Development of GIS Interoperability Infrastructure in Local Community Environment

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Key words: interoperability framework, GIS, mediation, spatial data infrastructure.

SUMMARY

Increasing number of geodata producers and users in local community environment have expressed the need for the integration of geodata from distributed information sources and for interoperable GISs. The systems that own this data must be capable of interoperation with systems around them, in order to make access to this data to become feasible. The system also must deal with issues unique to geospatial data. In this kind of environment, the interoperable organizations will be visible, usable and customer focused, whilst still maintaining their own unique branding within the portals through which their content is available.

In our local community environment (city of Nis, Serbia) integrating geodata from various sources increasingly becomes important because of growing environmental concerns, pressures on governments and businesses to perform more efficiently, and simply because of the existence of a rapidly growing body of useful geodata and geoprocessing tools.

In this paper we present research in Geographic Information Systems (GIS) interoperability. We will suggest and discuss possible future technological scenarios for realization of interoperability.

Result of our research activities is realization of a GIS semantic interoperability platform called GeoNis. GeoNis interoperability platform also includes tools and software Web applications/components (as part of development framework called GINIS), enabling exchange of spatial information between organizations in local community environment. Significance of our work is based on usefulness of GeoNis tools and components for realization of interoperable geo-spatial information nodes in local community organizations.

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1. INTRODUCTION

In recent years, large number of diverse, distributed and heterogeneous information sources (databases, knowledge bases, collections of documents, etc), become available over the Internet. The exchange of information has become a crucial factor in today's economy. Many activities in business world involve different organizations that have to work together, and use existing information whenever possible, in order to reach a common goal. Similar situation is also in GIS and their applications.

The realization of interoperable systems is weighty process, as a consequence of two main system characteristic - distributed data sources and their heterogeneity (Genesereth 1997). Information systems heterogeneity may be considered as structural (schematic heterogeneity), semantic (data heterogeneity), and syntactic heterogeneity (database heterogeneity) (Bernard 2003)(Bishr 1998). Structural heterogeneity means that different information systems store their data in different structures. Semantic heterogeneity considers the content of an information item and its meaning. Semantic conflicts among information systems occur whenever information systems do not use the same interpretation of the information. Syntactic heterogeneity means that various database systems use different query languages (SQL, OQL, etc). Semantic interoperability is a very complex field of research, especially in the GIS world.

Interoperability in general, and especially semantic interoperability, will lead to dramatic organizational changes in GI community. Integration of diverse information sources has many advantages:

- Quality improvement of data due to the availability of complete datasets.
- Improvement of existing analysis and application of the new analysis.
- Cost reduction resulting from the multiple use of existing information sources.
- Avoidance of redundant data and conflicts that can arise from redundancy.

The paper is structured as follows. In the second part, we describe related work in interoperability and mediation. The goal is to explore how these approaches can be scaled to the global interoperability context. The primary goals of our research activities, described in the third part of this paper, are to define architecture for integration of distributed and heterogeneous GIS data sources and to add integration technology to the existing framework. We examine a research whose final goal is to make heterogeneous and distributed data sources to work together. Proposed platform uses agent-wrapper and mediator technology to allow communications between GIS applications over the Internet/Intranet. The problem of semantic heterogeneity will be resolved by combining concepts of mediation and ontologies.

2. RELATED WORK

Research in information systems interoperability is motivated by the ever-increasing heterogeneity of the computer world. Complexity and richness of geographic data and the difficulty of their representation raise specific issues for GIS interoperability. The need to share and interchange geographic information is well documented (Vckovsky 1998). Increasing number of geodata producers and users have expressed the need for the integration of geodata and for interoperable GISs. From the perspective of geography these groups of users are named Geospatial Information Communities (GIC) (Buehler 1998). Each GIC is a group of users that shares a digital geographic information language and spatial feature definitions. Members of each community have mutual agreement on the most basic concepts. In decision-making process they often have the need for the geodata from distributed GIS sources. Each of these user groups has a different view of the world and available information is always distributed and mostly heterogeneous.

GIS interoperability has to overcome complexity of sharing and integrating data between systems with different data structures and models. This has become more important due to the fact that spatial data modeling has been the focus of many research projects. As a result of these projects different spatial data models exists on the market today. GIS interoperability also has to deal with problems of semantic heterogeneity (Bishr 1999). Research in integration of GIS data sources considering that the barrier of integration has conceptual rather then technical nature.

GIS applications often have to process geodata obtained from various geoinformation communities. In that kind of environment problem of semantic heterogeneity often arise. In such cases there is a problem with correct interpretation of datasets obtained from different geoinformation communities. Very often different datasets can use different terms for same kind of information. On the other hand different datasets can use same term for completely different piece of information. These problems can lead to serious conflicts during discovering and interpretation of geographic data.

For example let's consider geographic information system in local community environment (Stoimenov 2003). In such environment, information provided by GIS application can have key influence on decision make by local community authorities. In many cases this decision are crucial for everyday functioning of the community and for short-term and long-term planning of local community development. Geographic information, used during decision-making process, is originating from different organizations (local Telecom, water and soil service, transport service, power supply service, police and other local government services) in local community (*Figure 1*). The total number of geodata producers in local community environment is indeterminable and unlimited.

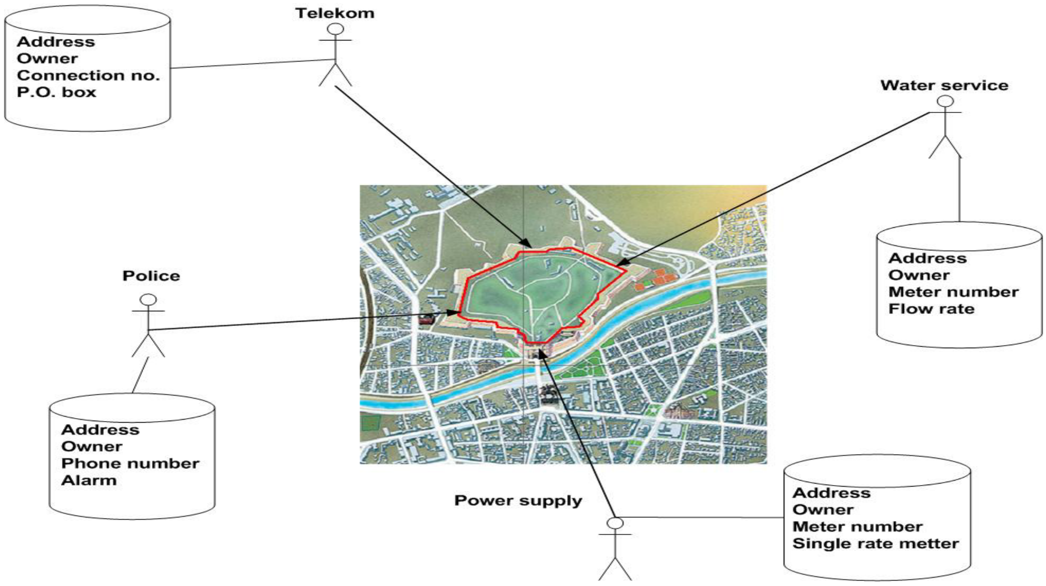

Figure 1 Local community environment

Very often, as shown in *Figure 1*, different organizations in local community are interested for same spatial object. But every organization has different view and different understanding of that object, and according to that produce different datasets that describes that object. Some attributes in this datasets are common for all organization in local community, some are common for few of them and every organization can have some specific attributes for dataset. At the same time different organizations can use different terms for same dataset attributes (synonyms) or same term for different dataset attributes (homonyms).

This is a problem of semantic heterogeneity and can lead to interpretation conflicts during interchanging of geodata. These conflicts can be resolved only by human intervention. Such situation can be acceptable only in case of small amount of data. But in cases of large amount of data (thousands of records) this process can be very tedious and ineffective. This process can be automated only if problems of semantic heterogeneity and interpretation conflicts are solved.

The first attempts to obtain GIS interoperability involve the direct translation of geographic data from one vendor or standard file format into another. However, these formats translations can lead to information loss. Alternatives that avoid this problem are usually more complex, like standards for spatial data interchange (such as Spatial Data Transfer Standard (SDTS) and Spatial Archive and Interchange Format (SAIF)). A broader discussion of geographic information exchange formats can be found in (Geographic Data Exchange Standards 2001). One of important strategies for interoperability is conversion of different data formats in common data structure. This kind of data structure is usually based on one of existing GIS standards.

One important initiative to achieve GIS interoperability is the OpenGIS Consortium (Open Geospatial Consortium 2005). This is an association looking to define a set of requirements, standards, and specifications that will support GIS interoperability. The objective is technology that will enable an application developer to use any geodata and any geoprocessing function or process available on ‘the net’ within a single environment and a single workflow. But, data standardization cannot solve the whole problem. The interoperability problem would go away if every system always uses the same data model to represent the same information (identical names, structure, and representations). OpenGIS standards will only partially solve this problem. There are several reasons why standardization will not be a complete solution:

- Constructing and maintaining a single, integrated standard data model is difficult problem.
- There will always be a requirement to communicate with information sources that do not conform defined data model standard (legacy systems).
- Existing, legacy information sources have own data models, and there are needs for data conversion from domain model to common model.
- The standard will change, but systems will not all simultaneously change to conform.

Making local geographic datasets available publicly and establishing a common interoperability framework over shared data interchange protocols are important parts of this research. However, there are institutional and technical problems of geodata sharing and interoperability. These problems have become the focus of international research and infrastructure efforts (Onsrud 1995)(Masser 1998). Also, several spatial data interoperability test beds have been developed - most notably are the Digital Earth Initiative (Digital Earth 2005) and OGC’s Web Mapping Testbed (Open Geospatial Consortium 2005)

A number of proven and well-established methods exist that allow heterogeneous data sources to communicate, including federated databases and schema integration (Larson 1998), object-oriented approaches (Chawathe 1994), data warehousing (Voisard 1998) and mediators and ontologies (Stoimenov 2000).

Mediator-based system is important for spatial data interoperability architecture. The 3-level architecture of mediator-based systems is constructed from an application layer, and large number of relatively autonomous information sources (heterogeneous data sources with wrappers), communicating with each other over a standard protocol (Wiederhold 1994). A wrapper is a program that is specific to every data source (Stoimenov 1999). Wrapper extracts a set of tuples from source file and performs translation in the data source format. The most important advantage is the fact that data integration system allows users to focus on specifying what they want rather than thinking about how to obtain the answers. As a result, it frees them of combining data from multiple sources, interacting with each source and finding the relevant sources. Nowadays, mediation concept is a part of the ARPA I3 (Intelligent Information Integration) reference architecture (ARPA 1995). The I3 reference architecture should be seen as a vision of how vast amount of heterogeneous information can be incrementally pulled into a gigantic, reusable library of information resources.

The use of ontologies as semantic translators is approach that can possible overcome the problem of naming conflict and semantic heterogeneity. Research on ontology is becoming increasingly widespread in the computer science community, and its importance is being recognized in a multiplicity of research fields and application areas, including knowledge engineering, database design and integration, information retrieval and extraction.

During past several years many different solutions for problems of semantic heterogeneity have been proposed (Bernard et al., 2003)(Klien 2004)(Stoimenov 2003). In this paper we proposed our ontology-based approach for discovering and retrieving geodata.

3. GEONIS PROJECT

GeoNis is a project that has to provide infrastructure, platform and software tools for data interchange in the local community environment. This project is developed with cooperation from Municipity of Nis and is partialy founded by Ministry of Science, Technology and Development, Republic of Serbia.

The goals of research activities in GeoNis project are:

- Defining interoperability architecture for integration of distributed and heterogeneous GIS data sources in local community environment;
- Defining a methodology and software support for resolving semantic conflicts in data from different information sources.

In order to to achieve interoperability, the first prerequisite is that individuals and organizations (i.e. Geographic Information Community - GIC) have knowledge of each others and of data which they possess. Second, there must be a willingness to make data available to users outside the source organization. Given that an organization is open to interoperability, it must announce its existence and willingness to exchange information. Then other individuals can discover the organization and assess whether there may be interest in accessing information. In order to achieve interoperability following six presumptions have to be fulfilled (Levinsohn 2005):

- *Simple* - users should not have to understand all details about the data or their source system to import and use them.
- *Transparent* - complexities associated with data transfer should be hidden from users.
- Open - interoperability should apply to all systems, and data exchange should be independent of the technology used.
- *Equal* – systems are equal and autonomous.
- *Independence* – systems have exclusive right to control its information and information processing without centralized control.
- *Effective* - data transfer should be reliable, and the resultant data should be useful for the intended purposes.
- *Universal* - all geospatial databases should be accessible.
- *Belonging* – each system belongs to one GI community, and has its own institution, policy and culture and value viewpoint.

Data sources are local services and offices that own geodata in some format. Specified communities own GIS application, often created with different GIS tools and with different underlying database management systems. GeoNis project for interoperability in local community environment implies several different prerequisites:

- Cooperation between participants
- Institutional willingness for realization of interoperability. All participants have to agree upon basic principles for realization of interoperability and to provide all needed data and resources.
- Infrastructure for realization of interoperability: network infrastructure (hardware and software), people, organizations and activities, rules and regulations for information exchange.
- Definition of communication protocols between participants
- Development of software tools for realization of interoperability
- Local information sources must be adapted in order to work properly in new environment.

The total number of geodata providers in local community environment is indeterminable and unlimited. This implies the need for a flexible approach that can deal with the existing and the future geodata providers in interoperable systems. A standard model for spatial data is the first step to approach the solution for schematic and syntactic heterogeneity. The Open GIS Consortium (OGC) specification aims to solve the problem of heterogeneity at the spatial data modeling level. Because of that, GeoNis uses OpenGIS standard as common data model to represent geodata on mediator level. Data models of local information sources are translated in common model using wrappers.

Semantic interoperability in GeoNis is the ability of sharing geospatial information at the application level, without knowing or, understanding terminology of other systems. The problem of semantic heterogeneity in GeoNis will be resolved by concept of mediation and ontology. A semantic translation is developed for a particular domain, in our case for GIS applications in local city services, which deals with network data structures (local Telecom with telephone cables, water and soil-pipe services, power supply services, etc.).

4. INTEROPERABILITY FRAMEWORK

GeoNis is framework for interoperability of GIS applications that have to provide infrastructure for data interchange in the local community environment (Stoimenov 2000). Data sources are local services and offices that own geodata in some format. A semantic translation in GeoNis is developed for a particular domain, in our case for GIS applications in local community services, which deal with network data structures (local Telecom, water and soil pipe services, power supply services, and some local government services) (Stoimenov 2003). Each type of information source requires a wrapper/translator that translates information flow between information source and GeoNis system. GeoNis solution to the problem of semantic heterogeneity is to formally specify the meaning of the terminology of each GIC using local ontology and to define a translation between each GIC terminologies (local ontologies) and an intermediate terminology (in top-level ontology). Architecture of GeoNis interoperability framework is described in (Stoimenov 2003)(Stoimenov 2002).

GeoNis is a generalized framework for GIS interoperability. The basic architecture of GeoNis framework is shown on Figure 2 (Stoimenov, 2003). GeoNis solution to the problem of semantic heterogeneity is to formally specify the meaning of the terminology of each GIC (i.e. local service or office) using local ontologies and to define a translation between each GIC terminology (local ontology) and shared domain terminology (in top-level ontology).

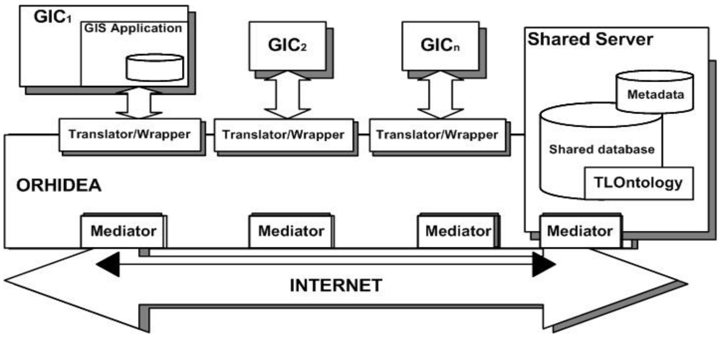

Figure 2 GeoNis framework for semantic interoperability.

In each node of GeoNis framework there exists GIS application and corresponding (spatial and non-spatial) databases. Data in local databases are accessible according to user privileges. Requests for specific data set are forward through local mediators. These applications may be either wrapped legacy applications or newly developed applications based on Ginis application development framework. The Ginis is a component-based, generic information integration framework for integrating existing local information sources. Information sources use the same ontology and there is not need for semantic translation in Ginis.

Developed platform has to provide (Stoimenov 2002):

- Integration of information from different sources with ability to add new information sources.
- Adaptation of existing data sources and queries without possibility for changing existing data.
- Independence of user applications from information sources
- Solving problems of semantic inconsistence between user requests and available data.

GeoNis generic architecture recognizes several different components that have important role in geoinformation discovering and retrieving process:

- GIC – every GIC contain GIS application and corresponding spatial data sources.
- Wrapper/translator - each type of information source requires a wrapper/translator that translates information flow between information source and GeoNis system.
- Data in local databases - accessible according to user privileges.
- Semantic mediators - requests for specific data set are forward through.
- Shared GIS server (Catalog Server) - maintains metadata and all shared/common geographic data as addition to domain oriented GIS applications.

According to GeoNis architecture every GIC environment can have several translators. There can be one translator for every information source in GIC environment. Translators can be implemented using different approaches and technologies. Ginis OLE DB data provider is an example of translator implementation (Stoimenov 2004). This approach (unified methods for data access) allows simply chaining of translators. Also we can easily add new information sources without influence on other GIC environments. In order to do this we have to provide semantic mapping only for the GIC environment with new information source. In this way we have simplified the problem of semantic heterogeneity.

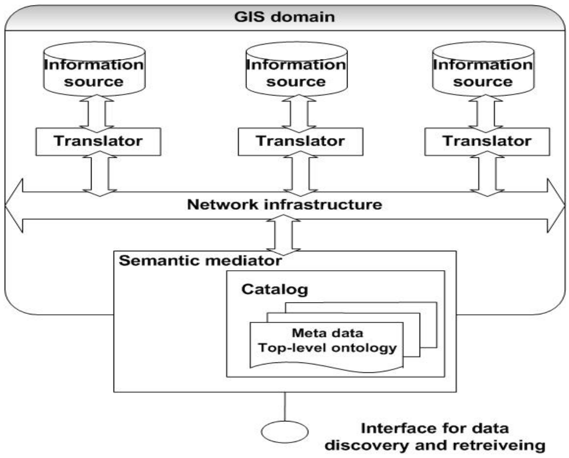

Figure 3 Domain oriented mediator role in GeoNis architecture

5. SEMANTIC MEDIATOR ROLE IN GEONIS FRAMEWORK

GeoNis architecture doesn't clearly define the role of semantic mediators and relations between semantic mediators and GICs. Let presume that we have a semantic mediator for a specific domain (for example, applications in local city services, which deal with network data structures such as Telecom, water and soil pipe services, power supply services, and some local government services). In such case we can threat semantic mediator as an access point for discovering and retrieving semantically heterogeneous data in that domain (*Figure 3*). If there are metadata and top-level ontology (share vocabulary) for a domain provided to a semantic mediator, it can provide semantic consistency for data from that domain and geodata exchange with terminology translation as described in GeoNis architecture.

Generic GeoNis architecture also allows chaining of the semantic mediators. Metadata and top-level ontology must be provided in order to integrate geodata from several different mediators (*Figure 4*). This metadata and top-level ontologies are maintained by shared GIS server (Catalog) as suggested by GeoNis architecture.

Common server owns information of top-level ontologies, interontology relations, ontology mapping rules and additional metadata information. Contained public information can be classified as follows:

- *user metadata*:
  - *user privileges* – user rights for accessing data in local GIC nodes or in common GeoNis server.

- *user profiles* – description of customized, intelligent, web-based user interface that is dynamically generated whenever user access data in local community environment.

- virtual organization metadata – local community structure description. Every new GIC who wants to participate in exchanging data must register with common GIS server in order to allow access to his public available data and local ontology. After that, users from registered GIC have access to all available data from other public GIC databases and access to shared data owned by shared GIS server (with possible given rights for access).
- *top-level ontologies* – domain shared vocabulary and description of available data sets
- *ontology mappings* – describes mapping between top-level and local (application) ontologies.

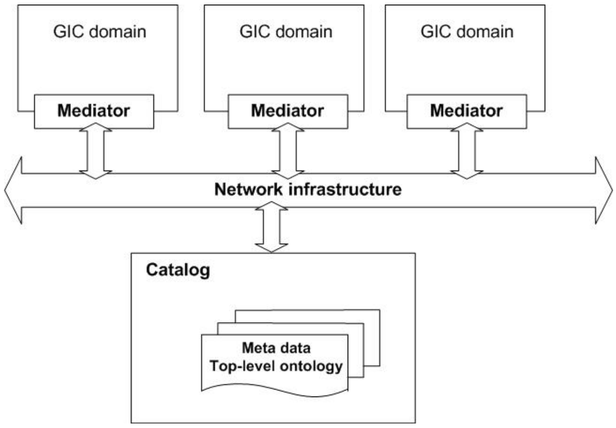

Figure 4 Semantic mediators chaining

OntoManager is a component that provides access to the shared metadata that resides on the common server. This component implements interfaces that provide means for discovery, access and management of metadata to the rest of the community. Interface *Publish service* allows GIC nodes to register their data and services and to create relations between their local ontologies and top-level ontologies. Interface *Query service provides* functionality for locating and accessing requested metadata.

All access to geoinformation in local community environment goes through *Web Feature Service* (*Figure 5*) defined by proposed OGC technology standards (Open Geospatial Consortium 2005). We enhanced this interface with additional functionality in order to support user profiles and privileges. This interface is implemented by *Semantic Mediator* component. This component acts as an access point for a number of independent geoinformation sources and allows integration of their information bridging over the semantic differences among them. *Semantic Mediator* enables users to access multiple information systems as though they were a single system with a uniform way to retrieve information and perform computations. It accepts high-level requests from users and automatically translates them into a series of lower-level requests for different GICs. Results of this low-level request are then combined into a result for a high-level request. In order to accomplish this task Semantic Manager must use metadata information, provided by *OntoManager* services, in order to discover every concept (top-level or local) in environment that can be targeted with user request.

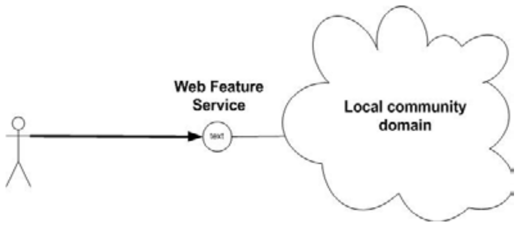

Figure 5 Access to geoinformation in local community environment

Intelligent UI component dynamically generates web-based user interface according to user privileges and user profiles. This interface allows users to query local community for metadata and geodata according to their privileges.

Interaction between components and information flow during semantic mediation is illustrated on *Figure 6*. When user wants to retrieve some information from local community environment, first, he has to logon on the system. According to his user profile and privileges *Intelligent UI* component builds appropriate Web based interface. This interface also includes tools that can help user to build query using top-level concepts obtained from local community environment.

In the second step user can query environment for geoinformation that he is interested in. In order to provide requested data, *Semantic Mediator* must analyze user query and discover every concept (feature) in environment that fits to user request. This analysis is done by *OntoManager* which builds *FeatureSchema*, metadata information that contain description and location of every concept (feature) in environment that can be treated as a result of a user query. Using this schema information, *Semantic Mediator* retrieves data from local GIC nodes and builds result dataset that is forwarded to the user, as a response to his query, in the form of a GML document.

6. CONCLUSION

Being seen to "be interoperable" is becoming increasingly important to a wide range of organizations, including central and local government. Increasing number of geodata producers and users in local community environment have expressed the need for the integration of geodata from distributed information sources and for interoperable GISs. In our local community environment (city of Nis, Serbia) integrating geodata from various sources increasingly becomes important because of growing environmental concerns, pressures on governments and businesses to perform more efficiently, and simply because of the existence of a rapidly growing body of useful geodata and geoprocessing tools. In this new environment, the interoperable organizations will be visible, usable and customer focused, whilst still maintaining their own unique branding within the portals through which their content is available.

Significance of our work is based on usefulness of GeoNis tools and components for realization of interoperable geo-spatial information nodes in local community organizations. A fully interoperable organization is able to maximize the value and reuse potential of information under its control. It is also able to exchange this information effectively with other equally interoperable bodies, allowing new knowledge to be generated from the identification of relationships between previously unrelated sets of data. In this paper we will suggest and discuss possible future technological scenarios for realization of interoperability.

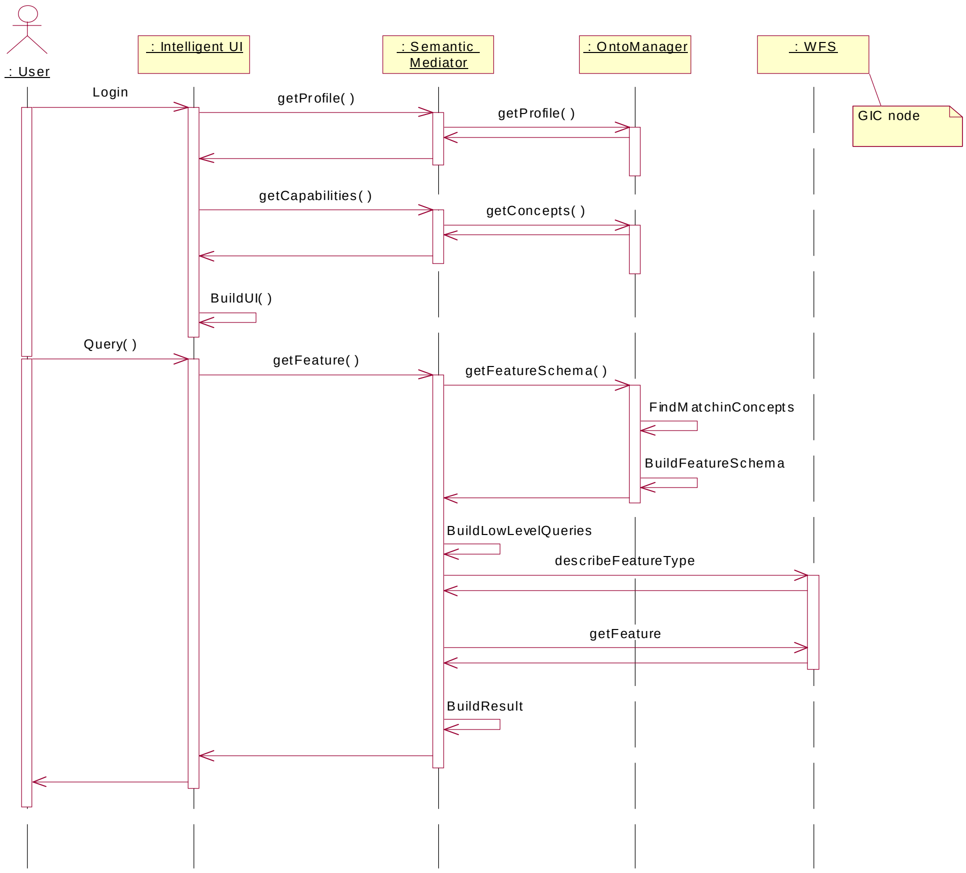

Figure 6. Semantic mediation of geoinformation

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Leonid Stoimenov received the BSc, MSc and PhD degrees in computer science at the University of Niš, Serbia. He is currently an associate professor in the Department of Artificial Intelligence at Faculty of Electronic Engineering at this University. His research interests in computer science include GIS, databases, mediators, ontologies and semantic interoperability. He is a member of IEEE and representative in AGILE association of GIS laboratories in Europe.

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