# Context-Awareness and Artificial Intelligence

**Mario Pichler[1], Ulrich Bodenhofer[1]**
**Wieland Schwinger[2]**

[1]**Software Competence Center Hagenberg**
Hauptstrasse 99, A-4232 Hagenberg, Austria
{mario.pichler, ulrich.bodenhofer}@scch.at

[2]**Department of Telecooperation, Johannes Kepler University Linz**
Altenberger Strasse 69, A-4040 Linz, Austria
wieland.schwinger@jku.at

## Abstract

This article advocates the viewpoint that a close cooperation between the artificial intelligence community and researchers studying context-aware mobile and ubiquitous applications will be indispensable for the future success of context-aware applications. The notions of context and context-awareness are introduced. It is shown that typical issues arising in context-awareness can be supported by concepts and methods developed within the AI community. The authors suggest establishing a multidisciplinary research effort for the development of future context-aware applications.

## Introduction

If people are talking to each other in a face-to-face manner, they have a rather good understanding of what is going on within this conversation. The conversation can be supported by using gestures or by adapting the loudness and accent of the voice in order to give the communication partner hints about the importance of one’s words. Also, background conditions like noise, who else is around, the place where the conversation takes place, etc., are used to adapt the conversation accordingly. If we are communicating to each other by telephone or other tele-cooperation means, the exchange of the above-mentioned hints to our communication partner is even harder. One can for instance observe three typical questions when calling someone with a mobile phone. These questions are: (1) "Do I disturb you?" (2) "Where are you just now?" (3) "What are you doing just now?" For each of these questions, the callee’s current situation is unknown by the caller and vice versa.

This task is much more complex if we are interacting with a computing device (computer, mobile phone, etc.). In order to make such devices *aware* of their users, the latter ones have to provide information that describes their current situation or preferences, manually into the computer in order to allow it to do some kind of adaptations. These adaptations can include adjustments to the display characteristics, or a selection of relevant information and services that are presented to the user etc. Nowadays, humans are confronted with an increasing number of computing devices they interact with in various situations in everyday life. Thus, the importance of considering this diverse situation is strongly increasing. By giving applications knowledge about personal preferences of their user, restrictions of the device used, the user's current location, etc., they would provide more accurate services to the user—by taking the current situation of use into account. To realize this, mobile devices as well as our surroundings are increasingly equipped with sensors in different forms, to recognize humans, their location, their current activities, their speech as input, etc. In order to allow applications to interpret the sensed information right and to act accordingly by providing the users with services relevant for their task, there is a fundamental need for much higher intelligence of applications and interfaces compared to traditional computing paradigms. Therefore, concepts and methods developed within the AI community appear highly promising.

The given contribution should be understood as an introduction to context-awareness for the AI community and as a plea for closer cooperation between traditional domains dealing with context-awareness and the AI community. References in the text are not intended to provide an exhaustive coverage of existing literature, but restrict to basic concepts, further reading, and existing links between context-awareness and AI—with an emphasis on Austrian research.

## Context-Awareness

All these (implicit, explicit, background, etc.) information that was stressed above can be referred to as *context*. According to the Free On-line Dictionary of Computing,[1] context is defined as “that which surrounds, and gives meaning to, something else.” Dey defines context as “any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves” [6, p. 4]. Context can be further specified by looking at the *scope* of the context, which is relevant for an application, comprising not only the different context properties (e.g. location, preferences, time) supported, but also the time dimension of context (e.g. validity of context information), how the context is *represented,* and how it is *acquired* in terms of automation and dynamics.

Dey further defines *context-awareness* as follows: "A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task." [6, p. 6] Context-awareness means that a service, although given the same request parameters, is perceived differently with respect to a given context. Two aspects are important for context-awareness: (1) the knowledge about the context of a service; (2) the issues in which way the information of the context is taken into account by adapting the service to be finally aware of the context.

### Benefits of Context-Awareness

Context-aware applications provide added value to their users. The three most important benefits, namely *adaptation*, *personalization,* and *proactivity,* will be discussed in the following.

*Adaptation* means to adjust a service or information according to available contextual information. It includes operations with different effects like filtering of information, invocation of additional services, and deactivation of service components. The complexity ranges from fine-grained adaptations like considering the location during selection of information to reconfiguring the complete service [17]. One remaining problem is to preserve semantic equivalence when applying such transformations. A good example is the context-aware postbox demonstrator [15]. It sends and receives multimedia data such as images, text, and business cards and adapts them accordingly with respect to the net-

[1] http://wombat.doc.ic.ac.uk/foldoc/

work and device context (e.g. connection speed, screen resolution).

The notion of *personalization* represents a major challenge since the end user has been put in the middle of concern when developing interactive applications, which dates back to the early 80s. Personalization means to adapt an application to different persons, such that they perceive the application differently at the same time, according to each person's preferences, habits, skills, tasks, etc.

Another benefit of context-aware applications is *proactivity*. Currently, most location-aware systems offer reactive services only. A reactive service requires the user to actively pull information from the service by issuing an explicit request. A proactive service, on the other hand, delivers or pushes information to a client without explicit request [12]. Proactive services work autonomously as background processes and they inform the user as configured. As an example, the Mobile Shadow system provides a distributed software infrastructure for proactive cell-based location-aware services [12]. As a demonstrator of a proactive service, a location-based reminder service is implemented that checks each time a user moves from one cell to another, whether there are any reminders available. If there are any available, then the user receives an SMS notification. The user enters the following data via a Web interface to set a reminder: cell id, reminder text, reminder start time and start date, reminder end time and end date, number of reminders he/she wants to receive. The cell identification is equivalent to the location, where a cell is constrained by the reachability of a WLAN access point. A similar prototype of a proactive service that uses location information is the Location-Aware Reminder prototype [14]. Via a graphical interface displaying a map, notes can be connected to any place in the map. The place, where the note was attached to, is represented by GPS coordinates. Being equipped with a PDA and a GPS receiver, an alert pops up on the screen, when the device reaches a position with a note attached to it. The range around the coordinates is adjustable, enabling proactive behavior of the service.

The above notion of proactivity is a rather wide one. Going one step further, proactivity is concerned with delivering services to the user on the basis of *predictions* of future context information [2, 24].

**Interfaces to Related Domains**

Context and context-awareness have been active research issues for a considerable time in a number of different areas. It has been emphasized for years in the *Computer Supported Cooperative Work (CSCW)* literature that efficient and effective cooperation beyond space and time requires that the cooperating individuals are well informed about their partners activities [7, 32]. Awareness thereby involves knowing who is "around", who is available for discussions, who is talking with whom, the others actions, the status of shared artifacts, etc. This kind of awareness is often referred to as group-awareness or team-awareness. Let us consider two examples relevant to this domain. ENI (Event and Notification Infrastructure) is an event-based awareness environment, which includes various sensors for the capturing of events and various indicators for their presentation [13]. A multi-user team awareness framework called CampusSpace has been developed for gathering the geographical position using WLAN access points [9]. The idea is based on using signal strength and quality to determine spatial proximity either to an access point or to another device also equipped with WLAN.

Context is also a key concept in *Human-Computer Interaction (HCI)*. Adaptive user interfaces aim at tailoring a system's interactive behavior to skills, tasks, and preferences of human users. The idea of using context-awareness here is to provide background information (context information) to the application, so that it can adapt to the user and his/her situation accordingly. An important research issue is dynamic adaptation of applications to fit the various constraints of display devices (e.g. display size and resolution, method of input, memory, disk capacity, and computational power, and software configuration), like mobile phones or personal digital assistants (PDA), tablet PCs or even wall computers [10]. Beyond the users' preferences, device characteristics as well as ambient conditions, like brightness and noise for speech output, are sensed and provided as context information. As an example, a location-aware mobile phone would switch to vibrating mode automatically when its user enters a concert. Gesture and sign language recognition are vital topics in HCI research to support mute individuals by providing sign language-to-spoken language translators [35]. By using a camera system combined with a *wearable computer* a mute individual is able to communicate with a hearing partner. Speech recognition, as input mechanism, is another area of HCI research [23, 36] that can be augmented by context-awareness. Most often considered as a problem, even background noise can provide additional context information (e.g. that the user resides in a public place like a train station). It can be exploited in that the volume of a sound output is increased or, alternatively, sound output is abandoned in favor of textual output, e.g. to maintain privacy. Activity recognition [20] provides another information essential to characterize the situation of a person. As most of the activities correlate to the user's motions or movements, the idea is to use simple distributed sensors and adequate processing algorithms, which allow deriving relevant movements and body positions.

*Mobile computing* is another area, where context-awareness plays a major role. We want to go further and state that contextual information is a vital ingredient for any application executing on mobile devices [15, 27]. The execution context is mainly static if we sit in front of a desktop computer and interact with one or more applications. The usage of contextual information for providing relevant information and/or services to the user will be essential for the success of upcoming mobile applications, where the execution context is fairly dynamic. Research on mobile computing began in the early 90s. One of the first projects reported in literature was the "Active Badge" project at Olivetti, where information about a user's physical location was sensed at any particular moment to modify the behavior of programs running on a stationary server [37]. Today, location information which can be made available by mobile network providers or using technologies such as the Global Positioning System (GPS) is used for realizing various location-based services, such as, geographically targeted advertising, fleet management, traffic control, or emergency services.

Plenty of research concerning context-awareness is also done in the closely related area of *ubiquitous computing* [39], also referred to as *pervasive computing*, *ambient intelligence*, etc. For a more detailed review of research, see [31].

## Context-Awareness and Links to Artificial Intelligence

Context-awareness poses completely new demands on the intelligence of applications. Context-aware applications need to have a sophisticated notion of the environment surrounding them and to take appropriate actions to changing contexts. From this viewpoint, context awareness naturally becomes an immediate application field for AI paradigms and methods. In this section, we will classify and describe important issues of context-awareness, concentrating on those to which AI can potentially make a significant contribution. In particular, we will highlight connections between the respective issues in context-awareness and existing fields of AI research. Note that we adopt a rather wide understanding of AI in this section, comprising an extensive range of research fields that are related to intelligent systems.

### Representations and Profiles

Contexts can have a different level of sophistication and abstraction. Very often, dedicated sensors like GPS sensors, accelerometers, etc., are invoked to provide context information. This information is mostly available at a very low level of abstraction bound to physical information. Other contexts, however, are not that easy to represent, as they have a much higher level of abstraction. The representation of contexts itself, therefore, is not at all a trivial task, but constitutes a discipline in itself. A typical example would be user preferences—leading to the area of preference modeling which is a distinct own sub-field of decision analysis [30]. A notorious example that is even more complex is the user's knowledge or background knowledge the application needs to make appropriate decisions and adaptations (knowledge as a whole or, more realistically, restricted to issues that are relevant to the application). The whole area of knowledge representation, therefore, is of vital interest for context-awareness, where ontologies are considered to provide a powerful, yet pragmatic, approach [34]. Such knowledge artifacts (e.g. preferences) are often called *profiles* (of the user or the application).

An important characteristic feature that is common to the examples stressed here is the fact that preferences, profiles, etc. are mostly difficult to capture with bivalent yes-or-no concepts. Therefore, non-classical logical constructs, such as, modal, temporal, many-valued or fuzzy logics, are supposed to provide powerful aid for context representation (e.g. [11]).

**Capturing and Sensing**

Even if a given context has a low level of abstraction (e.g. sensor data like temperature, acceleration, etc.), such information may be subject to uncertain availability, different actualization periods, and time-limited validity. Therefore, this physical information needs to be processed in that it is transformed, aggregated, or combined with explicitly given information (e.g. profiles) to describe the context at a logical level of abstraction suitable to be utilized by the service. This preparatory step is commonly called *feature extraction*. Another typical example is the utilization of audio or video information for context-awareness—a speech signal or a camera image cannot be considered as meaningful context on its own. Only the extraction of significant features, such as, content of speech, objects in an image, etc. provides context information at a level of abstraction that is appropriate to be utilized by a context-aware application. This implies that areas related to computational perception, including signal and speech recognition as well as computer vision (e.g. [22]), although they constitute separate disciplines, are highly relevant to context-awareness.

**Interpretation, Learning, Classification, and Prediction**

Contexts, in particular if they have a high level of abstraction, cannot always be considered as given and independent from other contexts. Often one context has to be determined (or guessed) on the basis of other contextual information by some mechanism (a function, decision rules, etc.). Consider the following example: for a mobile office application, it is important to classify whether the user is in the office or on travel. These higher-level contexts can be inferred, e.g., from the user's position, his/her movement, or other environmental contexts of low abstraction. In simple cases, the application designer or the user can define this mechanism a priori. Quite often, however, this is not possible and the appropriate decision/classification mechanism has to be identified over time, e.g. from user action. The areas that can contribute solutions here comprise rule-based systems at large, logic programming, inductive learning, clustering, data mining, data-driven modeling, statistical analysis, and many more (e.g. [21, 25, 26, 29]). A common feature also in this setting is the need for handling impreciseness, vagueness, and uncertainty, which again involves fuzzy logic [8, 16, 18], but also probability theory and belief calculus [33].

Context prediction is a related issue, but has a slightly different orientation. It is not concerned with the determination of a current high-level context, but with predicting whether or not a specific context (no matter whether low- or high-level) will occur in the future. To consider context prediction, therefore, is a must for proactive context-aware applications [24]. The technologies mentioned above are highly relevant for context prediction as well; however, the integration of the notion of time and the analysis of time series (with which method ever) are special conditions here, leading, for instance, to time series data mining and hidden Markov models [5, 38].

**Reasoning**

Context reasoning is concerned with the appropriate kind of adaptation, i.e. the decision what adjustments to the application have to be done according to contextual information. This includes the subject of adaptation in terms of what to change and the process of adaptation, characterizing how adaptation is performed. In any case, this involves mechanisms that examine contextual information to perform appropriate actions; prototypically, a context reasoning mechanism has conditions that involve contexts and actions that are performed if the respective conditions are fulfilled. Context reasoning, therefore, most often has a logical and rule-based nature, which makes it an application field for decision analysis, rule-based methods at large, expert systems, logic programming, etc. [19, 21, 28]. Beside deductive capabilities, it may also be the case that the decision mechanisms need to evolve or adapt over time, which entails the demand for inductive capabilities as well (leading again to inductive learning methods, clustering, and data mining [8, 16, 25, 26, 29]).

**Matching**

An important issue closely related to context reasoning merits being addressed separately: *context matching*. While context reasoning is concerned with inference based on conditions and actions, context matching is the way to match a given instance of context with a condition. In some cases this is a trivial task (e.g. the condition whether a temperature exceeds a given threshold can be answered unanimously for a given sensor value), for higher-level contexts, this is a difficult issue. Consider the following example: a user has specified his/her professional interests in some way to an intelligent mobile information appliance with the capability of spontaneous interaction (in order to avoid confusion, let us call him/her *primary user*). The appliance constantly seeks the primary user's proximity for other users that somehow fit to the primary user's interest profile. If a match is found, the appliance stores the other user's profile and displays it to the primary user. First of all, profiles can have a complex logical structure that make matching a difficult task. Secondly, it is a naïve assumption that a reasonable number of well-fitting matches can be found under all possible conditions. Realistically, perfect matches are too rare and very tolerant criteria potentially lead to a too large number of matches. The only way out are robust, yet tolerant, graded concepts of matching which incorporate the possibility to assign a degree of matching to each potentially interesting profile (like a modern Internet search engine use an index of estimated fitting to display expectedly more relevant pages first). In any case, there is a high need for matching methodologies that do not only provide yes-or-no answers, but provide gradual information about the closeness between conditions and potential matches. Note that this is not only relevant for spontaneous interaction, but it would potentially enrich the decision making in context reasoning as well.

Gradual matching is *the* topic of research in flexible query answering systems and fuzzy databases [1, 3, 4]. In order to process such gradual information also throughout the whole process of context reasoning, appropriate inference mechanisms and learning methods are necessary—a large set of concepts and methods for theses challenges is available, for instance, in the fuzzy logic domain [8, 16, 18].

## Discussion and Conclusion

There are a vast number of touching points between issues arising in context-awareness and AI topics, as the previous section demonstrates. From that point of view, it appears justified to state that context-awareness is a highly multidisciplinary research topic, not only involving software engineering, embedded systems, mobile and ubiquitous computing, human computer interaction, and conceptual modeling, but also integrating AI disciplines like expert systems, machine learning, fuzzy logic, uncertainty modeling, decision analysis, and computational perception.

The question arises to which degree these two worlds have been integrating so far to bring context-awareness forward. The answer is that there is only little evidence that any integration has taken place so far (e.g. [35]). Almost all research on context-awareness has been done in the traditional domains of mobile and ubiquitous computing on the one hand and hypermedia on the other hand. The topics addressed in the previous section have been investigated by researchers coming from these communities. Some of these works start only from a very basic level or deal only with a conceptual framework to plug in AI methods. Others explicitly address AI issues, but restrict to applying well-known methods [24]. Let us have a look to "the other side": context-awareness, at least under that name and with that specific meaning, is seldom known in AI communities and the particular features and conditions in the context-awareness domain is being neglected in the AI communities.

The only way to bring us closer to real context-aware applications that are non-trivial, usable, and beneficial for future applications, is to fully consider it multidisciplinary and to bring AI research closer to this field. It is not sufficient to rely on the cornucopia of AI methods and literature. Context-aware applications have special demands, in particular, if they are running on mobile and embedded platforms. These requirements may comprise, but need not be limited to, the following items (also compare with [24]): (1) fault-tolerance and robustness; (2) limited resources and, therefore, simplicity; (3) adaptivity. As traditional AI paradigms and methods usually assume generous conditions in terms of storage and performance, there is a fundamental need for radical new developments of methods that are especially suited for context-aware applications on platforms with (very) limited resources. Many systems based on traditional AI methods are highly complex. There is a fundamental need for adaptation to light-weight computers in terms of processing power and memory capacity. AI research communities are cordially invited to consider context-awareness as a new and interesting application area—much more than they did before.

## Acknowledgements

The authors gratefully acknowledge support by the Austrian Government, the State of Upper Austria, and the Johannes Kepler University Linz in the framework of the K*plus* Competence Center Program.

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