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Situational computing: An innovative architecture with imprecise reasoning

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Abstract

Situation awareness is introduced as a more holistic variant of context awareness where situations are regarded as logically aggregated pieces of context. Situational computing can be viewed as the pervasive computing paradigm that deals with situational context representation and reasoning. One important problem that arises in such paradigm is the imperfect observations (e.g., sensor readings) that lead to the estimation of the current user situation. Hence, the knowledge upon which the context/situation aware paradigm is built is rather vague. To deal with this shortcoming, we propose the use of Fuzzy Logic theory with the purpose of determining (inferring) and reasoning about the current situation of the involved user. We elaborate on the architectural model that enables the system to assume actions autonomously according to previous user reactions and current situation. The captured, imperfect contextual information is matched against pre-developed situation ontologies in order to approximately infer the current user context. Finally, we present a series of experimental results that provide evidence on the flexible, efficient nature of the proposed situational computing.

Keywords: Pervasive computing; Context awareness; Situational context representation; Ontological modeling; Fuzzy and approximate reasoning; Human–computer interaction

1. Introduction

In the recent years we have witnessed rapid progress in the ubiquitous and pervasive computing paradigms. Specifically, pervasive computing is emerging as the future computing paradigm in which infrastructure and services are seamlessly available anywhere and anytime. This exciting paradigm is the result of recent research and technological advances in wireless and sensors networks, distributed systems, mobile and agent computing, autonomic and context-aware computing. In order to engineer context-aware systems, it is of high importance to apprehend, and define the *ingredients* of context from an engineering perspective, as well as, a model-theoretic perspective.

Context-awareness is a very important aspect of the emerging pervasive computing paradigm. In order to render applications and services intelligent enough to support contemporary users everywhere/anytime and materialize the so called ambient intelligence, information on the present context of the user has to be captured and processed appropriately. Such information may refer to the user's position, physical properties like temperature or other general parameters (e.g., the specific devices that the user carries). The efficient management of contextual information requires detailed and thorough modeling along with specific processing and inference capabilities. A computing environment, which is based on such pervasive infrastructure, is called Pervasive Computing Environment (PCE). In a PCE, diverse pieces of context can appear (e.g., user is in her office, walking outdoor, driving a car, meeting someone in a train station), in which different user activities can be performed (e.g., attending a meeting, taking a break, preparing to ride a train, or buying souvenirs). For instance, the *attendance of*

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a meeting situation could be observed not only in a meeting room but, also, in an office room. Hence, context-aware applications have to be able to determine that the user is involved in different situations at different times.

Context-awareness is related to the manipulation of context pertaining to certain entities. Moreover, *situation-awareness* is considered as the particular kind of context-awareness, where situations are viewed as logically aggregated pieces of context. Situation-awareness is not restricted on location awareness, which means that a mere determination of a geographical location and knowledge about that location is only provided. The combination of sensor data with spatial knowledge leads to a detailed state of the environment, i.e., the current user situation. Situations are based on user activities in specific locations. By considering various sources of contextual information (e.g., noise level, lightness, and humidity), the context enrichment of a context-aware application can be augmented.

Moreover, the interaction between user and mobile device would be made easier and less intruding, if the latter recognized the current user situation and adapted its functions accordingly. The human intervention must be kept to a minimum since the context-aware application should be designed to *bother* the user as little as possible. Devices that know more about the user context are able to function efficiently and transparently adapt to the current user situation, leading to the idea of the invisible computer as discussed in (Weiser and Brown, 1996). The device autonomously learns and automatically suggests what actions the user prefers in designated situations. This is a challenge, since a device should react intelligently to everyday social situations. The efficient extraction, fusion and determination of relevant pieces of context from diverse information sources are, therefore, a key issue in the area of pervasive computing. In this article, we introduce the *situational computing* paradigm as the particular kind of the pervasive computing paradigm which deals with engineering *situation-aware* applications.

1.1. Context-awareness

A well-known definition of *context* was proposed in (Dey and Abowd, 2000). According to this definition, ''Context is 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 integration between a user and an application, including the user and the application themselves''. One could derive from this definition that context is a set of *situations* and *actions*. *Situation* in the pervasive computing paradigm is considered as a finite sequence of *actions* that have occurred, which might change over time, describing human behaviors, application and environmental states.

Context-awareness (CA) as defined in (Dey et al., 1998) is ''the work leading to the automation of a software system based on the context of the user''. Hence, CA is the ability of a computing device to detect and sense, interpret, and interact with aspects of a user's local environment and the physical proximate computing devices. Situation Awareness (SA) could extends the definition of CA, where the user *context* is interpreted as the user *situation*. According to the definition in (Billings, 1995), ''SA is an abstraction that exists within *our* minds, describing phenomena that *we* observe in humans performing work in a rich and usually dynamic environment''.

In the following paragraphs, we first outline the idea of situation awareness and introduce the situational programming paradigm in a PCE. Section 3 discusses the use of conceptual modeling in order to represent situational context, and in Section 4, we represent a contextual similarity measure taking into account context semantics. Section 5 focuses on reasoning about contextual similarity based on semantics and specific relations among diverse situational pieces of context. In Section 6, we discuss how the imprecise contextual reasoning is dealt with specific degrees of uncertainty. Section 7 focuses on several fuzzy inference rules, which allow the proposed system to take decisions with respect to the situation of the user and her reactions. In Section 8, we evaluate the proposed system. Section 9 discusses related work on that research area and, finally, Section 10 concludes the article.

2. Situational computing

Situation aware applications have the ability to estimate the user current situation(s) and react appropriately. An introductory definition of a computing paradigm based on such applications is the following:

Definition: Situational computing paradigm refers to the application of SA in a PCE. Specifically, such paradigm is a pervasive computing paradigm in which a situation aware application has the ability to interact (with the user), learn (from the user behaviors and actions), and autonomously adapt to the user's current situational context.

A framework for situation estimation/classification under *uncertainty* plays a central role in the area of situation-awareness. Actually, in such framework the *context* to be estimated may be human behaviors, activities, and interactions with other people, tasks, application and environmental states. It is known that many context-aware applications require support for managing imprecise context. In such applications, observations are recorded from a number of sensors (human and artificial). Specifically, in a PCE, contextual information is rather vague and cannot always be accurately determined. The situation estimation is characterized by vague knowledge and observations suffering from several kinds of imperfections (e.g., missing information, imprecision, uncertainty, unreliability of the source, and mutual, possible conflicting or reinforcing, observations of the same phenomena). The problem of handling possibly imperfect observations from multiple sources includes the problems of information fusion and multiple sensor data fusion. However, such vague informa-