Chapter 9

Hybrid Architecture to Support Context-Aware Systems

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Abstract

Any system that is said to be context-aware is capable of monitoring continuously the surrounding environment, that is, capable of prompt reaction to events and changing conditions of the environment. The main objective of a context-aware system is to be continuously recognizing the state of the environment and the users present, in order to adjust the environment to an ideal state and to provide personalized information and services to users considering the user profile. In this chapter, we describe an architecture that relies on the incorporation of intelligent multi-agent systems (MAS), sensor networks, mobile sensors, actuators, Web services and ontologies. We describe the interaction of these technologies into the architecture aiming at facilitating the construction of context-aware systems.

Keywords: multi-agent system, sensor network, web services, ontologies

1. Introduction

Context-awareness is the characteristic of a system that is capable of monitoring the environment continuously aided with physical sensors and mobile sensors. The goal of a context-aware system is to obtain real data from the context (user preferences, user logs, temperature, humidity, light, etc.) in order to build a multi-valued representation of the context in a particular time, and by means of intelligent processing and reasoning of such acquired data provide relevant information in a timely manner and support for decision-making, considering the physical space conditions. An important aspect of a context-aware system is the capability of internal representation of current context, including the presence of human beings and their profiles.

Three important considerations were to be taken into account during the design of the hybrid architecture reported in this chapter:

a. *What are the tasks performed within a context-aware system?* Guermah et al. [1] described the challenges of context-aware systems: context capture, context representation, context interpretation and reasoning, service adaptation, context management and context reuse. In response to this question, the proposed hybrid architecture presented in this chapter provides technological support for these tasks to be performed.

b. *What general concepts does a context cover?* Another important design decision of the architecture was to define the general concepts that constitute a context. According with Abowd et al. [2], context is divided into four classes: location, time, activity and identity. However, in specialized literature, reported context models include more or less concepts. It is out of the scope of this chapter to present a deeper analysis of the concept coverage of context. Instead, we present an extensible and flexible model that allows the amplification or reduction of the concept coverage.

c. *What are the general functional requirements of a context-aware system?* In Ref. [3], Orsi and Tanca described an overview of the main functional requirements for context-aware systems organized in three aspects:

- Communication is the capability to adapt content presentation to different channels or devices. Communication also covers the agreement and shared reasoning between users or agents.
- Situation-awareness refers to the characteristic of modelling location and environment aspects; modelling the user personal situation, and adapting the information to the user needs. One of the most important requirements of personalized service provisioning is the ability to provide the correct information to the correct user in the correct moment.
- Managing knowledge refers to the task of determining the relevant information and services to be delivered to the users. Abowd et al. [2] also stated that 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.

1.1. Hybrid solution approach

In order to attend the afore-mentioned design considerations, **Table 1** shows the technological approaches that were selected to integrate the hybrid solution approach. Current advances of these technologies present significant advantages that contribute to satisfy the complex requirements of any context-aware system. In this sub-section, we briefly describe the technological approaches and their contribution for the tasks and functionalities that should be supported by any context-aware system.

The rapid development of **sensor networks** that deliver network services, enabling remote control, remote supervision and automation of buildings, offices, hospitals, etc.; together with the emergence of new smart mobile devices integrated with sensors, wireless protocols and novel applications, provide the technological foundations to design and build applications that allow continuous **context data capture or acquisition**. Context data come from various information sources: from physical sensors, mobile sensors or from virtual sources such as web pages, logs, public databases, etc. The techniques used to acquire context can vary based on responsibility,

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Technological approach	Task contribution	Functionality contribution
Sensor networks	Context acquisition	
Intelligent agents	Context acquisition	Communication support
	Context management	Managing knowledge
	Context interpretation	
Web services	Context acquisition	
	Service adaptation	
	Service provisioning	
Ontologies	Context representation	Situation-awareness
	Context interpretation	Managing knowledge
	Context reasoning	
	Context reuse	

Table 1. Technological approaches that integrate the hybrid solution.

frequency, context source, sensor type and acquisition process [4]. Mobile devices also represent the means by which personalized information and services can be delivered.

Web services are reusable software resources that can be shared, composed and invoked independently of the hardware, operating system and programming language used at the server and client side. In this sense, Web services allow the interoperability between hardware devices, intelligent agents and servers in order to personalize **service adaptation** and **service provisioning**.

According to Jennings and Wooldridge [5], an **intelligent agent** 'is an encapsulated computer system that is situated in some environment, and that is capable of flexible, autonomous action in that environment in order to meet its design objectives. Of particular, interest is the notion of an agent as a solver entity capable of showing flexible problem-solving behaviour. The abilities of individual agents to solve problems and communicate are fundamental to integrate a multi-agent system (MAS). Intelligent agents provide **communication** mechanisms to **control** and **monitor** the entire context-aware architecture. They are also capable of acquiring additional context data by invocation of services, maintain a shared context representation, interpret current state of the context and trigger actions that will adapt or affect the context.

Ontologies are representational models based on description logic, logic programing and frame logic that allow the formal definition of concepts and relations comprising the vocabulary of a topic area as well as the axioms and rules for combining terms and relations to define extensions to the vocabulary [6]. During the last decade, ontologies have gained popularity for context modelling due to their expressiveness and reasoning support. Ontologies allow context representation, context interpretation by explicitly defining equivalences, context reasoning and context reuse.

In order to achieve the afore-mentioned requirements and facilitate the complex interactions that occur inside a context-aware system, in this chapter, we present a **hybrid solution** approach (see **Figure 1**) that leverages current technologies by incorporating a sensor network,

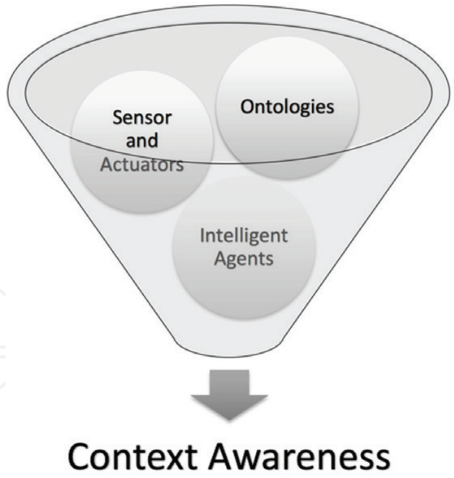

Figure 1. Integration of multiple technologies for context-awareness.

a set of specialized agents, a collection of software components deployed as Web services and context represented and reasoned by ontologies. We describe the complex interactions of these technologies facilitating the construction of context-aware systems.

The rest of the chapter is organized as follows: In Section 2, the general architecture is described; Section 3 describes the set of agents and their roles inside the architecture; Section 4 presents a multi-variable environment control system; Section 5 presents the ontological models defined for the architecture; Section 6 presents an overview of related work, and finally, in Section 7, conclusions are presented.

2. Description of the architecture

The proposed architecture is envisioned for a wireless networked **environment**, where users may be identified by their mobile device mac address or by a RFID card. Such an **environment** may be an office or laboratory into an academic institution or university, where users enter and leave the **environment** freely. The proposed architecture consists of five layers interconnected, which are described in this section. **Figure 2** shows the general description of the architecture.

2.1. Sensor network

This layer consists of a collection of physical sensors, mobile sensors and actuators. The objective of the network sensor is to obtain data from the physical context, user context and eventually activate some actuators. This layer aims at constant monitoring of environmental data such as temperature, lighting, humidity, smoke or fire and presence of humans into the environment. Another important objective of this layer is the possible identification of the users and the data generated by user interaction with the environment. The following types of sensors are considered as part of this layer:

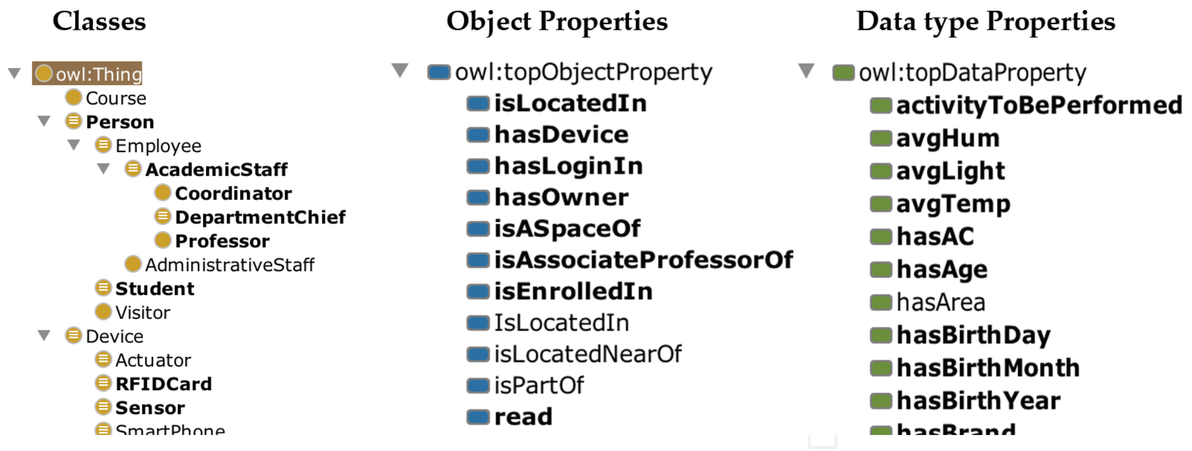

Table 7. Classes, object properties and data type properties of the ontology.

5. Related work

The use of ontologies for context modelling is not a new research topic; there are many works in literature that describe the utilization of ontologies to support context-awareness or pervasive environments. In this section, a chronological overview of works reporting ontologies, architectures and frameworks for context modelling is presented, highlighting the main differences (see **Table 8**).

Chen, Finin and Joshi [15] described **CoBrA**, a context broker agent architecture that is capable of managing a shared model of the context and reasoning support for context-aware applications. The objective of CoBrA is to facilitate knowledge sharing and reasoning between agents.

Razmerita, Angehrn and Maedche [16] presented in 2003 **OntobUM**, a generic ontology-based user modelling architecture. This architecture integrates three ontologies: the user ontology, the domain ontology and the log ontology. Later in 2007 [17], authors augmented their **OntobUM** model by representing the behaviour of user's concept, such as level of activity, type of activity, level of knowledge sharing, etc. They present a conceptual layered architecture integrated with a presentation layer, a middleware layer and a storage layer. This later

	Characteristics of the architecture or framework		Context concepts represented			Context management		
	Agent oriented	**Service oriented**	**Person or user profile**	**Physical context**	**Activities**	**Context representation model**	**Context reasoning**	**Context acquisition**
CoBrA [15]	Yes	Yes	No	Yes	Yes	Ontologies	Flora-2	Automatically by Sensors and mobile devices
CONON [18] SOCAM [19]	No	Yes	Yes	Yes	Yes	Ontologies	DL reasoning	Manually introduced by ontology designers
OntobUM [16, [17]	Yes	Yes	Yes	No	Yes	Ontologies	No	Manually introduced by users
CoDAMoS [20]	No	Yes	Yes	Yes	Yes	Ontologies	No	Manually introduced by ontology designers
mIO! [21]	No	No	Yes	Yes	Yes	Ontologies	No	Manually introduced by ontology designers
User profile ontology [22]	No	No	Yes	No	Yes	Ontologies	No	Manually introduced by users

Table 8. Related work of ontologies for context-aware system.

architecture is similar to the architecture proposed and described in Section 2; however, the purpose of their applications differs, **OntoBUM** is intended for knowledge sharing between users inside an organization; whereas our proposed architecture is abstracted from a particular organization and it was designed to support context-aware environments and context-aware systems.

Wang et al. [18] described in 2004 **CONON**, an ontology for modelling context in pervasive computing environments. Authors propose an ontology model divided into *upper* ontology and *specific* ontology. The upper ontology model defines computational entity, location, person and activity as the most important entities of a context model. Later in 2004 [19], authors presented **SOCAM**, a service-oriented context-aware middleware architecture to support the construction of context-aware services in intelligent environments. **SOCAM** architecture incorporates CONON ontology.

Preuveneers et al. [20] presented **CoDAMoS**, an extensible context ontology for ambient intelligence, which describes four main concepts: user, environment, platform and service. Authors described the requirements for ambient intelligence: application adaptability, resource awareness, mobile services, semantic service discovery, code generation and context-aware user interfaces.

In 2010, Poveda-Villalón et al. [21] presented **mIO**! ontology network for a mobile environment. **mIO**! ontology consists of 11 modular ontologies: user, role, environment, location, time, service, provider, device, interface, source and network. This ontology covers a wide range of concepts related with context representation, however; authors do not present any reasoning results.

Skillen et al. [22] presented in 2012 a user profile model for context-aware application personalization; authors concentrated on concepts to model a dynamic context: user time, user location, user activity and user context.

6. Conclusions

The work reported in this chapter incorporates various technological paradigms, such as intelligent agents, network sensors, Web services and ontologies. The main objective of integrating these technologies was to support the development of more complex and intelligent context-aware applications.

The use of models implemented with ontologies offers significant advantages: the ability to exchange, expand, extend and maintain the individual ontologies. An example is the **Person** ontology, which can be interchanged as needed to adapt to new application needs.

The incorporation and exploitation of agents, Web services and ontological models is a clear trend that promises to improve the automatic selection and invocation of legacy and new Web services.

All these technologies together (Web services, intelligent agents and ontologies) are key facilitators for the wise management of context-based systems.

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