

A Semantic-based Framework for Context-aware Pedestrian Guiding Services

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Abstract. Location-based services have evolved significantly during the last years and are reaching a maturity phase, relying primarily on the experience gained and the utilization of recent technologies. This paper identifies main fields of research and key challenges for the proliferation of such services and proposes a framework for building location aware applications that use Semantic Web technologies and advanced interactive interfaces. The approach, focusing on indoor environments, is structured around a RDFS ontology for capturing and formally modelling contextual information and also utilizes user-centered design for developing interactive map-based presentations for accommodating pedestrians. To test and demonstrate the approach, a prototype has been developed and a number of further extensions are analyzed that document the flexibility of the design.

1 INTRODUCTION

Location-based services and mobile applications represent an emerging research paradigm that aims at empowering users through personalized, context-aware and context-adaptive environments. Although mobile guides and navigation systems have come a long way since their first release, certain challenges have yet to be addressed, while new requirements are continuously becoming apparent. Thereby, new methodologies and advanced technologies are being developed that focus on providing flexible and extensible design models, on proposing efficient solutions for dynamic environments, on structuring solid context-aware infrastructures, as well as on promoting openness and interoperability in response to the current highly heterogeneous reality.

Considering recent trends, the present paper proposes a framework for structuring advanced location-based and context-aware services that integrates up-to-date technologies and develops novel mechanisms and interactive interfaces by applying techniques and formalisms from the Semantic Web and Ubiquitous Computing domains. The objective is to explore the intelligent pedestrian navigation by implementing a Context Pedestrian Guiding platform (CG) for users in indoor environments. We focus on modelling and representing context for efficient processing and dissemination of context-based knowledge in order to develop services for mobile users. The main contribution is the modelling of all aspects of context using Semantic Web technologies, coupling spatial and temporal entities, as well as the accommodation of users through flexible, interactive map-based interfaces, specifically designed for supporting guiding

services. Integrating web ontology languages with context-aware applications has manifold benefits. These languages offer enough representational capabilities to develop a formal context model that can be shared, reused, extended for the needs of specific domains, but also combined with data originating from other sources, such as the Web or other applications. Moreover, the development of the logic layer of the Semantic Web is resulting in rule languages that will enable reasoning with the user's needs and preferences and with the available ontology knowledge.

During the course of this project, we implemented a prototype that operates in the premises of the FORTH research facilities located in the technological and research park in Heraklion, supporting several of the basic functionalities that have been considered

This paper is organized as follows. In Section 2 key requirements of location-based applications are identified and an overview of current platforms is provided. The system architecture is presented next, while in Section 4 we describe the implemented services of a prototype system, along with a case scenario, focusing on the use of Semantic Web technologies. The paper concludes with a demonstration of parameters currently considered to extend the platform's functionality in the future.

2 CHALLENGES AND RELATED WORK

Context-aware systems rely on collaborations of technologies from different disciplines, underscoring the need to summarize and classify their requirements and challenges. In this section we briefly discuss such requirements, as well as previous work, in order to identify implementation gaps and motivate our own design choices.

2.1 Requirements for Pedestrian Navigation Systems

Challenges that need to be addressed in implementing location-based services range from those concerning engineering aspects of the supported infrastructure, such as location-sensing mechanisms, to software components and abstractions, such as context representation and user interfaces.

An important component of location-based systems is the positioning mechanism that locates a mobile device or user in the environment, exploiting some tracking technology, such as RF-tags, sensors, GPS etc. Positioning systems can be classified in different categories based on their accuracy requirements, availability of infrastructure and specialized hardware, signal modalities, representation of the positioning (absolute or relative), privacy needs, requirements for estimating the orientation of the devices, as well as energy

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conservation techniques. For example, a combination of ultrasonic and radio signal measurements has been utilized in systems, such as Bat [9] and Cricket [15], while other efforts address location-sensing in ad hoc networks, depending on cooperative self-organizing devices ([10], [5]). For the CG prototype, the IEEE 802.11 network infrastructure at FORTH has been used for both positioning and communication purposes, exploiting the existence of a positioning system that runs on the client (eg., CLS [8]). The Radar [3] and the robotics-based system in [13] use a similar approach.

Modelling context for representing, manipulating and accessing both static and dynamic information is essential for context-aware infrastructures. The significance of a flexible and practical context model is evident not only in facilitating the task of programming a context-aware system, but also in permitting the desirable degree of gathering, management, dissemination and reasoning on contextual information. Various context models have been proposed, but ontology-based are considered the most appropriate ones, as documented in [21], since they permit formal representation, richness of information and interoperability among different applications and devices. An RDF-based ontology context model has been designed for use in the CG platform, aiming at addressing issues concerning semantic context representation, knowledge sharing and context classification.

Visualization of the provided services and adaptation to user preferences and particular device specification have attracted significant interest lately. However, human-centric design using situated interfaces for enabling users to access services in an intuitive way is challenging. Plain cartographic representation integrating spatially related information is now considered inadequate; interactive maps with symbolic annotation or metaphors and adaptation capabilities greatly improve the usefulness and impact of mobile guides (i.e., see [16], [25]).

Furthermore, guiding systems need to function properly under dynamic situations, since wireless systems are still prone to unreliable connections, a parameter not regarded in most systems, as indicated in [4].

2.2 Related Work

The existing implemented prototypes can be classified based on several criteria, namely, the services they provide (information guides vs. navigation systems), the context representation model (semantic vs. non-semantic), the environment they work in (indoor vs. outdoor), the type of the interface (map-based vs. text-based, interactive vs. non-interactive) and their adaptation capabilities.

Two of the most prominent early mobile navigation systems were Cyberguide [1] and GUIDE [7], both of which were designed to provide visitors with up-to-date and context-aware information whilst exploring a city. While Cyberguide considers only the user's location to provide the relevant context information and services, GUIDE uses more types of context information, such as the visitor's interests, mobility constraints, available time and weather conditions.

Only recently, systems that integrate Semantic Web technologies with navigation services have been developed. mSpace Mobile [24] is a Semantic Web application that allows the collection of distributed semantic information concerning elements of the user's context that the user selects from an interactive interface. Further, the mSpace Mobile supports the lightweight publication of new information. Comments, annotations and recommendations can be semantically published on any element discovered through the interface, and reused by any other Semantic Web applications and services.

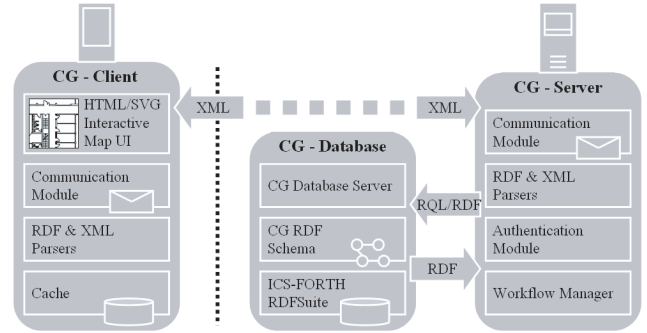


Figure 1. The system architecture.

COMPASS [22] provides tourists with context-aware recommendations and services. It uses various external map services through proprietary interfaces, a map service providing orthophotos and a map service providing cadastral maps. It builds on the open Web Architectures for Services Platform [23], which supports context-aware applications based on web services, described in OWL.

Navio [17] is based on ontologies and the way humans navigate, select and mentally represent routes. The project develops a route modelling ontology that provides both outdoor and indoor routing instructions by identifying and formally defining the criteria, the actions and the reference objects used by pedestrians in their reasoning for routes. OntoNav, an integrated navigation system for indoor environments, uses a hybrid modelling (i.e., both geometric and semantic) of such environments [2]. It is purely user-centric in the sense that both the navigation paths and the guidelines that describe them depend on the users' physical and perceptual capabilities, and particular routing preferences. A hybrid context model is also proposed in [20]. The central context database (UbiWorld) has been designed to model and query the characteristics of a user, including activity and environmental context. It also provides a symbolic spatial model to express location. For the creation of a hierarchical geometrical spatial model, they have developed the Yamamoto tool, which associates the spatial vocabulary of UbiWorld with real-world coordinates (as supplied by a GPS receiver). This model represents real-world places at different granularities as resources in the World Wide Web.

The distinct features of the Context Pedestrian Guiding platform are two, namely the extensible context ontology model and the interactive mechanism. The first includes representations of many aspects of context (such as people, devices, locations, rooms), and gives the ability to combine spatial with temporal entities in order to model events that take place in the premise. The second gives the users the ability to not only issue queries about their context but also change it, by updating the knowledge base through an interactive interface.

3 SYSTEM ARCHITECTURE

This section illustrates the basic components of the CG-platform and the information flow within it. A flexible structure is proposed (Fig. 1) that combines user-centered and device-independent design, in order to provide the technical feasibility for building a multitude of context-based services. The framework, intended for indoor environments, is based on a centralized configuration and achieves a high level of transparency in inter-device communication, context management and service deployment.

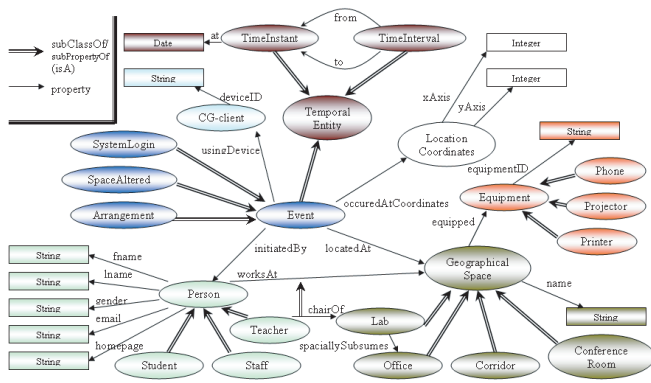


Figure 2. The schema of the context ontology (different shades denote groupings of distinct concept clusters)

3.1 CG-Database

At the core of the CG platform lies a contextual ontology. Written in RDF, the ontology captures the relevant notions of physical and semantic entities operating in the system and provides a formal vocabulary for structuring location and other context-aware services. The generic CG RDF Schema (part of which is shown in Fig. 2), follows the abstract design principles of other large-scale pervasive computing ontology frameworks, such as the SOUPA project ([6], [19]), and defines the high-level concepts of Person, Geographical Space, Location Coordinates, CG-Client and Event, as well as the relations among them. The model captures static information (i.e., device ID for CG-Client devices etc.) and dynamic contextual data. The latter, introduced by the Event class, refers to activities that have both spatial and temporal extensions, such as user login, change of location in the building and room arrangements.

The CG Schema, along with all static and dynamic information, is stored by means of the ICS-FORTH RDFSuite [11]. RDFSuite is a suite of tools for RDF validation, storage and querying, using an object-relational DBMS. The language used for querying the database is RQL [12], a typed language following a functional approach, which supports generalized path expressions featuring variables on both labels for nodes (classes) and edges (properties). Furthermore, since the CG-Database is expected to handle multiple requests simultaneously, a specialized multithreaded server has been integrated, for facilitating access to the underlying database.

3.2 CG-Server

The CG-Server component is an integral part of the infrastructure, implementing the fundamental functions, on top of which a multitude of advanced services can be built (see Section 4). It acts as a middleware for processing, managing and transforming stored and inferred knowledge and offers the medium for synthesizing and publishing the desired services.

The Communication Module is responsible for handling multiple client requests. All communication between the CG-Server and the CG-Clients is accomplished using XML message exchanges using a well-defined format. Each message, defined by the notion of envelop, includes information about the act of communication itself that allows the identification of intended action and the discrimination between senders. For example, "RQL" in the content language tag indicates a request for querying the database, while "RDF" indicates the triggering of a specific action, such as the generation of a specific

Event type. Message processing is being conducted in collaboration with the XML parser for validating the format and determining the appropriate tags.

The Workflow Manager classifies requests, determines the appropriate action in response to each request and collects the information needed to accomplish each action. This component coordinates the operation of the other elements of the CG-Server and regulates the interaction with the CG-Database and, potentially, with other agencies involved, such as the institution's secretariat agency, for example in the case a request for arranging a meeting in one of the conference rooms is desired. The Workflow Manager operates in close collaboration with the RDF parser, for interpreting incoming requests and structuring responses, and with the Authentication Module, for verifying user's credentials before performing certain tasks.

3.3 CG-Client

The CG-Client module characterizes the devices with which a user can experience the services provided by the CG platform. Different mobile devices can connect as CG-Clients in the system, such as PDAs or laptops, taking advantage of the flexible and portable Web-based model used for its development. In particular, a Java applet is the principal driver of this module, implementing the complex processes, while the user interface, an interactive multi-layered map, visualizes the relevant information by contacting the applet through a set of JavaScript functions.

The user interface consists of a number of SVG files, and is accessible through ordinary Web browsers. The choice of SVG (Scalable Vector Graphics) is not arbitrary. This is a vector graphics format suitable for the implementation of maps on the web, as well as on mobile devices [14], [16]. Its scalability guarantees that no information is lost while zooming. Furthermore, the Document Object Model (DOM) enables scripting SVG in order to dynamically change and interact with maps in several aspects (add or delete map objects and layers, change visual attributes of the map objects etc.).

A key component of the CG-Client is its caching element. Most systems assume a permanent and reliable connection to a server, in order to work properly. The cache component, implemented in the CG-Client, plays the role of managing efficiently the available information and delivering it to the user, even when the device is not within reach of the system's coverage range. The concern is mainly on preserving static information and, in addition to handling broken connections, this feature serves another purpose, as well; to reduce the communication load of the system, since this data changes in much faster rates than static one. As a consequence, there is no need to repeatedly store static information in the CG-Client device, whenever dynamic content is updated.

3.4 Implementation

For the CG platform to be adaptive to the complexity of context-aware scenarios, a number of up-to-date technologies and systems have been integrated in the architecture that collaborate through a set of primitive methods (java api). The core functionalities of the CG-components, such as remote communication, multithreaded design and caching, have been implemented in Java. The CG-client user interface is composed of numerous SVG 1.2 files augmented by Javascript 1.2 functions for accessing the underlying Java procedures. These files are imported in HTML templates, in order to allow familiarity with web-enabled interactions. Finally, all data is stored in RDF format using the ICS-FORTH RDFSuite semantic DBMS and

exchanged using XML messages, while queries, expressed in RQL, are automatically generated, validated and manipulated.

4 DEPLOYED SERVICES

The system supports several services that give users the ability to obtain information about their context, but also to superimpose data objects on the map in order to keep notes or make room arrangements. In the next paragraphs, we give a brief description of the supported services and present a concrete example that describes the system functionalities in more detail.

4.1 Semantic-based Services

Personal Information Retrieval: The user can have access to information regarding other users, namely their e-mail, homepage, current location and others, which are stored in the server's knowledge base. The client application enables the user to form queries through dialogue boxes that it displays as a response to the user's request. The client, then, creates an appropriate RQL query, embodies the query in a XML message, and sends the message to the server. The query is applied by the server to its knowledge base and the answer is sent back to the client, embodied in a XML message.

Room Information Retrieval - Room Reservation: The only room information that is initially available to the client is the names of the rooms. By clicking on a conference room, a new list of options is displayed. These options enable the user to reserve a conference room for a period of time, cancel a previous reservation, view the reservations that other users made for the same room or query the system about the events that are scheduled to take place in the room. The interaction that takes place between the client and the server is based on XML messages containing either RQL queries, in the case the user requests room information from the server, or RDF descriptions of the user's reservation requests.

Note keeping: The system enables the user to publish notes that are annotated with relevant information and in the future we plan to enrich these notes with contextual data obtained from the CG-ontology. Whenever the user moves the pointer over a note, its content is displayed in the information box. Our notion of notes is similar to the InfoBridge context-aware poster service developed in the course of MyCampus project [18].

4.2 Services Under Development

The semantic-based framework that we have developed has the potential to support many more semantic context-aware services that will better exploit the integrated technologies. Part of our ongoing work is the development of the additional services that we describe in the next paragraphs.

Personalized services. Users that interact with a context-aware system are expected to experience independencies not only from the application and location perspectives, but also from the device perspective. Adapting content to the users' preferences and tailored to the capabilities of the device used is a priority for the CG system. We can use the user's profile information to support a variety of personalized services, such as message exchange among user groups, context sharing, group note creation etc. We also plan to augment the user's profile with privacy preferences that the system must take into account whenever it tries to retrieve a user's personal information.

Navigation / Route Finding. Using some path planning algorithms, the context model, and the available information from the

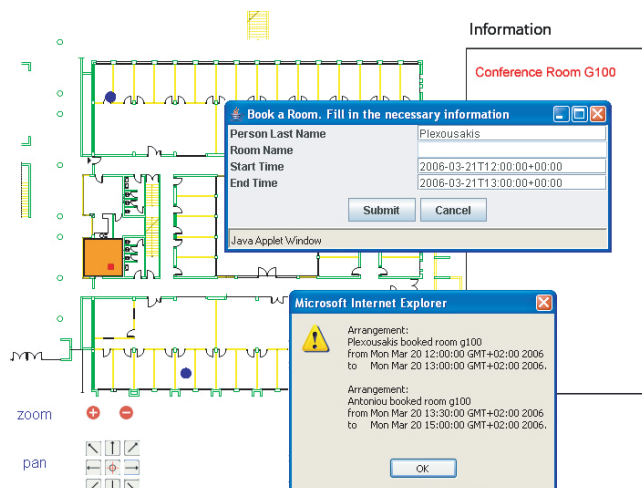


Figure 3. Room reservation of a conference room (screenshot).

user's profile, we plan to develop services that help users navigate in the premises. These services will take into account not only the start and end point of the user's route, but also the user's special needs and characteristics, e.g. the authorization to pass through specific areas, some possible corporal disabilities etc.

Calendar services. The integration of a calendaring application with the room reservation service is also part of the further development of the CG system. We plan to employ a web calendar application that supports semantic descriptions of the calendar entries, in order to combine these entries with the room reservation semantic descriptions, but also with data originating from other semantic-based applications and sources.

4.3 A Typical Usage Scenario

Below, we present a typical usage scenario that takes advantage of functionalities of the system that have either been implemented or are currently under development and also shows the internal processes that are carried out to support the services.

Suppose that Dr. Plexousakis wishes to arrange a presentation to the members of a workgroup at the G100 conference room of the Institute and chooses to do so using his CG-Client device. By clicking on the G100 room on the map, the room becomes highlighted and a list of options is displayed (Fig. 3). After confirming the availability of the room for the date he desires, he clicks on the "Arrange a reservation" option and the client applet initiates a dialogue in order to specify the parameters of the reservation (name, date etc.). Thus, the CG-Client applet constructs the appropriate XML message for the reservation request (Fig. 4a) and sends it to the CG-Server.

At the CG-server side, the server receives the XML message, identifies it as a reservation request and creates and applies a number of RQL queries to the knowledge base (Fig. 4b). The queries concern the availability of the room and the authorization of the user to book the room. For example, the RQL query in Fig. 4c returns all reservations made for this specific room at the 21st of March, 2006. If the requested reservation is approved, the server adds the appropriate RDF description to its knowledge base and sends a message of success to the CG-client.

Once the confirmation of the reservation is received, Dr. Plexousakis publishes a note concerning the presentation to inform both


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(a)
<cg-message>
<sender>device18</sender>
<receiver>CG-Server</receiver>
<language>RDF</language>
<content>
<cg:arrangement
rdf:about="event100343">
<cg:initiatedBy>
<cg:teacher rdf:about="dp"/>
</cg:initiatedBy>
<cg:locatedAt>
<cg:conferenceRoom
rdf:about="g100"/>
</cg:locatedAt>
<cg:timeInterval>
<cg:from>
<cg:timeInstant>
<cg:at rdf:datatype=
"xsd:dateTime">
2006-03-21T12:00:00
</cg:at>
</cg:timeInstant>
</cg:from>
<cg:to>
<cg:timeInstant>
<cg:at rdf:datatype=
"xsd:dateTime">
2006-03-21T13:00:00
</cg:at>
</cg:timeInstant>
</cg:to>
</cg:timeInterval>
</cg:arrangement>
</content>
</cg-message>

(b)
<!--Example of Static Data Instances-->
<cg:teacher rdf:about="dp">
<cg:fname>Dimitris</cg:fname>
<cg:lname>Plexousakis</cg:lname>
<cg:gender>male</cg:gender>
<cg:email>dp@ics.forth.gr</cg:email>
</cg:teacher>
<cg:conferenceRoom rdf:about="g100">
<cg:name>G100 Conference Room</cg:name>
<cg:equipped>
<cg:projector rdf:about="proj12">
</cg:equipped>
</cg:conferenceRoom>
<!--Example of Dynamic Data Instances-->
<cg:spaceAltered rdf:about="event100187">
<cg:initiatedBy>
<cg:teacher rdf:about="antoniou"/>
</cg:initiatedBy>
<cg:occuredAtCoordinates>
<cg:locationCoordinates rdf:about="loc15"/>
</cg:occuredAtCoordinates>
</cg:spaceAltered>
<cg:locationCoordinates rdf:about="loc15">
<cg:xAxis>118</cg:xAxis>
<cg:yAxis>224</cg:yAxis>
</cg:locationCoordinates>

(c)
SELECT DISTINCT X, Z, Start, End, LastName, Room
FROM
(1)Iname(LastName),
(2)arrangement.initiatedBy(X),
(2)locatedAt(Room),
(2)from(Start),
(2)to(End)
WHERE Room LIKE (g100) AND
Start >= 2006-03-21 AND
End < 2006-03-22

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Figure 4. Code examples: (a) part of an XML message, (b) RDF instances stored in the CG-Database, (c) RQL query.

members of his workgroup and others that might be interested in it. The system semantically matches the annotated information of the note with the preferences of users stored in the CG-Database and recognizes that the topic might be of interest to Dr. Antoniou, displaying the note on his map, as well.

At the date of the presentation, Dr. Antoniou, being too busy with office work, does not wish to interrupt until the presentation is about to begin. Therefore, he consults his CG-Client to see who is currently in G100 and whether Dr. Plexousakis is present (in the future other parameters of context might also be considered, such as whether the projector and the microphones are on, the level of lighting in the room etc.). Although Dr. Antoniou might not need guiding instructions from his current location to the G100 conference room, this functionality will be of particular use to persons that are not familiar with the environment.

5 CONCLUSIONS

The Contextual Pedestrian Guiding framework is a first effort to exploit the representational capabilities of the Semantic Web formalisms for the needs of a guiding application for the Institute of Computer Science of FORTH in Crete. This framework can be the basis of a broader system that can support more services, different contexts and different architectures. We already mentioned the ways that we plan to extend the system functionalities in the previous section. There are also thoughts for employing semantic web rule languages, in order to better support the reasoning mechanisms and the decision-making functions of the system; and a non-monotonic rule system seems to suit better in a system that works in a dynamic and unstable environment. Finally, a radical change of the system architecture, from the client-server to a decentralized schema, is an issue that needs to be considered.

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