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An adaptive rule-based approach for managing situation-awareness

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ABSTRACT

Situation awareness is a powerful paradigm that can efficiently exploit the increasing capabilities of handheld devices, such as smart phones and PDAs. Indeed, accurate understanding of the current situation can allow the device to proactively provide information and propose services to users in mobility. Of course, to recognize the situation is a challenging task, due to such factors as the variety of possible situations, uncertain and imprecise data, and different user's preferences and behavior.

In this framework, we propose a robust and general rule-based approach to manage situation awareness. We adopt Semantic Web reasoning, fuzzy logic modeling, and genetic algorithms to handle, respectively, situational/contextual inference, uncertain input processing, and adaptation to the user's behavior. We exploit an agent-oriented architecture so as to provide both functional and structural interoperability in an open environment. The system is evaluated by means of a real-world case study concerning resource recommendation. Experimental results show the effectiveness of the proposed approach.

1. Introduction

Situation-awareness (SAW) is a computing paradigm by which applications can sense and comprehend the user's *situation* in order to anticipate or predict her/his demand (Weißenberg, Gartmann, & Voisard, 2006).

The fundamental means to achieve situation awareness is the *context*, i.e., all relevant data and information (e.g., the user's position in space and time, the surrounding things and events, etc.) that help the decision maker to understand what is happening in the environment and then take more informed decisions (Anagnostopoulos & Hadjiefthymiades, 2008; Coutaz, Crowley, Dobson, & Garlan, 2005; Dey, 2001).

The various approaches available in the literature on context and situation awareness have produced a plethora of domain-specific frameworks, each characterized by proper sensors and databases (Gu & Pung, 2005). Usually, contextual data sources are provided via Service-Oriented Architecture (*SOA*) interfaces, and enriched with a domain *context ontology*, which is a powerful formalism to model context information, enabling context reasoning and context knowledge sharing among several, different applications (Bettini et al., 2010; Gu & Pung, 2005).

Of course, gathering appropriate and easily understandable information is particularly challenging in a mobile context where the workspace dynamically and rapidly changes, and data from multiple and heterogeneous sources may be uncertain and partially true (Korpipää, Mantyjarvi, Kela, Keranen, & Malm, 2003).

To this aim, Korpipää et al. (2003) have proposed a framework for managing uncertainty in raw data and inferring higher-level context abstractions with a related probability. The framework uses the shared blackboard metaphor to enable communications among entities in the system. All context sources publish their data in the blackboard, which acts as a centralized module to process contextual data and deliver high-level information, i.e., the user's situation, to the application. Fuzzy sets are employed to convert unstructured raw data into a representation defined in a context ontology by means of predefined fuzzy labels. A confidence value is associated with contextual data to describe the context uncertainty. Situations are recognized by means of a basic Bayes classifier, which learns conditional probabilities from training data for each situation. Mäntyjärvia and Seppänen (2003) have proposed a system to represent context information by applying fuzzy membership functions. In particular, raw data from sensors are converted into context information by means of fuzzy quantization. Such information is then employed as input to fuzzy rule-based controllers to adapt applications according to the context. However, no semantic description of context is considered. Ranganathan, Al-Muhtadi, and Campbell (2004) have modeled uncertainty in situation awareness by associating a confidence value with all pieces of contextual information. The authors adopt three methods to infer the user's situation, (i) probabilistic logic, (ii) fuzzy logic, and (iii) Bayesian networks. In the probabilistic and fuzzy approaches, developers have to write down their own rules to infer situations, whereas in

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the Bayesian approach developers have to define the network specifying the relations among contextual information. Gu, Pung, and Zhang (2004) have proposed a context-aware middleware to support context reasoning in order to derive the user's situation. Uncertainty is faced in two manners. First, the context ontology is extended to allow additional probabilistic markups. Second, Bayesian networks are adopted to support the inference process of the user's situation. In Cao, Xing, Chan, Yulin, and Jin (2005), the user's situation is assessed as a combination of context information which is expressed by fuzzy linguistic variables. More specifically, a situation is represented by a set of three-element tuples, where each tuple contains certain contextual information (e.g., the current network rate), a linguistic value that characterizes that situation (e.g., high), and finally the fuzzy membership degree of the contextual information to the linguistic value. Thus, the recognized situations contain a list of fuzzy degrees referred to several linguistic values and it is difficult to compare situations with each other and to rank them. Haghighi, Krishnaswamy, Zaslavsky, and Gaber (2008) have proposed an approach for situation modeling and reasoning under uncertainty based on fuzzy theory. Situations are expressed by multiple contextual conditions joined in a fuzzy rule, where the consequent represents the degree of confidence in the occurrence of a situation. Moreover, developers can specify weights to represent the relative importance of each contextual condition for inferring a situation.

One of the main problems with the above approaches is that the relationship between contextual information and situations is static, and cannot be adapted to the changing user's behavior. Indeed, as formerly pointed out by Byun and Cheverst (2003), when context awareness is reached by means of predefined rules, users have to reconfigure the system when their behavior changes, resulting in a frustrating and annoying task. In order to automatically recognize the user's situation related to the user's behavior, the authors propose to exploit context history. Adaption is provided by fuzzy decision trees, which take uncertainty in the raw data into account. More recently, Hagras, Doctor, Callaghan, and Lopez (2007) have proposed a novel learning technique to adapt the system to the continuous changing in the user's behavior. The technique is an unsupervised data-driven one-pass approach for extracting type-2 fuzzy membership functions and rules from the context history of the user. However, the authors do not separate the *situation determination* phase from the *system response* phase, on the basis of the inferred situation. Indeed, the sensed contextual information is immediately employed to adapt the system to the user's needs, which are application-specific. For instance, a particular configuration of some sensor values such as internal light level, bed pressure, and internal temperature can lead to activate the window blinds. Thus, the concept of situation is lacking in the system. Anagnostopoulos and Hadjiefthymiades (2010) have introduced advanced semantics in the context representation, combining the fuzzy logic approach with the semantic one. In particular, advanced representation schemes concern specialization, mereonomy, mutual exclusion and compatibility. By means of a neuro-fuzzy classification engine, the system learns to map sets of contextual information to particular situations, and builds the corresponding fuzzy rules. However, the proposed system is capable of dealing with physical contextual information only, such as orientation of the mobile device, illumination level, humidity. It does not deal with other indirect contextual information, such as user calendars or geographical maps. Finally, explicit means of representing user's situations are also lacking. The logical mapping between contextual information and situations should be accessible at the knowledge level, to be easily inspected and edited by the user or by an analyst.

This paper tries to address the question of how to provide a robust and general approach to situation awareness, in which both system architecture and behavioral knowledge can be easily integrated in an open environment, by supporting a variety of contextual, possibly uncertain, inputs and providing situational knowledge to multiple applications. To guarantee such structural and functional interoperability, the proposed system has been designed in compliance with an *agent-oriented* approach (Greenwood, Lyell, Mallya, & Suguri, 2007), which operates at the knowledge level, shows flexible behavior, easy maintenance, reusability and platform independence. This is achieved thanks to the use of highly standardized technologies, such as Semantic Web and Approximate (Fuzzy) Reasoning (Wang, Ma, Yan, & Meng, 2008), as well as architectural patterns such as the Event-Control-Action (ECA, Costa, Pires, & Sinderen, 2005; Etter, Costa, & Broens, 2006).

More specifically, the basic behavioral model of the proposed situation agent is expressed in terms of condition rules. The antecedent part of each rule is made of a logical combination of contextual conditions, referred to as an event in ECA pattern. The corresponding consequent part models a reaction to the event, assessing the new user's current situation and delivering the related results to an external service. Hence, the transitions of the user's current situations are established by the rule base, which represents the *control* of the situation-aware system.

Of course, automated context reasoning has to deal with events that may occur gradually and conditions that are inherently vague and imprecise. To this aim, fuzzy logic has been adopted in order to associate a truth degree with each context condition. If more than one situation is inferred from a given condition, a certainty degree for each such situation is computed based on the truth degrees of the condition. In this way the inferred situations can be ranked on the basis of their certainty degrees. Finally, situations are associated with a set of relevant tasks that the user would perform in the specific situation (Luther, Fukazawa, Wagner, & Kurakake, 2008), by means of domain knowledge expressed through task ontologies.

In general, context awareness and situation awareness rely on a distributed system. Hence, knowledge portability, integration and extensibility are key features since context reasoning implies collaboration among software agents that manage their own contextual sources. For this purpose, our proposal employs web knowledge standards such as Semantic Web Rule Language (SWRL, Horrocks & Patel-Schneider, 2004) and Fuzzy Markup Language (FML, Acampora & Loia, 2005).

Finally, rule bases are usually created by domain experts that model the situations in which the average user can be involved, and her/his behavior. However, users have different habits that may affect the way in which situations arise. Thus, an appropriate tuning aimed at adapting the situation model to the specific user is desirable. In our approach, this can be automatically achieved by using the context history and exploiting genetic algorithms.

The paper is structured as follows. In Section 2 we present the adopted architectural pattern (called ECAA in the following); Section 3 provides a detailed description of the structure of the proposed general-purpose situation reasoner (called GEPSIR in the following). Section 4 concerns the design of the Fuzzy Context Ontology. Section 5 discusses the representation languages employed in the model. Sections 6–8 are devoted to describe in detail the modules of the proposed architectural pattern. Section 9 presents an evaluation case study and, finally, Section 10 draws some conclusions.

2. The extended architectural pattern ECAA

According to the ECA pattern (Costa et al., 2005), the basic situational model can be expressed in terms of condition rules, which have the form