A Semantic Context Service for Smart Offices

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Abstract

Smart Home environments aim to integrate physical devices, human beings and computing entities in homes and buildings. They have to support characteristics coming from mobile computing, ubiquitous computing and sensor networking in order to provide intelligent, context-aware and pro-active applications.

In this vision, "context" plays a central role; but, the raw context data, obtained by various data sources, are represented in heterogeneous formats and thus it's not possible to understand their meanings without a prior knowledge of the particular context information model.

Therefore, data sources are not able to produce high-level context information, but provide only raw information. Such low-level information should be combined in order to generate higher-level context information.

In this paper we propose a Semantic Context Service, that exploits Semantic Web technologies to support Smart Offices.

In particular, this service relies on ontologies and rules to classify several typologies of entities, which can be involved in smart homes and offices, and to infer higher-level context information from low-level information coming from positioning systems and sensors in the physical environments.

1. Introduction

Today's technology provides the users with the possibility to access information and communication services wherever and whenever they are.

Homes, hospitals, workplaces, classrooms, vehicles, and other spaces use embedded sensors, augmented appliances, stationary computers, and mobile handheld devices to gather information about users' locations, companions, and other aspects of their activities.

As the interaction with these smart homes and offices becomes a major part of the daily activities, their potential to shape, improve and change the wider social, cultural and creative context increases dramatically.

In this scenario, with the proliferation of sensor techniques and technologies, context plays a key role. Smart homes and offices must be context-aware, so that they can react to the changes by performing dynamic reconfiguration and behaviour adaptation without user distraction. Besides, they must be able to provide a less obtrusive and a more natural way of interaction, resulting in a better user experience and higher user satisfaction.

As a result, context information must be vastly available, ranging from low-level context (e.g. temperature, noise level, location coordinates, etc) to high-level context (e.g. activity schedule, relations between individuals, event profile, etc).

Diverse types of sensors and positioning systems can be used to detect the context data related to people and mobile objects. The inter-working of more data sources can undeniably provide a synergetic approach for describing contexts.

But, raw context data obtained from various sources come in heterogeneous formats, and applications and services are not able to understand their meanings without prior knowledge of the context representation.

Moreover, higher-level contexts, such as user's state, activities and needs, surely augment context-aware services, but data sources can't recognize such context information because provide only raw data.

To tackle these issues, a Smart Home environment needs a way to explicitly represent context meanings, so that independently developed services or

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applications can easily understand them. Besides, it must be able to perform logic and reasoning mechanisms in order to infer higher-level context information from the raw ones obtained from the various data sources.

Our solution, presented in this paper, is a Semantic Context Service for Smart Offices. The service exploits Semantic Web [11] technologies to support explicit representation and reasoning of contexts in Smart Offices.

In particular, we have realized a unique and unambiguous model for describing the different kinds of entities present in a Smart Office, such as services, devices, users, data sources and so on. Besides, we have defined some types of contextual information for a Smart Office, such as lighting and sound level or mobile entities presence and position. Ontologies and rules have been utilized to represent the proposed model and to infer higher-level context information.

The rest of the paper is organized as follows. Section 2 discusses some motivations and related work. Section 3 overviews a proposal of model for a Smart Office. Section 4 describes the Semantic Context Service and outlines the implementation details. In section 5 we present our environment and describe some applicative scenarios. Finally, section 6 concludes the paper.

2. Motivations and related work

2.1. Motivations

Smart Home researches envision the future environments as being filled with sensors and positioning systems, that can determine various types of contexts of its inhabitants, such as location, lighting or sound level. In this scenario, the environment uses this information to provide context-sensitive services to the inhabitants and for context-aware home automation.

For example, if the environment senses that the user is in the bedroom, the user is breathing normally and the eyelids are closed, the room is dark and quiet, and it is past midnight, then it could infer that the user is sleeping and would like to not be disturbed. The environment then could, for example, make the phones in the home silent and redirect incoming calls to the voice mailbox, without letting the ringer make any sound.

The process of gathering contextual information from the surroundings consists of acquiring one particular raw contextual information such as temperature, location, lighting level and so on.

But, Smart Home environments can be equipped with a multitude of different sensors and positioning systems able to provide heterogeneous context data. As a matter of fact, these raw data may be in different low-level formats and thus making it harder to deal with in services. Moreover, the emerging of new technologies doesn't produce the replacing of the old ones, but the integration of the new and old systems is realized by placing them side by side. Thus, this increases the number of data sources present in the environment.

Therefore, data sources are not able to produce high-level context information, but provide only raw information. Even if such low-level information may be used directly and sufficiently, in many cases higher-level information is required and so raw data should be combined in order to generate higher-level context information.

As a result, these issues increase the complexity of the Smart Home services, for the following reasons: i) the services should deal with many and different context data sources and their low-level protocols; ii) they should know all the specific representations, defined and used by the data sources, for the context information. Besides, they should convert the context information from each specific representation to an internal one and this produces several different representations for each service; iii) high-level context information should be produced by the specific services.

2.2. Our contribution

This paper proposes an enhanced Semantic Context Service able i) to provide context information by using diverse types of data sources and sensing techniques and ii) to integrate context information characterized by a specific format.

In detail, our work consists in the following issues:

Semantic integration of different sensors and positioning systems: The Semantic Context Service exploits the inter-working of more than one data context source i) by hiding the specific details of the data source and ii) granting both the syntactic as well as the semantic interoperability between services and data sources.

Definition of a context model: We have defined a context model able to i) provide a unique and uniform representation for context information, independently from the particular sensor or positioning system; ii) represent both raw and high-level context information of the entities of a Smart Home. We have developed the context model by using the Semantic Web technologies and in particular OWL [2] ontologies and SWRL [1] rules.

Logic and reasoning mechanisms: The Semantic Context Service performs logic and reasoning mechanisms in order to generate high context information from the raw ones coming from the various sources.

2.3. Related work

In the last few years context-aware computing and services have been of interest in several research areas. AT&T Laboratories at Cambridge [4] built a dense network of location sensors to maintain a location model shared between users and computing entities. Microsoft's EasyLiving [5] focuses on a smart space that is aware of users' presence and adjusts environment settings to suit their needs. Hewlett Packard's CoolTown [6] provides physical entities with "Web presence" and lets users navigate from the physical world to the Web by picking up links to Web resources using various sensing technologies.

These projects have greatly contributed to Smart Homes research by exploiting different features, but they don't organize contexts in a formal structured format and don't provide any generic mechanism for context reasoning.

Instead, an approach similar to ours has been adopted and realized in CoBrA [3]. It is an architecture to support context-aware services in smart spaces. A set of ontologies has been defined for modelling context information and Semantic Web languages are used for representing them and for supporting context reasoning.

Nevertheless, CoBrA doesn't aim at realizing a semantic integration of different types of data sources technologies. As a result, the context ontologies and rules don't model the raw information, but provide only a uniform and well-defined representation for the high-kevel context information which can characterize an environment. This choice is purely based on the type of context-aware applications to be supported in prototyping CoBrA.

3. The Semantic Approach

3.1. Our proposal of a context model

The approach presented in this paper relies on a context model that we have defined to provide a unique and uniform representation for context information, independently from the particular sensor or positioning system.

As a result, the model is based on the ideas of physical (or low-level) and semantic (or high-level) context information.

Physical context information specifies the raw data sensed by a source and is characterized by different granularities and scopes, depending on the particular sensor or positioning system.

Instead, a semantic context information can represent the meaning of a physical information or can be the result of a combination of the sensed information. This combination can use different kind of context data sources or the same kind of sources placed at different positions.

As an example, physical context information can be GPS coordinates, the lighting or sound level, the temperature in a room. Whereas, a semantic context can be a building, a room, an activity in a room. The latter can be obtained, for instance, combining location, lighting and sound level information: a person is sleeping if she is in bedroom, and the lighting and sound levels are low.

Our model specifies three kinds of physical context information, that is location, lighting and sound level. Sensing the lighting and sound level involves the Smart Home environment be equipped with infrastructures of appropriate sensors.

Locations can be specified by determining the proximity to well-known points, but it can also be easily extended by defining other types of locations.

The technique of proximity requires the Smart Home be also equipped with positioning systems, that reveal mobile users presence, or of particular devices to which mobile users can connect, for example to access the Internet. So, the locations we have modeled are not referred to coordinate systems, but identify the regions, called sensed areas, covered by a positioning system.

We have focused on two specific types of positioning systems, respectively based on Wi-Fi and RFID technologies, and so we have defined two types of sensed areas:

- a Wi-Fi sensed area, which is identified by the location covered by a specific wireless Access Point (AP), i.e. a mobile entity is located by an AP when her mobile device becomes active into its area;
- an RFID sensed area, which is identified by the location covered by a specific RFID reader, i.e. a mobile entity is located by an RFID reader when her RFID tag is sufficiently near it.

Each raw location information can be associated to higher-level semantic location [12], as building, room and so on. We have subdivided semantic locations in many atomic locations, that represent the minimal semantic locations in which a mobile entity can be localized. As an example, an atomic location can contain a desk, a pc, a table or it can be empty.

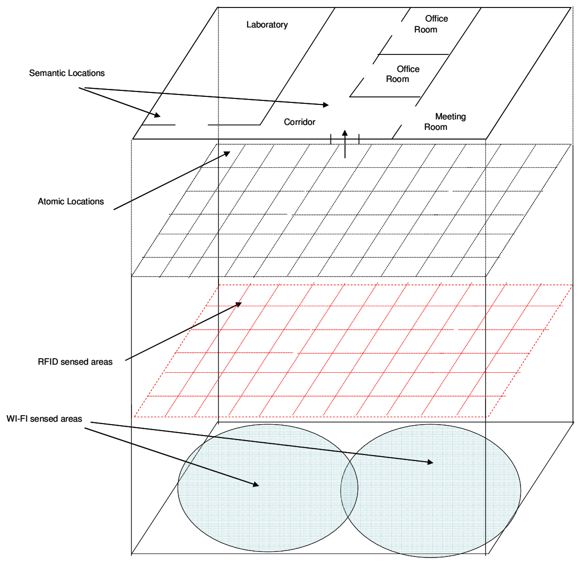

Figure 1 – A representation of the location information in our model

Figure 1 illustrates the relationships existing among semantic locations, atomic locations and sensed areas. Our model is general and, thus, can be applied for describing a large number of location-aware environments. As an example, we can consider the Smart Office in Figure 1, which is composed by semantic locations, such as laboratories, meeting rooms, office rooms, corridors. Each of this location is subdivided in atomic locations (that are identified, in Figure 1, by the rectangular shapes in the black grid).

A sensed area maps one or more atomic location, and, in particular, an RFID sensed area (that is identified by a rectangular shape in the red grid) covers one atomic location, whereas a Wi-Fi sensed area (that is identified by the oval shape) covers more atomic locations. This choice has been motivated by technological issues, that is the RFID based positioning systems we have adopted provide finer grain location information rather than the Wi-Fi based ones, even if this is not true in general. As a result, the relationship between a sensed area and one or more atomic locations allows to identify the atomic and also the semantic location of a mobile entity.

In adding to the physical context information, our model also defines semantic context information. Nevertheless, Smart Home paradigm covers a range of different types of environments, such as homes, offices, workplaces, classrooms, and vehicles. Each of them is characterized by different types of semantic context information. As an example, a context as a room can be specialized in laboratory, meeting room or office room in a Smart Office, and in bedroom, living room or kitchen in a Smart Home.

As a result, we have realized a context model which defines a set of basic semantic context information, common across different environments, and that specializes some of this semantic context information for a particular environment as a Smart Office. Moreover, because context-aware services must adapt to changing situations, the model also provides a detailed description of users and computing entities present in a Smart Office.

3.2. Ontologies and rules for our context model

The context model defines physical and semantic information in a unique and uniform way, but these information must be represented in an unambiguous and well-defined formalism and expressed in a machine-readable format. Besides, it has to provide a support for granting both the syntactic and the semantic interoperability between the environment and sensors or positioning systems.

The Semantic Web technologies, which have been widely applied in many areas in the recent past, can be used to face such needs because: i) ontologies and rules respectively enable the definition of domain vocabularies and allow declarative data processing, by providing a way to share knowledge without misunderstandings; ii) RDF [7], SWRL and OWL are semantic representation languages with high degree of expressiveness; iii) ontologies and rules can be reasoned by logic inference engines. We can use ontologies and rules coupled with subsets of first order logics to infer new knowledge and to ensure that the system is always in a consistent state.

We have modelled five OWL ontologies and a set of SWRL rules related to context issues for a Smart Offce. In the following, a brief description for the defined ontologies and rules is reported.

The first OWL ontology represents the upper ontology and identifies entities and contexts of a Smart Office. Context Entity and Semantic Context are the root concepts and represent respectively the generic entity and semantic context of the environment. User and Computing Entity are sub-concepts of Entity and represent respectively the users and the computing entities that can be present in the environment. For instance, a user can be characterized by a name, a surname, an e-mail, a profile and so on. Instead, Location and Activity are sub-concepts of Semantic Context and represent the environmental and social contexts that can characterize a Smart Office.

Moreover, Device, Service and Context Data Source are sub-concepts of Computing Entity and model respectively all the possible devices, context-aware services and sources of context data. Sensor and Positioning System represent the two possible typologies of data source present in a Smart Office.

All these concepts are generic and can be used in every kind of Smart Office.

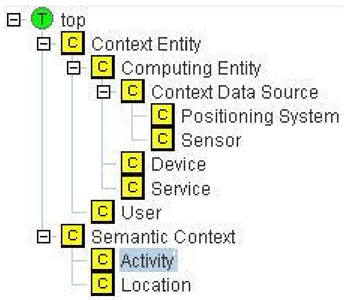

Figure 2 – Upper Ontology for Smart Offices

The second ontology specializes the sub-classes of Computing Entity, that is defines specific concepts for our Smart Office, by inheriting the super-concept properties and adding new features to them. An RFID Tag and a mobile PC are particular devices and are described by specific properties. For example, a mobile PC is characterized by a set of hardware and software properties, which describe memory capabilities, connection's bandwidth, cpu speed, available applications, and so on.

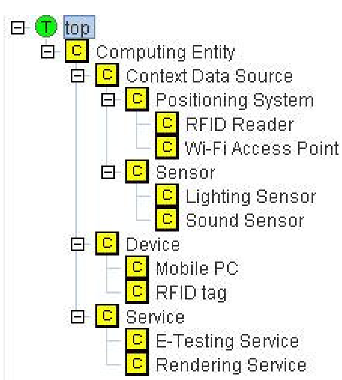

Figure 3 – Ontology for Computing Entities

RFID Reader and Wi-Fi Access Point are sub-concepts of Positioning System and define the two positioning systems we have integrated and described in the model. A mobile user can be equipped with an RFID Tag or can be the owner of a mobile PC. An RFID Tag can be sensed by an RFID Reader, whereas a mobile PC can be sensed by a Wi-Fi access point. Moreover, Lighting and Sound Sensors are sub-concepts of Sensors and define the two kinds of sensors we have integrated in our Smart Office; whereas E-Testing Service and Rendering Service represent two services available in our environment.

The third ontology models all the concepts for defining semantic locations. Location is the root concept of this ontology and represents the generic location of an environment. Each location has a name and can contain or be contained in an other location. Room, Building, Floor and Corridor represent the particular semantic locations of such an environment. For instance, a building is characterized by an address, a number of floors and is composed by corridors, floors and rooms (that is, these concepts are related to the Building concept by a whole-part relationship). We also define different types of rooms, as office-room, meeting-room and laboratory, by specializing the Room concept.

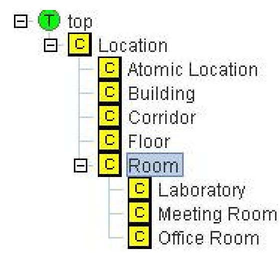

Figure 4 – Ontology for semantic locations

All these possible semantic locations are composed by atomic locations and so all the sub-concepts of Location are related to the Atomic Location concept by a whole-part relationship.

The fourth ontology models all the concepts useful for specifying some kinds of possible social activities that can be performed in our Smart Office, such as Meetings, Presentations or Sessions of E-Testing, that is on-line evaluation tests.

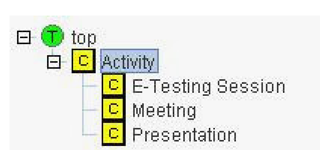

Figure 5 – Ontology for Activities

The last ontology specifies all the concepts that describe the physical context information. Context Data is the root concept of this ontology and represent generic context data sensed by a source, such as a sensor or a positioning system. Sensed Area represents a generic area covered by a positioning system, whereas RFID Sensed Area and Wi-Fi Sensed Area are sub-concepts of Sensed Area and. represent the regions respectively covered by an RFID Reader and Wi-Fi AP. The relationship between a sensed area and one or more atomic locations allows to identify the atomic and, as a result, the semantic location of a user. Lighting and Sound Levels are the context data produced respectively by Lighting and Sound sensors.

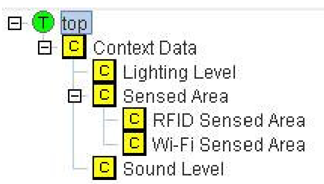

Figure 6 – Ontology for physical context information

Moreover, as an example, we describe two SWRL rules, we have realized on the top of these OWL ontologies, to choice the physical location information with the finest granularity when an object is located by more positioning systems.

In particular, the next rule makes us able to conclude that, if a mobile entity is sensed by an RFID reader, then it is located in the atomic location associated to the sensed area covered by that RFID reader.

sensedBy(entity, RFID reader) Λ *covers(RFIDreader,RFIDSensed Area)* Λ *maps(RFIDSensedArea, AtomicLocation)* ⟹ *isLocatedIn(entity,AtomicLocation)*

Instead, by using the second rule, we can conclude that, if a mobile entity is sensed by a Wi-fi AP and is not sensed by an RFID reader, then it is located in the atomic location associated to the sensed area covered by that Wi-Fi AP.

sensedBy(entity,Wi-Fi AP) Λ *notSensedBy(entity,RFID reader)* Λ *covers(Wi-Fi AP, Wi-Fi APSensedArea)* Λ *maps(Wi-Fi APSensed Area, AtomicLocation)* ⟹ *isLocatedIn(entity, AtomicLocation)*

If a mobile entity is sensed by both an RFID reader and a Wi-Fi AP, we can obtain the atomic location with the finest granularity by utilizing both the rules shown above. As a matter of fact, there is a condition that is not verified in the second rule (the mobile entity is sensed by an RFID reader), only the first rules hits and thus we can conclude that the mobile entity is located only in the atomic location associated to the sensed area covered by the RFID reader.

4. The Semantic Context Service

Current implementation of our Semantic Context Service integrates lighting and sound sensors and two distinct positioning systems for locating active mobile objects, like Wi-Fi enabled devices and RFID tagged entities. It has been developed in a real Smart Office environment.

The service architecture consists of the following components:

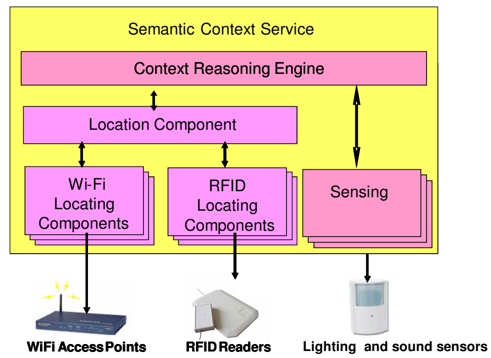

Figure 7 – The Semantic Context Service architecture

Currently, we have developed sensing components that interact with lighting and sound sensors and two locating components that identify the location of mobile objects by using respectively the Wi-Fi and RFID based positioning systems. New sensing and locating components for other sensing or positioning technologies, such as the Bluetooth technology, can be realized and easily integrated in the service.

The *Wi-Fi Locating Component* is in charge of locating Wi-Fi enabled mobile devices, by periodically interrogating Wi-Fi APs. Indeed, each AP writes an event into a log file whenever a device becomes active into its area. By comparing such logs and by handling global states, it is possible to detect location changes. A similar approach has been realized in [8]. This technique can not be used to recognize when a device becomes inactive, because hand-offs are not reported in the log file. It is possible to adopt a strategy based on checkpoints, and in particular the environment can periodically detect each mobile device with a ping operation. After having issued a ping message, the environment waits for a response or for a timeout. A mobile device is declared inactive after having missed a certain number of consecutive ping messages. Current implementation uses 3Com Office Connect Wireless 11g Access Points.

The *RFID Locating Component* is in charge of locating RFID tagged entities, by periodically interrogating RFID readers. When an entity is sensed by a reader, we can obviously conclude that it is located in the atomic location covered by that reader. A similar approach has been described in [9]. Current implementation uses the passive, short-range (30 cm), Feig Electronic RFID, model ISC.MR 100/101.

The *Location Component* is in charge of handling global location states obtained by combining information coming from Locating components.

The *Sensing Component* is in charge of obtaining and handling context data coming from the sensors present in the Smart Office. Current implementation uses the PASPORT Temp/Light/Sound Sensor, model PS-2140.

The *Context Reasoning Engine* is the core-component of the context service and is in charge of managing the context ontologies and rules. First of all, it makes use of the context ontologies and rules to specify context information in a uniform representation. As a result, it is able to grant both the syntactic as well as the semantic interoperability between the environment and any sensor or positioning system.

Besides, it uses a logic inference engine to perform reasoning mechanisms about the context information. In particular, our context ontologies and rules are submitted to the inference engine and reasoned by it in order to i) generate the semantic context information of mobile entities from their physical context information and ii) give the location information with the finest granularity when a mobile entity is located by more than one positioning system.

Nevertheless, the *Context Reasoning Engine* cannot use SWRL rules and OWL ontologies in a unique inference engine, because a complete integration of them in a unique system is inapplicable because of decidability issues. Besides, a solution based on a stack of inference engines doesn't represent an efficient, simple, and scalable solution for obtaining a sound and complete reasoning process.

The solution we have adopted is based on i) the use of a unique inference engine for rules and ii) the translation of OWL ontologies in SWRL rules. But, OWL syntax constructs can not all be translated into SWRL rules, and so we have used the DLP OWL language [10]. It represents the OWL subset that can be translated in SWRL, that is DLP OWL ontologies can be translated into SWRL rules and vice versa.

So, the *Context Reasoning Engine* translates DLP OWL ontologies into SWRL rules and then it is able to use a unique rule engine to infer and reason in a complete and sound way. It is worth noting that DLP OWL is less expressive than either the ontology or rule languages, but, in many cases, the complete expressiveness of OWL is not needed and a restriction such as DLP OWL is enough.

5. An experimental scenario

The experimental scenario consists of a Smart Office located in a three floors building. The environment uses two floors of the building.

Floor zero has a computing laboratory in which a cluster of 24 linux PCs, a 12 processors Silicon Graphics workstation, and a motion capture system are deployed. Such resources are collected in a wired grid built at the top of the Globus Toolkit 4.0 platform.

On floor two, wireless access to the grid is available. As a matter of fact, two 3Com Office Connect Wireless 11g Access Points identify two distinct locations. L1 is a laboratory where our students develop their activities and periodically perform E-Tests. It contains two multimedia displays and some desktop PCs. L2 is a meeting room equipped with a projector, an interactive monitor, and other multimedia devices. The floor two is subdivided in atomic locations, and each of them is equipped with a Feig Electronic RFID reader.

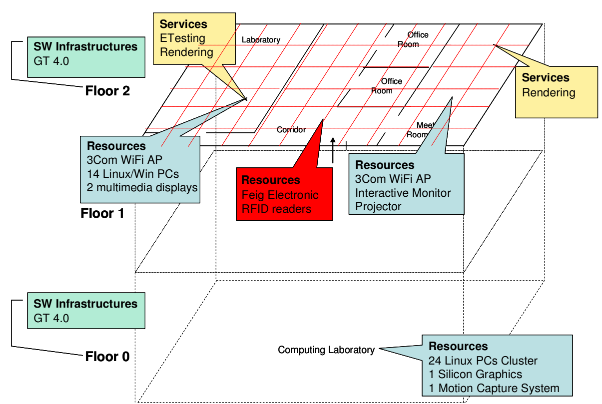

Figure 8 – Smart Office Architecture

Some services are available:

RenderingService – This service enables users to submit row motion data and to build 3D graphic applications.

ETestingService – This service performs on-line evaluation tests for courseware activities. Evaluation

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tests are synchronized and students have a predefined period of time for completing each test section.

In the last part of this section, we present some example scenarios in which the presence of a Semantic Context Service is required for supporting Smart Office environments. Specifically, we refer to our Smart Office and describe our services that need information about context, and in particular information about user's location.

A first possible scenario can be represented by an evaluation test which can be performed in the laboratory of our Smart Office. The access to this service has to be enabled only to the students which are physically located in the multimedia laboratory in which the test is executed. When a student, equipped with and RFID tag, enters the laboratory and stays at a specific atomic location, the RFID reader placed in it reveals his presence and loads test on his desktop pc. If the student leaves the atomic location during the test execution, the RFID reader reveals his movement and, as a result, the test is interrupted and any resources associated to it have to be released.

Another possible scenario is a mobile user which launches a rendering operation submitting it to the rendering service to build 3D graphic applications. When the results are ready, this service returns them to the user depending on his position, that is:

- if a WI-FI AP locates the user, for example, in the laboratory, the results can be indiscriminately presented on one of the displays placed in it, rather than on his mobile device;
- if the user is also equipped with an RFID tag and his presence in the laboratory is revealed by both a WI-FI AP and an RFID reader, the location information with the finest granularity, that is the one produced by the RFID reader, is used and, as a result, the rendering service presents the results on the display placed in the atomic location nearest the user.

6. Conclusions and future work

In this paper we propose a Semantic Context Service, that exploits Semantic Web technologies to support Smart Offices.

In particular, we have realized a unique and unambiguous model for describing the different kinds of entities present in a Smart Office, such as services, devices, users, data sources and so on. Besides, we have defined some types of contextual information for a Smart Office, such as lighting and sound level, mobile entities presence and position. Ontologies and rules have been utilized to represent the proposed model and to infer higher-level context information.

This facility provides the Smart Office with support for customizing services depending on the user's context, as well as enabling users to get access.

Future work will aim to integrate new sensing and positioning technologies, such as Bluetooth. As a result, the context model will be extended by defining the concepts related to these new systems, and in particular the new types of physical locations provided by them.

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