definition of the concept, although many of them emphasize its complexity and offer examples of important constituents of context. For example, in an often cited paper about context-aware applications, Schillit offers the following view upon context [Schillit]:

“Three important aspects of context are: where you are, who you are with, and what resources are nearby. Context encompasses more than just the user location because other things of interest are also mobile and changing. Context includes lighting, noise level, network connectivity, communication costs, communication bandwidth, and even the social situation; e.g. whether you are with your manager or with a co-worker.”

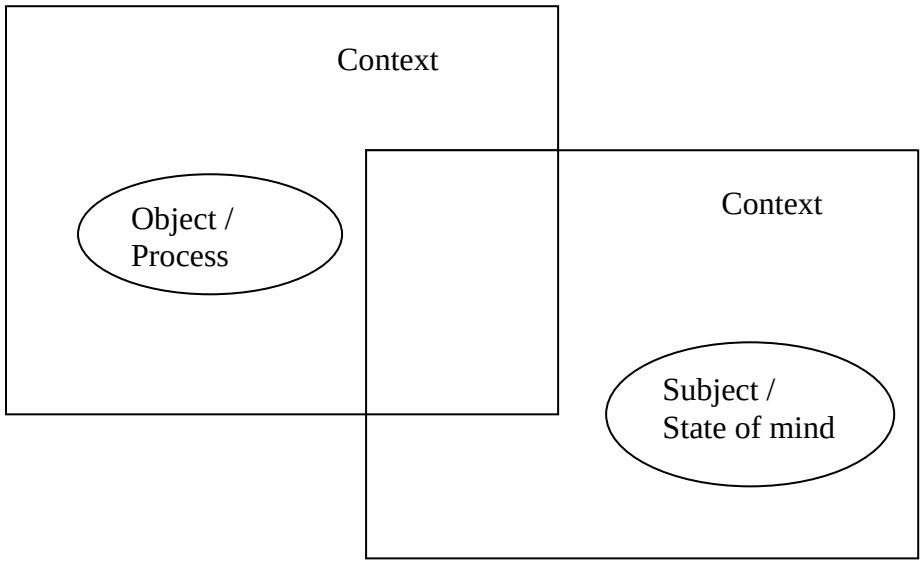

Figure 1: Context as “situation” or “state of mind”

3 Representing Context

In the last section we addressed the subject of defining and interpreting context as a valuable knowledge source in computer science. We presented different attempts to define context and to identify essential types of context elements and characteristic properties of contextual knowledge. However, in order to tap the full potential of context in a computing application one needs machine understandable ways to represent it.

Context is integrated in an implicit or explicit manner in computing systems. The implicit approach is often present in mobile applications. In Artificial Intelligence (e.g.

rule- based systems or natural language processing) we find mostly (formal) representations by means of rules.

McCarthy was the first researcher introducing a formal context representation to deal with the problem of generality in Artificial Intelligence [McCarthy]. Starting from the assumption that the notion of truth of an axiom is closely related to a certain context of this axiom, he formalizes the idea of relativized truth value of an axiom by means of first order logics. Further on, the work of Guha concentrates on the contextual dependence of theories and its logical formalization [Guha]. Lifting rules are used to transfer facts between contexts. A similar approach both in terms of interpretation and representation can be found in [Giunchiglia]. In this case context is represented explicitly as a logical theory and treated as a particular state of a system. Since contexts are considered to be partial approximations of a complete state of the world at a given time point, they are not situations, but the perspective of an agent of this state. The formalization of this thought adopts a modal logic perspective. A more mathematical approach is adopted by Buvac and Mason [Buvac]. In their attempt to investigate logical properties of context they extend the classical propositional logic to a kind of “propositional logic of context”. Semantics and syntax of the context language are discussed in terms of the model theory.

Though subject of long-lasting, extensive projects, Artificial Intelligence is still confronted with serious problems and seems to reach its limits in this matter. Therefore researchers have increasingly proposed a more *pragmatic* view upon context, which tries to distance itself from logics-oriented representations. Nothing in a sound logical representation may be taken for granted as such. Therefore such representations “are subject to the infinite regress of trying to decontextualize context. The new terms or rules themselves depend on interpretation that is not represented in the system” [Winograd]. Since when dealing with context there is no clear limit between relevant and non-relevant facts, such formalizations are always in danger to incorporate too many or too few facts about the situation. Besides, it is not clear which facts depend on the interaction with their environment [Ekbia]. The general opinion of the detractors of the AI context definition argue that computer science should adopt much more ideas from relating science fields like philology, linguistics, cognitive psychology or even philosophy, but in the same time offer no alternative for a context representation appropriate for information systems of knowledge bases. Since the failure of the logical approach has been frequently demonstrated, another pragmatic possibility may be the elaboration of a taxonomy of generic context interpretations, explicit context representations may reference to. The benefits of explicit knowledge representation techniques are less subject of debate, since there is no other way to integrate contextual information in computer systems in a flexible and machine-understandable manner.

4 Processing Context

“Context effects are everywhere”
(Clark, Carlson in [Clark])

Given the difficulties encountered in the attempt to precisely define context, some researchers asked themselves whether the problem of finding the ultimate definition of context might not have been overestimated. Since context may embrace a broad area of meanings, depending of the domain and task at hand, maybe it will be reasonable to search for the roles context may play in knowledge processes and the ways computer science applications may use it. The notion of context is a “functional” one and therefore one should ask rather about the *influences of context* than the kind or types of context information.

Depending on the way it is defined and interpreted, context has been used in several forms in computer science:

Domain Classification: McCarthy and the research group developing Cyc recognized the importance of contexts in complex domains and used them to organize the broad knowledge area contained in their knowledge base of human common sense and common knowledge. McCarthy introduces therefore the idea of “lifting rules” that activate relevant packets of rules and contexts are represented by grouping rules into packets.
Natural Language Processing: context has been seen as having a disambiguation function. Context eliminates certain ambiguities or multiple meanings and is therefore a central part in the communication. Besides eliminating ambiguities, context may be used to complete missing information in natural language utterances. [Gale, Iwanska]
Information Retrieval: context, as in *domain of discourse* or *background knowledge*, may be used in query rewriting. A query will be completed with contextual information, thus it will contain more information and will be better specified than a few ambiguous keywords. By these means one can enhance the precision and recall and redefine the measure of document relevance. The notion of relevance is closely related to that of context and the most recent research approaches attempt to redefine it, by including not only thematic contextual information, but also user-specific relevance criteria [Huibers].
Information Integration: context is understood in a similar way as in Information Retrieval as a specific domain of discourse and may improve interoperability when explicitly represented. By defining both context and its properties (data quality, security) as a mediation policy one achieves a higher rate of semantic interoperability between (semantically) heterogeneous environments [Reddy].
Mobile Computing: context is used as a filter to improve the quality of information services. Usually context information is acquired from application- specific information sources and its usage is hard-coded in the system implementation. The most prominent example of context is location. Parameters, like orientation, time of the day, temperature,

radiation level, are frequently taken into account by context-aware applications [Brown].

The classification above underlines two key issues in context processing: processing depends strongly on the application domain and the underlying procedures are too specific to be used in a generic scope. Second, the ways contextual information may be exploited in a certain application is usually implicit, even in situations where the context information is explicitly coded. There is no common methodology for the development of context–aware applications, no matter which domain of computer science they belong to.

Aspects like the way context changes and how the system deals with this dynamic process are seldom considered. Further on, it is not clear when context information should be involved in knowledge-intensive processes: all the time, user-specific, by request are only a few of the possibilities. Logical approaches rely completely on the reasoning mechanism for changes in the context, i.e. only conscious and voluntary actions may change the context. Moreover all changes take place relatively rarely and in large discrete steps, i.e. when the particular context should be changed in order to cope with the problem from another point of view. The latter 2 possibilities have been recently addressed in the area of mobile computing.

5 Context Information for the Semantic Web

In the previous sections we gave a survey of the most important directions in context-related research from the point of view of computer science. After reviewing the approaches in the AI and the influences from cognitive psychology and philosophy the trend is towards a more pragmatic attitude vis-à-vis context. Initial requirements related to representation and completeness issues are restricted and the diversity and fuzziness of the concept is not only understood, but also overcome by the reviewed requirements. A typical approach for the new generation of context research is mobile computing. Mobile applications adopt a particular, restrictive definition of context and use it as a filter for retrieval purposes. The major drawback here is the lack of generality, flexibility and extensibility [Schmidt].

Another approach proving often its efficiency is encountered in Ontology Engineering and Management, a domain area of the Semantic Web. The Semantic Web [SW] initiative is developing tools and technologies for a new generation of the World Wide Web. It envisions a machine- processable network of semantically annotated documents and semantics-aware web services. For this purpose, the Semantic Web proposed on one hand standards for representation languages, which originate from the well-established field of the old KR, but are adapted to the particular requirements of the World Wide Web setting. On the other hand it supports the deployment and the dissemination of ontologies, regarded as a means for a shared knowledge understanding and a way to represent some domain of the world.

In the setting of the Semantic Web we deal once more with contextual aspects. As in other areas of computer science, researchers define context in their own way, but the most frequent definitions regard this concept either as some specific *ontology* standing for a domain of discourse, or as a *mediation layer between ontologies*.

Context is used either as a filter for disambiguation purposes (Semantic Web-based IR), or as a means to integrate or merge different ontologies.

A third definition of context for the Semantic Web is influenced by the way context is understood in mobile applications: as information surrounding some object in the real world. Semantic Web is dealing with information sources and agents (Web Services) capable to interpret the meaning of the annotated documents in terms of ontologies. Both the information sources and the services processing them are strongly influenced by contextual aspects.

We intend to continue research in this domain in order to define a framework for the development of context ontologies and their (semi-) automatic integration in domain ontologies for the deployment of context-aware applications. Concretely we will concentrate on the following issues:

- The representation of contextual information and the design of an appropriate terminology to share and exchange context data in the setting of Semantic Web, with Semantic Web technologies.
- The explicit (rule-based) representation of context processing within Semantic Web applications
- The contextualization of available knowledge sources (integration of context and domain ontologies, the annotation of existent information sources with controlled context terminology etc.)

References

[Akman] V. Akman, M. Surav: “Steps Towards Formalizing Context”, AI Magazine, Vol. 17, No. 3, 55 – 72, 1996.
[Baddeley] A. Baddeley: “Depth of processing, context, and face recognition”, Canadian Journal of Psychology, Vol. 36, No. 2, 1982.
[Barwise] J. Barwise, J. Perry: “Situations and Attitudes”, MIT Press, Cambridge MA, 1983.
[Brezillon1] P. Brezillon: “Context in Artificial Intelligence: I. A survey of the literature”, Computer & Artificial Intelligence, Vol. 18, 321 – 340, 1999.
[Brezillon2] P. Brezillon: “Context in Artificial Intelligence: II. Key elements of context”, Computer & Artificial Intelligence, Vol. 18, 425 - 446, 1999.
[Buvac] S. Buvac, I. A. Mason: “Metamathematics of contexts”, Fundamenta Informaticae, Vol. 23, No. 3, 1995.
[CC/PP] CC/PP: www.w3c.org
[Chen] G. Chen, D. Kotz: “A Survey of Context- Aware Mobile Computing Research”,
[Clark] H.H. Clark, T.B. Carlson: “Context for comprehension”, in J. Long, A. Baddeley: “Attention and Performance”, Vol. IX, 313 – 330, Hillsdale, NJ: Erlbaum, 1981.
[Cyc] http://www.cyc.com.
[Ekbia] H. R. Ekbia, A. G. Maguitman: „Context and Relevance“,
[Fisher] D. Fisher, J. P. Yoo: “Categorizing and problem solving”, “The psychology of learning and motivation”, Vol. 29, 219 – 255.

[Gale] W. Gale, K. Church, D. Yarowski: “On the Evaluation of Word- Sense Disambiguation Systems”, Proc. of the 30th Annual Meeting of the Association for Computational Linguistics, 1992.
[Giunchiglia] F. Giunchiglia: “Contextual Reasoning”, Technical Report, 1992.
[Guha] R. V. Guha: “Context dependence of representations in CYC”, Technical Report CYC 066 – 93, Microelectronics and Computer Technology Corporation, 1993.
[Huibers] T. W. C. Huibers, M. Lalmas, C.J. Rijsbergen: “Information Retrieval and Situation Theory “, SIGIR Forum, Vol. 30, 1996.
[Hörnig] R. Hörnig: “Kontext: Der Wald und die Bäume”, KIT-Report 141, http://flp.cs.tu-berlin.de/kit/r141_inhalt.html.
[Iwanska] L. Iwanska: “Summary of the IJCAI-95 Workshop on Context in Natural Language Processing“, International Joint Conference on Artificial Intelligence, Montreal, 1996.
[Lenat] D. Lenat: “Dimensions of the Context Space”, 1998.
[Mahr] B. Mahr: “Gegenstand und Kontext”, KIT Report 141, http://flp.cs.tu-berlin.de/kit/r141_inhalt.html.
[McCarthy] J. McCarthy: “Notes on Formalizing Context”, Proc. of the IJCAI, Chambery, 1993.
[Merriam] Merriam Webster’s Dictionary: http://www.m-w.com .
[Myrhaug] H.I. Myrhaug: “Towards Life-long and Personal Context Spaces”, 2001.
[Öztürk] P. Öztürk, A. Aamodt: A context model for knowledge-intensive case-based reasoning. *International Journal of Human Computer Studies*. Vol. 48, 1998. Academic Press. pp 331-355.
[Pascoe] J. Pascoe: “Generic Contextual Capabilities to Wearable Computers” in Proc. of the 2nd International Symposium on Wearable Computers, 92 – 99, 1998.
[Reddy] M. P. Reddy, A. Gupta: “Context interchange: A Lattice based Approach”, Knowledge- Based Systems, Vol. 8, No. 1, 5 – 13, 1995.
[Schillit] B. Schillit, N. Adams, R. Want: “Context- Aware Computing Applications”, 1st International Workshop on Mobile Computing Systems and Applications, 85 – 90, 1994.
[Schmidt] A. Schmidt, M. Beigl, H. Gellersen: „There is More to Context than Location“, Computer & Graphics, Vol. 23, 893 – 901, 1999.
[Surav] M. Surav, V. Akman: “Modelling Contexts with Situations”, Proc. of the Workshop about Context at IJCAI, Montreal, 1995.
[SW] Semantic Web: http://www.w3c.org.
[Want] R. Want, A. Hopper: “Active badges and personal interactive computing objects”, in IEEE Transactions on Consumer Electronics, 38(1):10 – 20, 1992.
[Winograd] T. Winograd: “Thinking machines: Can there be? Are we?” In: D. Partridge and Y. Willis: “The Foundations of Artificial Intelligence: A Sourcebook”, Cambridge, UK, Cambridge University Press, 167 – 189, 1990.