

# AMBIT: Towards an Architecture for the Development of Context-dependent Applications and Systems\*

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## ABSTRACT

The development of ubiquitous services tailored to the needs and expectations of a very large number of potential users (especially mobile users) requires that future applications and systems be aware of the service fruition contexts and possibly of accurate user profiles.

The AMBIT research project aims at providing a general model of context as well as a platform that can be exploited to build and deploy different kinds of context-dependent applications and systems. We aim at overcoming the restrictions of the existing approaches, which are mainly due to the limited notion of context they propose (if any). In particular, we stress the fact that current technologies do not accurately consider the notion of context semantics and user profile, which is the main source of the flooding of useless data that overload systems and often users' minds.

## Categories and Subject Descriptors

H.3.1 [Information Storage and Retrieval]: Content Analysis and Indexing; H.3.3 [Information Storage and Retrieval]: Information Search and Retrieval; H.3.4 [Information Storage and Retrieval]: Systems and Software—*question-answering (fact retrieval) systems, user profiles and alert services*

## General Terms

Design

## Keywords

context-dependent, context model, applications

## 1. INTRODUCTION

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More and more our lives rely on ICT systems and applications that exploit services that are ubiquitous in order to support different kinds of human activities. However, the availability of many services can turn out to be confusing rather than useful, since the users are often overwhelmed by the large number of “proposals” which they are generally not able to consider thoroughly to find what they really need. To overcome this problem, many researchers have proposed to develop new applications with (or to incorporate in existing applications) context-awareness capabilities [2, 6]. A context-aware application is one that “knows” the context in which the client is operating and possibly also the profile/characteristics of the user who is enjoying the corresponding service(s). Clearly, such knowledge must be gathered (often under real-time constraints), stored in well-organized fast-access data and information systems, and exploited with the goal of delivering “personalized” high-quality *context-dependent* services.

In the literature we can find different approaches that address specific problems that arise in the development of context-dependent applications (e.g., [1, 5, 10, 15, 17]). We think, however, that a *global* approach is still missing, which is able to guide and support the development of a broad range of applications and systems. The main limitations of the existing efforts lie in the limited notion of context they adopt, and especially in the almost complete absence of any attempt to model the semantics of the context.

In this scenario, the AMBIT (Algorithms and Models for Building context-dependent Information delivery Tools) project<sup>1</sup> aims to study and implement a prototype software architecture for the development of *context-dependent applications and systems*, i.e., tools that provide users with services that are fully customized according to the context in which they operate.

Preliminary to the platform implementation is the study of models, algorithms and data structures for the representation and manipulation of contexts. At the abstract *modeling level*, a context will be likely described using such high-level information structures as semantic networks, taxonomies/ontology's, property-graphs and so on. *Data structuring* will amount to the accurate selection (and possibly the development of new) concrete memory structures able to support the implementation of efficient context-manipulation algorithms: dictionaries, graph and/or relational databases with efficient indexing structures will play a major role at this stage of the overall design. Indeed, together with data organization, the development of *fast algorithms* that are

<sup>1</sup><http://www.agentgroup.unimore.it/ambit/>

able to deliver high-quality context-dependent information is the most challenging aspect of the AMBIT project. The software *platform* we envision will then provide an Application Programming Interface that could be personalized for the development of a number of vertical context-dependent applications, some of which described in the rest of this paper.

As already outlined, the main innovative aspect of the project lies in the study and implementation of a very broad idea of context, including (among others) the modeling of the external environment, the users' profile and the history of the actions performed by them. From this point of view, we expect important consequences, in terms of both research and application outcomes, that could improve the quality of services provided by our industrial partners and later by other providers (companies as well as public organizations). From this point of view, we have initially identified some application scenarios that seem particularly suitable for the adoption of our general notion of a context.

A major example is undoubtedly *on-line advertising*, which provides services for delivering customized AD messages. In this area, limited context information is already used by specialized companies, such as AppNexus. One of our project partners is continuously developing solutions that help companies such as AppNexus to improve the information they supply to the AD space buyers. Clearly, with better context (as well as user profile) information, AD space buyers, who usually participate to on-line auctions to "acquire" the space, are in a better position to decide where to spend their money for advertising (i.e., specific online newspaper or press-agency pages, web portals, etc).

Aside for the world-level AD market mentioned above, the delivering of high-quality context information can be of great-benefit also for regional and even local economies. Clearly, to this end a crucial piece of context information is precisely the location where the ADs are likely to be seen. The availability of such data will allow small companies, municipalities, and associations to deliver specialized commercials (such as local opportunities, events, products, fairs, ...) to potential customer who are physically close to the place where the advertised "products" can be bought.

The remainder of the paper will start presenting some related work (Section 2) and then will analyze more in depth the AMBIT project research objectives (Section 3), the envisioned application scenarios (Section 4), the innovative aspects of the research and its derived applications (Section 5) and, finally, their expected impact (Section 6).

## 2. RELATED WORK

There is already an impressive body of work that addresses many challenging research problems in the area of context-awareness and context-dependent service delivery. These efforts are largely motivated by the astounding growth of the mobile device market and the need to support the evolution of the traditional Web into the so-called "Web of Things and Services". For some comprehensive surveys the reader is referred to [7, 11, 18, 19, 22] and the many references contained therein.

Within this huge active area, our research interests are primarily (though not only) directed towards context modeling, representation, and efficient handling. It must be pointed out that the meaning associated to the word "context" is not unique to begin with. Rather, it depends on the particular

applications that researchers have in mind. For instance, in automotive applications context clearly refers to driving environment, while in health-care applications context is likely to refer to environmental, physiological and behavioral variables that apply to a specific patient. As another example, in online advertising the context is essentially the page (say, the page of an on-line newspaper) where the commercial is to be displayed, namely, its contents, the prevailing sentiment, etc.

Here we are interested in a general notion of context, that can possibly include all of the above and much more. There are a handful of research contributions that are relevant to this narrow area. Bettini et al. [3] take different types of context information into account (physical, computational, user context) and approach the problem of modeling and representation from within the perspective of automated reasoning. The rationale is that modeling real-life situations requires the ability to process basic context facts and reasoning makes it possible to attain pieces of information that are appropriate for use by context-aware applications. This highly cited survey is also important since it covers some prominent approaches to context modeling (object-role based, spatial models, ontology-based).

Falcarin et al. [8] propose a general architectural framework for context data management, which include separate components for context source and context provider modeling. To move closer towards interoperability, they also propose the definition of standard languages for data context representation (ContextML) and access (Context Query Language). The proposed architecture is interesting for our purpose, but our aim is to include also semantic information about the context.

Bolchini et al. [4] survey various research works related to context modeling and awareness within the Context-ADDICT project of the Politecnico di Milano (see <http://poseidon.ws.dei.polimi.it/ca/>). They propose to design a context management system to be placed aside what they call the "operational system". While the latter is application dependent, the context management system is not, and exhibits a hierarchical structure in terms of observable (i.e., external) parameters that have a symbolic internal representation within a context schema. We will consider this separation of concerns also for our project, and will add semantic exploitation of the context.

Villegas and Muller [21] report the result of a study on various context modeling and management approaches. They outline four main research challenges that have to be tackled to support context-awareness in the light of the Smart Internet. They propose an operational (as opposed to a conceptual) definition of a context as well as a *context taxonomy* based on previous classifications of context information, which includes the following five fundamental context categories: individuality, time, location, activity and relational. Our aim is to be more general, but the idea of a taxonomy turns out to be very useful to our semantic approach.

An approach that is interesting because it takes into consideration different aspects is the one proposed by Peko et al. [16]. In fact, they start from the consideration that enterprises must be adaptable to the changes in the context they operate, but at the same time they must be sustainable in terms of economic, environmental, societal, and cultural concerns. They approach consider the enterprises' context in terms of strategy, organization, process, and information.

This global approach can influence our work and we could extend it to be more general.

Venkataram and Bharath [20] propose a context-based approach for service discovery. The focus on services makes this work interesting for our purpose, even if we do not focus on the discovery. We will evaluate their formal definition of the context and possibly make it more general.

From the analysis of the existing work, we have defined the objectives of our research, reported in the next section.

### 3. RESEARCH OBJECTIVES

The project scientific objectives aim to contribute to a significant advancement of the knowledge in the field of context-dependent services through the study and achievement of innovative results along the following lines:

- definition of general *models* and techniques for the representation of contexts; these will be exploited by systems and applications able to provide information and/or services dependent on context data (geographical location, chronological time, season, weather, user profile or simple access chronology, ...);
- identification of *storage solutions* (relational databases, graph databases, ad-hoc data structures, ...) and *algorithms* suitable for the efficient handling of contexts (access, dynamic update, learning, ...);
- design of a general *software architecture* and a prototype *platform* supporting client/server context-dependent applications and mobile device client-side execution;
- *vertical integration* of the platform with respect to significant test applications.

In particular, the study of models for the representation of contexts, the design and analysis of the algorithms and data structures which are most suitable for an efficient and effective modeling and exploitation of contexts will be carried out throughout the first part of the project. The study of possible models will require particular attention, as the rest of the research will be based on the choices made.

Possible alternative models will be evaluated in synergy thanks to the contribution of the operational partners that will provide important case studies (see Section 4). One aspect that will be taken into consideration is the completeness of the model, i.e., the ability to represent context, taking into account the following three factors: the user's external environment, profile, and past history of actions.

Having defined a relatively "stable" model, we will proceed to: (1) identify possible storage solution options and/or develop ad-hoc data structures for the efficient management of contexts; (2) design the algorithms underlying the primitives provided by the platform. The proposed data structures and algorithms must allow for the storage, querying and efficient analysis of a large amount of structured context information. The algorithms will be exploited, for example, to detect recurrent patterns and "categories" of user profiles, to efficiently identify the correspondence between the stored context information and the current environment, in order to extract the most relevant information to be presented to the user according to his/her profile, etc.

As to the architectural design of the context-dependent service platform, its logical architecture will have to be suit-

able for different operating environments (in particular mobile devices), and it will be characterized by a set of interface functions (API) for manipulating contexts (definition, population, querying, ...), also in function of possibly available user characterization profiles. Finally, the platform will be implemented for different specific architectures.

### 4. ENVISIONED CONTEXT-DEPENDENT APPLICATIONS

The project will identify and define several application fields with the highest level of detail possible, providing relevant case studies in these fields. In this way, the envisioned scenarios will contribute to the identification of a general model for the representation of contextual information that can be used to improve actual user services.

Applications (or case studies) are identified by the operational partners in their respective fields of interest; this choice will provide valuable and detailed information for the platform implementation, and will provide the partners great innovation prospects in their market sectors. Some application contexts and case studies that seem suitable for the analysis and testing of the platform have already been suggested by the partners and will be subject of a detailed analysis:

- **Context-aware advertising.** Providing tailored advertising is a very well established application, one that is "hidden" in many sites and online portals. Even the presentation of "sponsored sites" by common search engines, as a result of a user query, is an obvious form of advertising. A more effective personalization can be done in the case where a user's profile is available; this can be obtained for instance starting from the history of accesses recorded by search engines or other sites providing online services. The introduction of context dependence (geographical, seasonal, linked to the weather or time of day) will allow the empowered techniques to provide an even more precise "targeting" of promotional messages. A very simple example can be the notification of an event which is geographically close to the location of the user (say, a country fair with local farm exhibitors), which falls under the interests associated with his/her profile (e.g., gardening enthusiast). This form of advertising is certainly useful to the companies that produce the goods/services being advertised; moreover, it can also be very useful to the consumer that, in addition to receiving potentially interest information, will avoid being overwhelmed by useless, annoying or even just "out of context" ones;
- **Cultural territorial enhancement (ebook and proactive applications).** Ebooks are becoming more and more common as a tool for reading books and, in general, access information in a variety of situations; the possibility of having context-dependent ebooks, such as smart guides, can provide different ways of reading that, adapting to the reader context, can make reading more immersive, i.e. by adapting the contents to make them more effective, and by providing the information which is most of his/her interest. Proactive applications are those that can monitor users' interests and contact them to suggest events or activities that they may have not noticed or examined. The creation

of electronic books and proactive applications allows users to be more involved in knowing their territory and its initiatives; therefore, it is an ideal application to be taken into consideration in the project. As a concrete application example, we can imagine a specific mobile application (smart-phone or tablet), which continuously monitors the owners' habits in order to propose interesting activities in the place where they are located and at the appropriate time, local events to attend, places to visit, as a sort of "virtual companion". In this case, the context-exploitation algorithms will have to evaluate and exploit such information as usual map locations, written and received text messages/emails, type of movements, and so on;

- **Smart help-desk solutions:** One of the most frequent communication means between a company (or public entity) and its "clients" is certainly the help desk. Although phone-based help desks with dedicated staff are still widely used, equivalent computer-based services are becoming more and more common, thanks to the availability of increasingly advanced and low cost software and communication technologies. While this computer-based approach can provide a net cost containment, its coverage of the customers' needs is not always perfect. By taking into account the context in which the question is asked (including, for example, communications with the customer prior to the company, the products/services used by him/her, his/her past navigation history on the support pages, etc.), an help desk service may evolve into an intelligent system that automatically provides the most reliable and targeted answers. From this point of view, a considerable improvement may derive from semantic text analysis techniques, which are also positively influenced by contextual information. An intelligent help-desk system will also have self-learning abilities based on the occurrence of questions/answers in a multi-user environment, and can configure itself by distinguishing between different types of users, e.g. between private and business users.

## 5. INNOVATIVE ASPECTS

From a research point of view, the literature provides some approaches to context-dependence that, however, show two main limitations. The first is the limited notion of context. Often, the context is only identified with external user information, such as location and time; other times, it is reduced to the user profile alone. Finally, most of the times, the context does not take into account the users' "history", as a set of choices made by them in the past. The project will consider a model of context that involves all the aspects mentioned above, and possibly others.

A second limitation is that most approaches do not consider the semantics of the context: the information is interpreted in a "syntactic" way, without any meaning attributed to it. In AMBIT, this aspect is rather important and is a foundation of the proposed approach. The techniques devised in AMBIT will make the most of the previous experiences and strong background of the participants in related and complementary research fields, such as semantic text analysis [12, 14], semantic data sharing [13] and semantic personalization [9].

Moreover, the project results will also provide innovation from the application scenarios' points of view. An example is for context-aware advertising: in this field, the limit of existing systems is the lack of a semantic understanding of the input information, that could provide a semantic analysis on the user profile and, thus, eliminate many possible ambiguities. As to e-books, there are no solutions on the market that offer an immersive reading experience allowing full customization in function of the different reading paths, the reader's profile and the surrounding context. The same applies to smart help-desk solutions, where the market offers products providing a static response to a number of questions, independently from both the users' profile and their past history of questions and answers.

The AMBIT software platform aims to overcome the above mentioned limitations through a general management of the notion of context and of an API on which to develop standard and mobile applications in various application scenarios, including those discussed in Section 4.

## 6. EXPECTED IMPACT AND CONCLUSIONS

Besides an important impact from a research point of view (see also Section 3), our work in AMBIT is also expected to have several practical outcomes. First of all, it will improve the operational partners' competitiveness, which can be achieved (especially in the computer science field) only by continuously producing innovation. Moreover, the project has interesting objectives at the local level of our territory. In fact, context-dependent services offered by (for instance) associations of municipalities and/or particular categories of businesses (e.g., the consortia for the Traditional Balsamic Vinegar of Modena, or for the Parmigiano Reggiano), can help to improve the offer and to increase the volume of business: for instance, by means of notifying users of retail outlets of interest, cultural and gastronomic fairs, traveling or periodical markets, etc.

For the involved companies, a first result will be measured in terms of increased know-how. The AMBIT activities will allow partners to gain proficiency in software technologies that could have been hardly developed in an isolated context. An impact of employment is also expected: the researchers involved in the project will have opportunities for more advanced training and for possible involvement in new markets.

Finally, the proposed application scenarios will provide a cultural development of the area, using smart guides and widespread promotion of business/local events.

With regards to future work, the next step is to define the architecture of the proposed platform, which will enable us to have a more concrete idea of it, and to understand the direction of development. This will be done in collaboration with the involved companies, and possibly in a modular way in order to meet the requirements of the different case studies they proposed.

## 7. REFERENCES

- [1] GregoryD. Abowd, ChristopherG. Atkeson, Jason Hong, Sue Long, Rob Kooper, and Mike Pinkerton. Cyberguide: A mobile context-aware tour guide. *Wireless Networks*, 3:421–433, 1997.

- [2] Matthias Baldauf, Schahram Dustdar, and Florian Rosenberg. A survey on context-aware systems. *International Journal of Ad Hoc and Ubiquitous Computing*, 2:263–277, 2007.
- [3] Claudio Bettini, Oliver Brdiczka, Karen Henriksen, Jadwiga Indulska, Daniela Nicklas, Anand Ranganathan, and Daniele Riboni. A survey of context modelling and reasoning techniques. *Pervasive and Mobile Computing*, 6(2):161–180, 2010. Context Modelling, Reasoning and Management.
- [4] Cristiana Bolchini, Giorgio Orsi, Elisa Quintarelli, Fabio A. Schreiber, and Letizia Tanca. Context modeling and context awareness: steps forward in the context-addict project. *Bulletin of the Technical Committee on Data Engineering*, 34:47–54, 2011.
- [5] Jenna Burrell and Geri K Gay. E-graffiti: evaluating real-world use of a context-aware system. *Interacting with Computers*, 14(4):301 – 312, 2002.
- [6] Giacomo Cabri, Letizia Leonardi, Marco Mamei, and Franco Zambonelli. Location-dependent Services for Mobile Users. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems And Humans*, 33(6):667–681, 11 2003.
- [7] Alfonso García de Prado and Guadalupe Ortiz. Context-aware services: A survey on current proposals. In *SERVICE COMPUTATION 2011, The 3rd Int. Conf. on Advanced Service Computing*, pages 104–109, 2011.
- [8] Paolo Falcarin, Massimo Valla, Jian Yu, Carlo Alberto Licciardi, Cristina Frà, and Luca Lamorte. Context data management: An architectural framework for context-aware services. *Serv. Oriented Comput. Appl.*, 7(2):151–168, June 2013.
- [9] F. Grandi, F. Mandreoli, R. Martoglia, E. Ronchetti, M. R. Scalas, and P. Tiberio. Ontology-based personalization of e-government services. In *Intelligent User Interfaces: Adaptation and Personalization Systems and Technologies, Constantinos Mourlas and Panagiotis Germanakos (Ed.), IGI Global*, pages 167–187. 2008.
- [10] Daniele Grassi, Anas Bouhtouch, and Giacomo Cabri. Inbooki: Context-aware adaptive e-books. In *Proceedings of the 2nd International Conference on Context-Aware Systems and Applications*, 11 2013.
- [11] Georgia M. Kapitsaki, George N. Prezerakos, Nikolaos D. Tselikas, and Iakovos S. Venieris. Context-aware service engineering: A survey. *J. Syst. Softw.*, 82(8):1285–1297, August 2009.
- [12] F. Mandreoli and R. Martoglia. Knowledge-based sense disambiguation (almost) for all structures. *Information Systems (Information)*, 36(2):406–430, 2011.
- [13] F. Mandreoli, R. Martoglia, W. Penzo, and S. Sassatelli. Data-sharing p2p networks with semantic approximation capabilities. *IEEE Internet Computing (IEEE)*, 13(5):60–70, 2009.
- [14] F. Mandreoli, R. Martoglia, and E. Ronchetti. Versatile structural disambiguation for semantic-aware applications. In *Proceedings of the 14th ACM International Conference on Information Knowledge and Management, November 2005 (ACM CIKM 2005)*, pages 209–216, Bremen, Germany, 2005.
- [15] M.A. Munoz, M. Rodriguez, J. Favela, A.I. Martinez-Garcia, and V.M. Gonzalez. Context-aware mobile communication in hospitals. *Computer*, 36(9):38 – 46, sept. 2003.
- [16] Gabrielle Peko, Ching-Shen Dong, and David Sundaram. Adaptive sustainable enterprises: A framework, architecture and implementation. In *Context-Aware Systems and Applications*, pages 293–303. Springer, 2014.
- [17] Nissanka B. Priyantha, Anit Chakraborty, and Hari Balakrishnan. The cricket location-support system. In *Proceedings of the 6th annual international conference on Mobile computing and networking, MobiCom '00*, pages 32–43, New York, NY, USA, 2000. ACM.
- [18] Quan Z. Sheng and Schahram Dustdar. Introduction to special issue on context-aware web services for the future internet. *ACM Trans. Internet Technol.*, 11(3):9:1–9:2, February 2012.
- [19] Hong-Linh Truong and Schahram Dustdar. A survey on context-aware web service systems. *International Journal of Web Information Systems*, 5:5–31, 2009.
- [20] Pallapa Venkataram and M Bharath. A method of context-based services discovery in ubiquitous environment. In *Context-Aware Systems and Applications*, pages 260–270. Springer, 2014.
- [21] NorhaM. Villegas and HausiA. Müller. Managing dynamic context to optimize smart interactions and services. In Mark Chignell, James Cordy, Joanna Ng, and Yelena Yesha, editors, *The Smart Internet*, volume 6400 of *Lecture Notes in Computer Science*, pages 289–318. Springer Berlin Heidelberg, 2010.
- [22] Jong yi Hong, Eui ho Suh, and Sung-Jin Kim. Context-aware systems: A literature review and classification. *Expert Systems with Applications*, 36(4):8509 – 8522, 2009.