A Semantic Web GIS based Emergency Management System[*]

Vlad Tanasescu[1], Alessio Gugliotta[1], John Domingue[1],
Leticia Gutiérrez Villarías[2], Rob Davies[2], Mary Rowlatt[2], Marc Richardson[3]

[1] Knowledge Media Institute, The Open University,
Walton Hall, Milton Keynes, MK7 6AA, UK
{v.tanasescu, a.gugliotta, j.b.domingue}@open.ac.uk

[2] Essex County Council, County Hall,
Chelmsford, CM1 1LX, UK
{Leticia.gutierrez, maryr}@essexcc.gov.uk
rob.davies@mdrpartners.com

[3] BT Exact
Adastral Park Martlesham, Ipswich IP5 3RE, UK
marc.richardson@bt.com

Abstract. Public organisations access spatial-related data for management as well as for communication purposes. The approach of using traditional Geographical Information Systems (GIS) is not always satisfactory; users have to cope with distributed heterogeneous data sources to find appropriate resources for particular situations. Developments in the field of Semantic Web Services (SWS) show the opportunity of adding higher semantic levels to the existing frameworks, to improve their usage and ease scalability. We outline a Semantic Web GIS in which data sources and services are made available through SWS, described by ontologies, allowing interoperability as well as reasoning to create a comprehensive response adapted to user goals. The Emergency Management System described in this paper as a practical example of Semantic Web GIS instantiation provides a goal oriented tool for emergency planners.

1 Introduction

In an emergency situation, multiple agencies need to collaborate, sharing data and information about actions to be performed. However, many emergency relevant resources are not available on the network and interactions among agencies or emergency corps usually occur on a personal/phone/fax basis. The resulting

---

interaction is therefore limited in scope and slower in response time, contrary to the nature of the need for information access in an emergency situation.

Emergency relevant data is often spatial-related, and *Spatial-Related Data (SRD)* is traditionally managed with the help of *Geographical Information Systems (GIS)*. GIS allow access to different layers of SRD such as highways, transportation, postal addresses index, land use, etc. GIS support decision making by facilitating the integration, storage, querying, analysis, modeling, reporting, and mapping of this data.

Unfortunately, GIS are often centralized and isolated systems, and heterogeneity arises in the way different organisation collect and manage data, according to a particular view of the world. This is often a barrier to SRD exchange. The lack, and maybe the impossibility, of consensus about the spatial domain limits communication and knowledge of available information, leading to inaccuracies whilst introducing an increased amount of manual work. These inefficiencies can lead to disastrous consequences in an emergency situation.

To alleviate this, service-oriented architectures are becoming popular in the implementation of e-government programmes; combined to recent developments in the area of *Web Services (WS)* and the *Semantic Web* [3] they can enable the creation of agile networks of collaborating applications distributed within and across public organization boundaries ([4], [9]).

Using WS, SRD can be shared on the internet via services which become autonomous and platform-independent computational elements. Unfortunately, despite the acceptance of standards for WS description (WSDL[1]) and publishing (UDDI[2]), syntactic definitions do not completely describe the capability of a service and cannot be understood by software programs; a human developer is always required to interpret the meaning of inputs, outputs, applicable constraints as well as the context in which services can be used.

The Semantic Web aims to allow the development of easy to use applications and transparent access to services and data, by giving machine understandable meaning (semantics) to services as well as contents on the Web, and to create a universal medium for information exchange. In particular, the *Semantic Web Services (SWS)* technology provides an infrastructure in which new services can be added, discovered and composed continually [4], by combining the flexibility, reusability, and universal access that typically characterize a WS, with the expressivity of semantic markup and reasoning. This allows the invocation, composition, mediation, and execution of complex services with multiple paths of execution, and levels of process nesting.

In this paper, we describe results in the development of a Semantic Web GIS *Emergency Management System (EMS)* relying on SWS technologies. The EMS assists the *Emergency Planning Officer (EPO)* in the task of retrieving, displaying, and interacting with emergency relevant information. This can include, according to the kind of emergency, weather forecasts, available rescue corps, evacuation procedures, supplies providers, available rest centres, categories of affected and vulnerable people, nature and location of damaged or endangered facilities, access of critical spots, etc. As a result, involved agencies become able extend their knowledge about the emergency situation by making use of different functionalities based on data

---

[1] http://www.w3.org/TR/wsdl

[2] http://www.uddi.org/

held by other agencies which otherwise might not be accessible to them or slow to obtain manually.

Sections are arranged as follows. Section 2 gives an overview of the Semantic Web GIS framework we propose. Section 3 provides a detailed overview of the architecture of the EMS prototype. Section 4 briefly outlines its practical usage. Finally, Section 5 concludes and discusses future work.

2   A Semantic Web GIS Framework

Any information system can gain advantage from the use of semantics [10]. In GIS, the use of semantic layers, although not yet firmly established, is being investigated in a number of research studies [5], [7], [11]. Having ontologies describing the SRD repository and its functionalities is believed to make cooperation with other systems easier and to better match user needs. In order to ease the transition to a *Semantic Web GIS (SWGIS)*, we adopt WSMO[3] – a promising SWS framework – and IRS-III – a tested implementation of this standard [1] – in order to expose data sources. In the following, we briefly describe these two technologies as well as give a whirlwind introduction to GIS technologies, before describing the framework we propose.

2.1   Semantic Web Services with WSMO and IRS-III

The *Web Service Modelling Ontology (WSMO)* is a formal ontology for describing the various aspects of services in order to enable the automation of WS discovery, composition, mediation and invocation. The meta-model of WSMO defines four top level elements: *Ontologies*, *Goals*, *Web Services*, and *Mediators*.

Ontologies [2] provide the foundation for describing domains semantically. They are used by the three other WSMO components.

Goals define the tasks that a service requester expects WS to fulfil. In this sense they tend to reflect the service user's intent.

Web Service descriptions, in terms of *capabilities* (what the service can do) and *interface* (how to use it), represent the behaviour of a deployed Web Service. The description also indicates how WS communicate (*choreography*) and how they are composed (*orchestration*).

Mediators handle issues of data and process interoperability that arise between heterogeneous systems. One of the characterizing features of WSMO is that all components – Ontologies, Goals and Web Services – are linked by Mediators. In particular, WSMO provides four kinds of mediators:

- *oo-mediators* for mediating between heterogeneous ontologies;
- *ww-mediators* connect WS to WS;
- *wg-mediators* connect WS with Goals;
- *gg-mediators* link different Goals, solving input conflicts and transforming processes.

[3] http://www.wsmo.org/2004/d2/v1.0/

The incorporation of four classes of mediators in WSMO facilitates the clean separation of different mapping mechanisms.

IRS-III, the *Internet Reasoning Service* [1], is a platform which allows the description, publication and execution of Semantic Web Services, according to the WSMO conceptual model.

Based on a distributed architecture communicating via XML/SOAP messages, it provides an execution environment for SWS; ontologies are stored by the server, and used in WSMO descriptions to support discovery, composition, invocation and orchestration of WS. It allows *one-click publishing* of "standard" program code to WS by automatically generating an appropriate wrapper. Standard WS or REST services can also be trivially integrated and described by using the platform.

Also, by extending WSMO's goal and Web Service concepts, clients of IRS-III can invoke web services via goals. That is, IRS-III supports so called *capability-*, or *goal-driven* service invocation which allows the user to use only generic inputs, hiding the possible complexity of a chain of heterogeneous WS invocations.

2.2 Geographical Information Systems

A GIS allows the creation and management of objects composed of spatial attributes (polygons, nodes, maps, etc) as well as descriptive ones (names, numeric values, etc). GIS are "smart map" tools that allow users to express complex queries, visualize and analyze spatial information, as well as edit it.

Maps available on the web, for spotting an address or getting transportation information, are popular but allow only simple queries.

However, recently, a new type of mapping systems emerged; highly responsive mapping frameworks providing API (Google[4], Yahoo[5], Mapquest[6], etc.). They are also usually enhanced with "reality effects" – e.g. seamless transition between maps, satellite and hybrid views, 2.5-3D visualisations, street level photography, etc. – which make them even more appealing. API allow developers to populate online maps with custom information – location of "events" or "things" –, by collecting data from standard documents such as RDF files, or simply by ad hoc "web scraping" of HTML resources. These embryonic but very agile *Web GIS*, called *mashups*, can merge more than one data sources and add functionality such as filtering and search features.

However, although extremely popular[7], relatively easy to build and to enhance, Web GIS do not avoid traditional issues attached to non semantic applications; indeed (i) handling data heterogeneity still requires considerable manual work, (ii) the lack of semantics limits the precision of queries, and (iii) limited expressiveness usually drastically limits functionality [13].

---

[4] http://www.google.com/apis/maps/

[5] http://developer.yahoo.com/maps/

[6] http://www.mapquest.com/openapi/

[7] cf. http://googlemapsmania.blogspot.com/ for a number of mashups using Google Maps API.

2.3   A Semantic Web GIS Proposal

A *Semantic Web GIS (SWGIS)*, as sketched in [13], is a system which answers geographically oriented queries in a smart way while integrating multiple and heterogeneous information sources. As such, it needs to address the previous issues. In order to achieve this, a multi-layered architecture is needed (Fig. 1). The elements of this architecture will be discussed in turn.
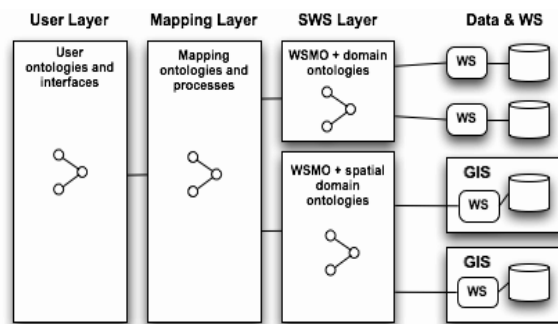

Fig. 1. A schema of the proposed Semantic Web GIS framework.

Data and Web Services Layer. The WS layer allows distributed datasets to be accessed through the network. They also hide the underlying relational access interface to provide simpler but well defined query operations.

Semantic Web Services Layer. The operations provided by the WS layer can be semantically described using the WSMO framework. However the spatial domain ontology to use is far from generating consensus. Several ontology modelling solutions have been explored in the literature [15]; typically, top-level spatial ontologies include models of topology and mereology (the formalization of *part-of* relationships), but point based set theory can also be used as a fundamental structure [16], moreover the ontological status of typical geographic objects such as *regions*, *boundaries*, *processes* or *events* as opposed to more common entities is unclear ([8], [5]). The debate also involves the importance of *graduation* and *fields* for the representation of spatial concepts, as well as describes a hiatus between the scientific notion of space and its cognitive apprehension, mostly qualitative, as studied in the field of "Naïve geography" [6].

User Ontology Layer. Although conventional GIS exhibit various levels of graphical user interface complexity, as well as custom query languages, accessing the underlying data level is often the only way to express complex needs, i.e. by using a database query language. Indeed, GIS usage can hardly be called intuitive and often requires from the user technical or even programming skills.

However, complexity has to be avoided in a semantic web context [3]. To allow this without loosing expressivity goal orientation should be combined with context in order to allow the user to access relevant goals at any moment. In SWGIS, we believe that attaching goals to objects, as described in an ontology, and using the sequence of goal invocation as well as the location of the query as a context may help simplifying the task of query specification.

Moreover, to efficiently support an activity such as emergency planning, precision is essential; only goals and data related to the emergency have to be displayed. Therefore an appropriate user ontology must capture the decision making process in terms of goals and relevant information.

Also, as the number of information sources increases, generic cognitive concepts have to be used since the user may not know beforehand what domain concept he is asking for. For example a request for "shelters" will only include heated accommodations in a snow storm context, but will have a different extension elsewhere.

From a user interface point of view, the SWGIS client may only know how to represent data up to a certain degree of specificity. To this purpose we are using a generic (archetypal) ontology including "image schematic" concepts, i.e. notions supposedly immediately understandable such as *container* or *link* [14].

In the future, qualitative reasoning features characteristic of "naïve geography" will also find room in the user ontology layer.

Mediation Layer. The mediation layer must allow a smooth and non destructive transition from the SRD and service description ontologies toward user oriented cognitively sound information, such as goals and schemas. For this purpose, this layer needs to transform some concepts but also offer an environment in which other concepts can merge, through inheritance or other multi-representation techniques, to allow multiple views of a same domain, and give the possibility of representing the same element differently according to semantic context such as task at hand, or spatial context, scale, or dimensionality (2-3D).


3   Description of the Prototype

The prototype was designed for the *Essex County Council (ECC) Emergency Planning Department*. The ECC is a large local authority in South-East England (UK). Following several interviews with SRD holders in the ECC it was decided to focus the scenario on the ECC Emergency Planning department, and more concretely, on an previous emergency situation: the snowstorm which occurred in the vicinity of Stansted airport on the 31st of January 2003. In order to avoid all interferences, data from the ECC Emergency Department and the Meteorological Office was replicated. This will also allow us to compare EPO' decisions regarding contact with rescue corps and voluntary associations, or actions necessary to provide refuge and supplies to trapped travelers, etc. – with those of the prototype users.

The EMS prototype is a decision support system, which assists the end user – currently the *Emergency Planning Officer (EPO)*, but we believe our design extensible to other emergency corps such as ambulance service, fire service, police, etc. – in gathering information related to a certain type of event, faster and with increased precision.

3.1 Architecture

Based on the SWGIS generic framework introduced in Section 2.4, we developed the following prototype architecture (Fig. 2).
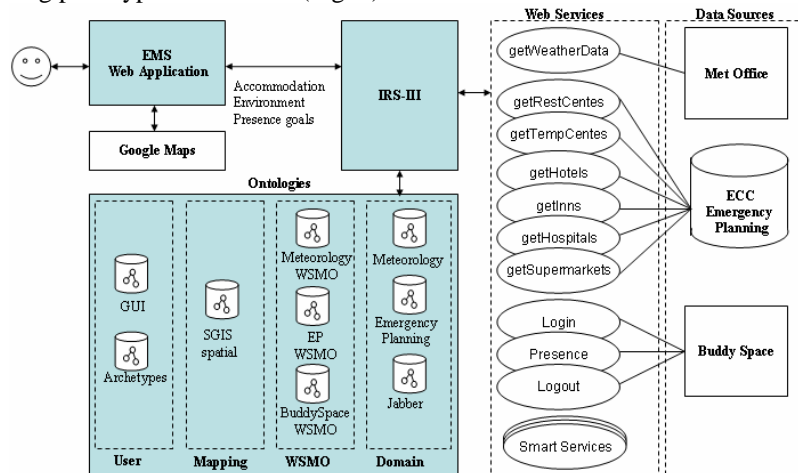
Fig. 2. Architecture of the EMS prototype. Dark boxes represent the main modules of the prototype, white ones are external distributed resources.

Data and functionalities of external information sources are exposed by means of *Web Services* (Section 3.3), semantically described by *Ontologies* (Sections 3.4 and 3.5), and accessible to the EPO through the *EMS Client* (as described in Section 4) which is a web interface using *Google Maps API*. At the heart of the system stands *IRS-III* (Section 2.2). At the moment, the system handles *accommodation*, *environment* and *presence* related goal invocations, discovering SWS that satisfies these goals, managing SWS orchestration and mediation, executing the WS, and returning mediated WS results.

3.2 Data

The EMS aggregates data and functionalities from three different sources:

- *Meteorological Office.* In the UK, it is an official provider of environmental data (e.g. weather forecasts).
- *ECC Emergency Planning.* A collaboration between ECC and British Telecommunications (BT) resulted in the creation and maintenance of a central spatial data repository for the usage of the County, and related agencies such as district councils. In the future it might be made available via the internet to the general public as expected by it[8]. We adopt this repository for SRD retrieval and in particular as source for accommodation information regarding structures that may qualify as shelters during an emergency.

---

[8] http://technology.guardian.co.uk/weekly/story/0,,1731386,00.html

- *BuddySpace.* An Instant Messaging client built on top of the instant messaging protocol *Jabber*[9] and providing lightweight communication and collaboration means [12]. It allows: (i) presence management, (ii) customizable and interactive graphical visualizations (e.g. maps), (iii) automated contact list generation which facilitates access to a community, and (iv) a high degree of scalability. Additional context information can be pushed or requested from location-aware technology or knowledge of a particular community. Filtering of such contextual information, provided by BuddySpace, allows users or systems to find relevant people (functional role and spatial position) in a given emergency situation, and to easily interact with them through text chat. Interestingly enough in an emergency situation, BuddySpace client interfaces can be accessed using smartphones and other handheld devices.

All data sources and functionalities are described and bublished in IRS as Semantic Web Services.

3.3 Services

We distinguish two classes of services: *data* and *smart*. The former refers to the three data sources described above, and are exposed by means of WS:

- *Meteorological Office services* provide weather information (e.g. snowfall) in specific spatial areas.
- *Emergency Planning services* provide the SRD with information about *primary* and *temporary rest centres*, *hotels*, *inns*, *hospitals*, and *supermarkets*. Each WS requires a query area as input, and return the list of required shelters in that area, together with their properties, such as address, key holder, telephone number, etc. The query area is a circle represented by the centre point (in longitude and latitude) and a radius, but can also by a polygon represented by its edges' coordinates.
- Finally *BuddySpace services* allow the EPO to *connect* to the Jabber network, and retrieve the list of relevant *presences*.

Smart services represent specific emergency planning reasoning and operations on the data provided by the data services. They are implemented in Common Lisp and published by means of IRS-III. In particular, we created *Filter Services* that select SRD responding to emergency-specific requirements (e.g. rest centres with heating system, hotels with at least 40 beds, easy to access hospital, etc.). They capture the EPO selection criteria and protocols. As a result the user retrieves only the most suitable information in a specific situation.

Services communicate with IRS-III through XML/SOAP messages. To get the information up to the semantic level (ontology instances), IRS-III implements a *lifting/lowering* module; by defining specific lifting functions, it is possible to create instances of the relevant ontologies by *lifting* information from the XML output data of WS. Inversely, a *lowering* function allows to create XML data inputs of WS from ontology instances. Through lifting WS results are attached to domain ontologies,

---

[9] http://www.jabber.org/

then through lowering, they are all converted to an XML format understandable by the interface.

3.4 Ontologies

The following ontologies have been developed to semantically support the EMS SWGIS system. For each ontology we specify where they fit in the SWGIS framework described in Section 2.3:

- *HCI Ontology*: part of the user layer, this ontology is composed of HCI and user-oriented concepts. It allows to further specialize the lowered results on the particular interface which is used (e.g. stating that Google Maps API is used, defining "pretty names" for ontology elements, etc.).
- *Archetypes Ontology*: part of the user layer, this is a minimal ontological commitment ontology which tries to provide a cognitively meaningful insight into the nature of a specialized object; by conveying the cognitive ("naïve") feeling that for example an hospital, as a "container" of people and provider of "shelter" can be assimilated to the more universal concept of "house", which we consider to be as an *archetypal* concept, i.e. based on image schemata and therefore supposed to convey meaning immediately [14]. It is moreover assumed that any client, whilst maybe lacking the specific representation for a specific basic level concept, knows how to display such archetypes.
- *SGIS Spatial Ontology*: part of the mediation layer, it describes high level but common concepts of GIS, such as points, spatial objects with attributes, polygons, and fields.
- *Meteorology, Emergency Planning and Jabber Domain Ontology*: representing the concepts used to describe the services attached to the data sources, such as *snow* and *rain* for Met Office, *hospitals* and *supermarkets* for *ECC Emergency Planning*, *session* and *presences* for Jabber. These are part of the domain ontology layer.

3.5 WSMO Descriptions

WSMO based Goals, Mediators, and WS descriptions of our prototype refer to the Met Office, ECC Emergency Planning, and BuddySpace WS. Goal descriptions are using user ontologies, while Web Service descriptions are linked to domain ones. Finally, mediators link goal and web services of each ontology, solving existing mismatches.
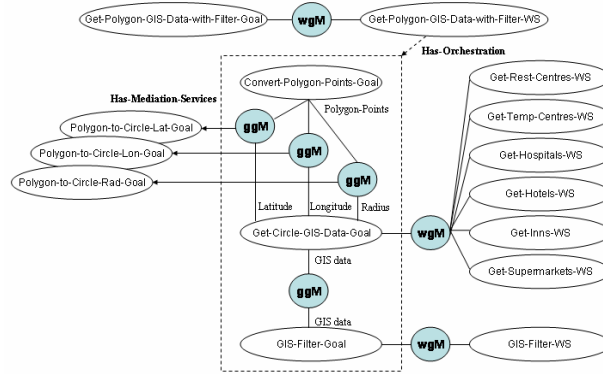
Fig. 3. Structure of the WSMO description of the EMS prototype. To avoid cluttering the diagram, wgM and Web Services balloons were omitted.

To illustrate this interaction we describe in the following (Fig. 3) the structure of the WSMO descriptions associated with one of the goals, *Get-Polygon-GIS-data-with-Filter-Goal*. This goal describes the request of a class of shelter (hospital, inn, hotel, etc.) in a delimited query area. The user (i) specifies the query area through a sequence of at least three points (a *polygon*) before (ii) selecting the requested class of shelter, while ECC Emergency Planning's WS returns the specific class of shelter in a *circular* query area. The results also have to be filtered in order to return only shelter relevant to the specific emergency type (in our case, a snowstorm). The problems are: (1) *selection* of the adequate WS; (2) *mediation* of the different area representations (polygon *vs* circular); (3) *orchestration* of the retrieve and filter data operations. IRS-III offers approaches to solve these problems:

- *WS Selection*: each WSMO description of WS defines, in its *capability*, the specific class of shelter that the service provides. All descriptions are linked to *Get-Circle-GIS-Data-Goal* by means of a unique *wg-mediator (wgM)*. The goal expects as input a class of shelter, and a circular query area. At invocation time IRS-III discovers through the wgM the WS associated to it. Then it selects one amongst them according to the specific class of shelter described in web-service capabilities.

- *Area mediation and orchestration*: *Get-Polygon-GIS-data-with-Filter-Goal* is associated to a unique web service that orchestrates – here, invokes in sequence – three sub-goals. The first one simply gets the list of polygon edges from the input; the second is the above mentioned *Get-Circle-GIS-Data-Goal*; and finally the third invokes the smart service that filters the list of GIS data. The first two sub-goals are linked by means of three *gg-mediators (ggM)* that convert the list of polygon edges provided by the first sub-goal to the centre (latitude and longitude) and radius of the circle that circumscribes that polygon. To accomplish this, we created three mediation services invoked through *Polygon-to-Circle-Lat-Goal*, *Polygon-to-Circle-Lon-Goal*, and *Polygon-to-Circle-Rad-Goal*. The results of the mediation services and the class of shelter are the inputs of the second sub-goal. A unique ggM connects the output of the second to the input of the third sub-goal. No mediation service is necessary.

4   EMS Prototype Interface

The EMS prototype's user interface is web standards based, using *xhtml* and *css* for presentation. *JavaScript* is used to handle user interaction as well as *AJAX* techniques for IRS-III goal invocation. The significant components of the interface are a central *map*, which uses Google Maps API to display *polygons* and *objects* (custom images) at specific coordinates and zoom level. Objects are attached to *goals* and *attributes*, which are displayed in a pop up window or in a hovering transparent region above it.
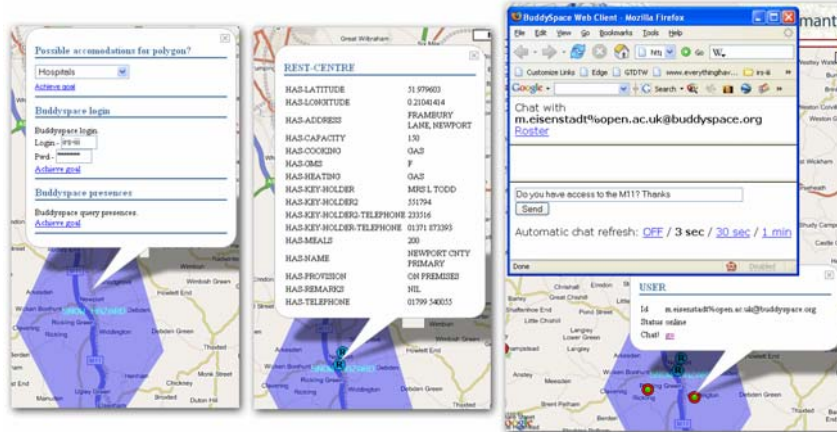
Fig. 4a, 4b and 4c: once defined the area present goals which can be queried to obtain objects and allow further interaction.

As an example of practical usage, we describe how an EPO describes and emergency situation (a *snow hazard* or a *snow storm* each offering different goals), before trying to contact relevant agents. The procedure is as follows:

1. Based on external emergency information the EPO draws a polygon on the map, then assigns a type of emergency to the region. Here, *a snow storm*.
2. Described in an ontology, the new instance has attached *features* and *goals*. Here three goals, one *gets shelters* at distance from the area, two others *connect* to BuddySpace and *get relevant presences*. (Fig. 4a)
3. First, the user requests all *rest centres* inside the region, they are retrieved with their features and attached goals. (Fig. 4b)
4. With that information the EPO *logs* into BuddySpace, then *contacts* the relevant persons to requests action or information. (Fig. 4c)

A screencast of the interaction as well as a live version are available online[10].

---

[10] http://irs-test.open.ac.uk/sgis-dev/

5   Conclusion and Future Work

In this paper, we describe an ongoing project. Improvements will include adding data dynamic sources (e.g. GPS trackers), extending the ontologies, and verifying that changes integrate naturally at the user level.

However the SWGIS framework we designed and used is operational and proved useful. We believe that this project demonstrates how the Semantic Web - and specifically SWS based systems – can be applied to improve spatial frameworks notably in e-government contexts. Immediate advantages of such an approach are:

1. Automatic selection of the most suitable resources based on current use case.
2. Easing interoperability amongst several SRD providers.
3. Improving the scalability, flexibility, and maintainability of the system.
4. Capturing EPO selection criteria and processes through ontologies for further use.

The final product of this project will be used in ECC. Its usage could be extended to highway agencies, transportation as well as airport authorities. In the long term the SWGIS framework could be opened to citizens in order to provide seamless access to geographic data stored by government agencies.

References

1. Domingue, L. et al. IRS-III: A Platform and Infrastructure for Creating WSMO-based Semantic Web Services. (2004)
2. Gruber, T. R. A Translation Approach to Portable Ontology Specifications. (1993)
3. O. Lassila T. Berners-Lee, J. Hendler. The semantic web. (2001)
4. A. Gugliotta, et al. A Semantic Web Service-based Architecture for the Interoperability of E-Government Services. (2005)
5. R. Casati et al. Ontological tools for geographic representation. (1998)
6. M. J. Egenhofer and D. M. Mark. Naive geography. (1995)
7. D. Peuquet, B. Smith, and B. Brogaard. The ontology of fields. (1999)
8. B. Smith. On drawing lines on a map. (1995)
9. Klischewski, R. Semantic Web for e-Government – a Research Agenda. (2004)
10. Semantic Interoperability Community of Practice (SICoP). Introducing Semantic Technologies and the Vision of the Semantic Web. (2005)
11. F. T. Fonseca and Max J. Egenhofer. Ontology-Driven Geographic Information Systems. (1999)
12. M. Eisenstadt, J. Komzak, M. Dzbor. Instant messaging + maps = powerful collaboration tools for distance learning. (2003)
13. V. Tanasescu, Toward User Oriented Semantic Geographical Information Systems. (2006)
14. D. Mark. Cognitive Image-Schemata for Geographic Information: Relations to User Views and GIS Interfaces. (1989)
15. Agarwal, P. Ontological considerations in GIScience. (2005)
16. Galton. A. A formal theory of objects and fields. (2001)