Semantic Web GIS Services for Cultural Heritage Domain

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***Abstract*—World is a collection of objects of cultural and natural heritage resources. Every human activity happens somewhere and sometimes. Each application projected in the Cultural Heritage sector takes a different view of the time period of the Cultural Heritage resource. In other words, projects belonging to the same time period but different geographical locations could be correlated with each other. However, users from all over the world are still faced with the perennial problem of finding those resources that will be most relevant to any particular research project. Cultural Heritage documentation is definitely going digital, but this trend may not be able to solve the problems arising when it is desired to perform e-heritage solutions in order to share Cultural Heritage knowledge. On the other hand, Cultural Heritage is a promising application domain for semantic web technologies due to the semantic richness and heterogeneity of cultural content. In this study, a coherent and standardized architectural framework -'GeoGCHEAF- has been designed as a "Semantic Geospatial Information System (GIS) Services" and proposed to the Cultural Heritage domain.**

Keywords-cultural heritage; geospatial informatics; semantic web technologies; ontologies.

I. INTRODUCTION

Clues from the past life styles and habits of the mankind have always been interesting and valuable to people who are living on the same land at different time. Documentation and protection of the historical places and structures is not only a local or national issue, but also a global interest to keep the memory of the past of the mankind. Discovering and comprehending habitats and creations of mankind in the past, not only adds to knowledge, but also unfold rich heritage setting conservation responsibilities for societies. The expectations from the local, national and international authorities are highly increased to protect the historical areas for the next generations. Currently, numerous Cultural Heritage (CH) recording, documentation, conservation, restoration, reconstruction, renewal, rehabilitation, digital preservation projects, etc., are in progress [1].

Archaeologists may be committed to studying the past, but their use of technology is quite up-to-date so that digital heritage, e-heritage, digital archaeology, virtual archaeology and open archaeology are fast-moving fields. In the digital age with ever-increasing quantities of CH data being collected, stored, and distributed in computer-readable forms, interconnection of information is becoming essential.

Organizations from across the CH sector have been able to take advantage of Information and Communication Technology (ICT) to offer new forms of access to their resources for users. They are creating geoservices, moving from data sharing to sharing resources, such as maps, models, data, content, knowledge. Many web-based GIS applications of CH resources are being designed and implemented all over the world. However, users from all over the world are still faced with the perennial problem of finding those resources that will be most relevant to any particular research project. Furthermore, it is difficult for the data/information/content/application/service to be integrated because it is stored in stove-piped systems or because two CH communities use different terminology to describe the data/information.

To conclude this, the "Geo-enable Global Cultural Heritage Enterprise Architecture Framework (GeoGCHEAF)", a global internet-connected spatially-enabled CH sharing network based upon the open standards and semantic technologies, has been specifically designed to expand communication and dissemination of the CH data, information, knowledge, content, applications and services to the different levels of users and the public.

The aim of this study is to promote the digital preservation, integrate the heterogeneous sources using semantic web technologies and make them available primarily to a wider audience of researchers, specialists and decision makers but also to the general public in order to foster wider understanding of the past.

The rest of this article is structured as follows: Section II discusses why Semantic Web technologies are needed in the CH domain. Section III explains the use of ontologies in the CH field. The article concludes by presenting conclusions and recommendations.

II. MOTIVATION

CH data, information, knowledge, content management and research are inherently distributed among many users, projects, organizations, systems, enterprises, applications and services. Each CH organization develops some, but not all, of its data/information content. At least some of the resources come from outside the organization. Moreover, many of today's CH organizations rely on digital ICT to gather, organize, interpret, and disseminate data, information and knowledge relating to their various projects. In many cases, this involves applications and services that were

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created at different times and designed for heterogeneous hardware and software platforms. The challenge now faced by these organizations is not only data, information, content distributed management, but also the CH organizations increasingly face the challenge of providing efficient and effective methods, such as integrating various distributed open web services, loosely-coupled applications, geoinformation technologies and infrastructures for CH resources into a single semantic interoperable framework, by which these disparate technologies can work together to achieve academic and/or commercial objectives that are constantly evolving [2].

Not only spatial data/information sets, topographic and thematic maps, vector and raster layers but also demographic data, geo-demographic data, census data, archaeological, architectural, historical information (including date of recording, recording by, structural changes (e.g., shape, size, width, length, height), construction date-material, technique, archaeological finds (e.g., ceramic, lithic, metal, textiles, bone) and other geodata/geoscience data (e.g., geomorphological information, earthquakes, fault zone maps, climate change information), and GIS files/contents are shared via open standard data and information formats, such as Extensible Markup Language (XML), Geographic Markup Language (GML), compact GML (cGML), CityGML, Keyhole Markup Language (KML), Geospatial JavaScript Object Notation (GeoJSON), Web Ontology Language (OWL) and services on the web through a geoweb portal among CH scientific community, decision-makers, NGOs, field teams, authorities and public. This is because long-term conservation depends on the involvement of people from all levels, from government structures to experts to public.

III. SEMANTIC ARCHITECTURE

A. *Semantic Approach*

The key to faster, better, discovery of CH information is metadata, which can be quickly and thoroughly searched by computers and presented in an understandable form to users. Therefore, the CH domain needs standardized metadata entries (e.g., Resource Description Framework, RDF) and a standard metadata framework or frameworks (e.g., RDF Schema, RDF-S). CH spatiotemporal data, information, content and application are encoded and presented with a structured XML document along with its standard CH-specific & CH community-wide defined schema, such as XML CIDOC-CRM, MidasXML, OCHRE (formerly XSTAR), ArchML, Dublin Core or combinations of these, rather than a common XML schema, that can be validated to ensure data integrity and coherence without the need for human interaction. The benefits of an ontology-driven database search are potentially enormous. Effective XML-based data/information integration among the distributed heterogeneous systems, applications, databases, web portals/portlets, data providers and CH specialists are performed through ontologies (e.g., OWL).

When conducting online portlet-based research, aggregating information from these searches across the different datasets, and making data available from different sites in different locations for different user groups need dynamic interoperable data sharing on a global scale for the CH domain via XML-formatted datasets. Whichever method is used to support technical interoperability, including data, information, application, services, process, policy and rules interoperability, web-portals with portlet specifications/protocols (e.g., Java Specification Request (JSR), Web Services for Remote Portlets (WSRP)) also need to achieve semantic interoperability between databases to return useful sets of results to its users to share information on the semantic web.

Ontologies play a critical role in associating meaning with data such that computers can understand enough to meaningfully process data automatically. Compared to syntactic means, the semantic approach leads to high quality and more relevant information for improved decision-making. Equally important is the use of ontologies to achieve shared understanding. Ontologies are also evolving as the basis for improving data usage, achieving semantic interoperability, developing advanced methods for representing and using complex metadata, correlating and integrating information, knowledge sharing and discovery.

Ultimately, ontologies can be an important tool in expediting the advancement of related sciences, and they can reduce the cost by improving sharing of information and knowledge. In such an architecture, distributed repositories can be searched and relevant information according to user specified criteria are found and merged by means of an intelligent web agent or web services through the semantic web. For instance, a sort of specific artifact in the Ottoman fortresses of “Seddülbahir” and “Kumkale” belongs to 17th century can be searched in different CH projects’ databases and portals, digital archives, museum collections and old antiquarian reports [3].

The goal of the semantic architecture of “GeoGCHEAF” is to develop a semantic solution for providing a great level of geospatial semantic interoperability, enabling knowledge sharing and geospatial information integration at different levels of granularity. This open and interoperable semantic solution based on the explicit use of geo-ontologies through geospatial semantic web also provides a cooperative human-computer environment for the composition of spatial- and context-aware semantic web applications in a dynamic and flexible manner within the Internet-connected CH domain. While such a semantic approach facilitates geospatial information storage, search processes, query formulations and retrieval models on the heterogeneous distributed repositories, the ultimate goal of this architecture is to develop knowledge-based spatial information web services for the CH domain [3].

If different web sites that contain CH information share and publish the same underlying ontology of the terms they all use, then computer agents can extract and aggregate information from these different sites. The agents can use this aggregated information to answer user queries or as input data to other applications. This enables the communication and collaboration inside the CH domain and among the domains and improves understanding of how different CH enterprises exchange geospatial information.

B. Ontology Design Methodology

There is no single correct way or methodology for designing ontologies. Ontology design is a creative process of modeling the given domain, by choosing the most important concepts and identifying the most relevant relations between them. Hence, no two ontologies designed by different modelers would be the same. The potential applications of the ontology and the designer's understanding and view of the domain will undoubtedly affect ontology design choices. The quality of the ontology can be assessed only by using it in applications for which it was designed. Thus, an iterative process has been addressed to ontology design methodology in this research. It is started with a rough first pass at the ontology. Then, the evolving ontology is revised and refined, and filled in the details. Along the way, the modeling decisions that a designer needs to make, as well as the pros, cons, and implications of different solutions are discussed. That is, deciding what the ontology is going to use for, and how detailed or general the ontology is going to be will guide many of the modeling decisions down the road. Among several viable alternatives, it is needed to determine which one would work better for the projected task, be more intuitive, more extensible, and more maintainable. It is also needed to remember that an ontology is a model of reality of the world and the concepts in the ontology must reflect this reality. After the initial version of the ontology is defined, users can evaluate and debug it by using it in applications or problem-solving methods or by discussing it with experts in the field, or both. As a result, it is almost certainly needed to revise the initial ontology. This process of iterative design will likely continue through the entire lifecycle of the ontology [4].

For the purposes of this research an ontology that helps to present objectivity as agreement about subjectivity is a formal explicit semantic definition of set of concepts and relations in the CH domain. The methodology for designing ontologies attempts to establish the types of objects (e.g., fortress, mosque, tower); relations (e.g., Hadice Turhan Sultan built the fortress, commander managed the fortress); events (e.g., World War I, repairment of the structures); and processes (e.g., deterioration, architectural changes) at different levels of scale and granularity, from out of which the geospatial domain is constituted. In order to resolve the conceptual and terminological incompatibilities on case-by-case basis, developing such an ontology, once and for all, includes:

- Underlying conceptualization (conceptual ontologies): Determination of what is wanted to model, checking whether existing ontologies can be reused, if there is, drafting the ontology by making use of existing one. Embracing conceptual issues concerning what would be required to establish an exhaustive ontology of the geospatial and CH domains. Establishment of explicit formal and consensual specification of the concepts with their definitions and the relations among them populating in the CH domain. Underlying conceptualization can be performed by interacting with the specialists in the area of the application, such as scientists/researchers/ontologists from CH domain.
- Ontological commitment to this conceptualization (CH domain-specific logical ontologies): Determination of what certain terms mean in the CH domain and what terms the CH community uses for certain concepts. Preparation of the robust, comprehensive and shared taxonomies (canonical reference taxonomy) of the terms exisiting in the CH domain, which are sufficiently detailed to capture the semantics of the CH domain, and definition of classes and properties.
- Geo-ontological commitment to the abstraction (Geospatial domain-specific logical ontologies): Representations of classification of geospatial entities of real world/spatial phenomena (canonical formalization), their properties and relations within geospatial domain.
- Logical statements (semantic relations): Generation of the rich (thematic-spatial-temporal) relationships among the classes within the CH domain and between geographic entities/features within the geospatial domain.
- Associative relations: Synonymy, hyponymy, hypernymy, and antonymy are semantic relations defined between related words and word senses. Synonymy (syn same, onyma name) is a symmetric relation between word forms. Hyponymy (sub-name) and its inverse, hypernymy (super-name), are transitive relations between sets of synonyms. Antonymy (opposite name) is synonymous with opposite.
- Hierarchical relations (subclass–superclass relations)
- Inheritance or generalization/specialization or taxonomic relationships (superordinate-subordinate relationships): "is-a-kind-of" and "has-kinds" relationships
- Aggregation or partonomic relationships (part-whole relations): "is-a-part-of" and "has-parts" relationships
- Quantitative spatial relations
- Distance: quantitative distance relations (within a specified distance), for instance, space distance, such as "withinMetersOf", or time distance, such as "withinMinutesOf."
- Qualitative spatial relations (vague spatial relationships): includes relative locational properties of objects, such as containment, distance and directions, (near, north, between, inside, outside, in front of (a mosque), along (a street))
- Distance: qualitative distance relations
- Direction: the 8-sector model to express the cardinal directions North, NorthEast East, SouthEast, South, SouthWest, West, NorthWest, or isNorthOf, isLeftOf, isBehindOf
- Topological relationships: the OpenGIS Simple Features Specification of topological relations based on the Dimensionally Extended 9-Intersection Model Based on Components (DE-9IMBC), the ontology includes the following eight relations: equals, disjoint, intersects, touches, crosses, within, contains, and overlaps.
- Mereological relationships: Parthood relations, e.g., "isWholeOf", "isPartOf". Region Connection Calculus

(RCC-8) abstractly describes regions by their 8 basic relations: disconnected, externally connected, equal, partially overlapping, tangential proper part, tangential proper part inverse, non-tangential proper part, non-tangential proper part inverse.

- Semantic mediators (semantic translators): Connection between CH domain ontologies and geo-ontologies is made by semantic mediators.
- Formalizing ontologies (translating ontologies into ontology-derived classes): An object-oriented mapping of multiple ontologies to the system classes. Translation of the ontologies specified in a standard, system-independent form into classes that are specific computer language representations, that is, machine-interpretable definitions of the concepts. Ontology-derived classes are software components that can be used to develop applications and they are fully functional classes with all the operations that can be applied to entities.
- Defining slots and describing allowed values for these slots: Each class describes various features and attributes of the classes and instances.
- Implementation: Establishment of the mapping between information sources and the common ontology. Mapping the ontology into the basic data models and representations necessary for scientific computing about CH domain and geospatial phenomena, and semantic associations in applications that integrate data, metadata, and knowledge queries.
- Creating a knowledgebase: Creating a knowledgebase by defining individual instances of these classes. Filling in specific slot value information and additional slot restrictions for instances.
- Validation: Definition of test cases in the CH domain to validate the ontology being developed.

C. Implementation Methodology for Building Ontologies

Protégé [5] has been chosen to use as an ontology-development environment to specify the ontologies since it is free, open source, and supports a wide variety of plugin and import formats, such as Web Ontology Language (OWL) [6] and RDF-S [7]. In addition, OWL has been adopted as a web-based ontology language to present ontologies and represent knowledge. Semantic web contents and declarative frame-based ontologies in this research are being currently developed using the Protégé-OWL plugin. Protégé-OWL editor is able to present conceptual modeling of the CH domain, edit ontologies developed, create classes, slots, facets, and instances.

The Geographic Markup Language (GML) provides a syntactic approach to encoding geospatial information through a language in which symbols need to be interpreted by users, because associated behavior is not accounted for [8]. GML can be viewed as an alternative not just to geography in RDF, but to RDF itself. These are the differences, data model and type system. GML is built on the XML data model and the XML Schema type system. RDFMap and RDFGeom are built on the RDF data model, and RDF Schema or OWL can be used to express typing information. OWL is the appropriate choice for this job, since its expressiveness corresponds more closely to that of XML Schema. The application of RDF to geography is at an early stage, whereas GML is a mature effort. RDFMap combined with the companion RDFGeom language cover only a fraction of the ground covered by GML3 [9]. In this research, the GML of geospatial instances obtained from the spatial datasets has been translated into OWL using XSLT style sheet.

Fortress is a term in the CH domain ontology and “Seddülbahir Fortress” is an instance of the fortress that is-a-kind-of a CH site. The renovation project directors consider the fortress as a high-level ontology that a consensus can be reached about which are the basic properties of the fortress. From the point of view of this ontology, the fortress is an Ottoman architectural monument belongs to 17th century and built by Hadice Turhan Sultan at the entrance of the Dardanelles. The fortress can be seen differently by different systems, such as architecture sub-domain, archaeology sub-domain, art-historian sub-domain, etc. For the architecture sub-domain the fortress can be building. For the archaeology sub-domain it is an excavation site. For the art history sub-domain it is a recreation site. Although the conceptualization of the architectural sub-domain of the fortress is derived from higher level, architecture sub-domain has a view (building concept of the fortress, e.g., the structural characteristics of the buildings of the fortress) that is more detailed than the previous higher level. This is done using inheritance. Architecture sub-domain will have all the basic properties defined in the higher level ontology plus the add-ons that the architects think are relevant to their concept of fortress. The same happens with the other sub-domains. Inside the archaeology sub-domain, the section in charge of the excavation will have an even more detailed view of the fortress. If all sub-domains inherit from higher level ontology, they will be able to share complete information at this level only, although they can share partial information at lower levels. The users have the means to share information through the use of common classes derived from ontologies. The level of detail of the information is related to the level of detail of the ontology.

The semantic architecture of “GeoCHEAF” stores entities and their associated relationships in the knowledgebase, classifying them according to a hierarchical entity class tree. A given entity can belong to multiple entity classes, that is, there are classes of concepts, which constitute a hierarchy with multiple inheritances. Figure 1 shows an example of a graph representing the ontology of buildings of a fortress as an OWL. The class ‘building’ is a subclass of the class ‘fortress’, and the class ‘tower’ is subclass of the class ‘building’. Other branches of the class tree contain buildings with subclasses Turkish bath, wall, mosque, and military barrack. Classes typically have instances, for instance, a specific tower is an instance of the ‘tower’ class, such as Algerian Tower, Cannon Tower, South Tower, Poyraz Limanı, Lodos, Tophane of the “*Seddülbahir Fortress*”. A ‘tower’ class/entity must have a geometric shape, for example, the round or polygonal plan of the tower. Conceptually, a tower can be placed on both types of tower figure; however, a specific tower can only reside on either.

For example, the instance of Algerian Tower is-a prominent rounded seaside tower or South tower is-a hexagonal tower-hexagonal tower ako tower.

The use of multiple inheritances allows an application developer to make use of the existing ontologies to build new classes. The application developer can combine classes from diverse ontologies and create new classes that represent user needs. These new classes represent objects that have diverse characteristics [10][11][12].

For instance, towers have geometric characteristics along with alphanumeric attributes. Instead of having a single class that needs to include information on the geometric shape of the tower, as well as associated information about construction date, construction material, construction techniques, and so on, multiple inheritance is utilized in this research by inheriting geometric characteristics and methods from a geometric/spatial class of spatial ontology, such as polygon, and inheriting/descending application-specific characteristics and methods from a more generic Tower class (parent class) of CH domain ontology. In the first group, all necessary representational and locational data can be handled by inherited methods, while in the other information on the semantics and behavior of the tower are inherited from CH specific ontology-derived classes. The views can be combined enabling the user to have a geometric/alphanumeric view. An example of the use of this combined view is a "point-and-click" operation over a tower that highlights its shape and shows its alphanumeric data.

In the knowledge generation phase of the semantic architecture of "GeoCHEAF", the ontology editor stores a formal representation of the ontologies and provides a translation of the ontologies from multiple independent data sources into software components (e.g., Java classes) to be used in a semantic web applications, such as information retrieval, web mining. These classes are linked to geospatial information sources through the use of mediators. The application developer can combine classes from diverse ontologies and create new classes that represent the user needs. For the knowledge use phase, the ontologies are available to be browsed by the end user using ontology browser at different levels of detail depending on the ontology level used, and they provide semantic metadata on the available information. The ontology browser can be used during ontology specification by users who wish to collaborate in composing a shared ontology. Once the ontology has been specified, the ontology browser is used to show the available geospatial entities to the users. Hence, the user can query and update the ontologies using remote applications on the Internet. The query processor matches the terms in the user ontology to the system component ontologies. The information about ontologies is provided by the ontology server that holds a standard catalog of ontologies for the user to search and browse, using mappings between ontologies and the structures in data repositories. The connection with the information sources is done through mediators that are pieces of software with embedded knowledge. Mediators connect instances of the entities available in the ontology server to features in spatial databases and translate them into a format understandable for the end user. Figure 2 shows the proposed framework, in terms of its components and their intuitive relations.

For instance, a researcher wants to make cross-archive searches on distributed digital archives encoded in RDF/OWL using the CIDOC-CRM ontology in order to retrieve information, or execute a complex query about the CH data/information on the web. First, the researcher browses the ontology server looking for the related classes. After that, the ontology server starts the mediators that look for the information and return a set of objects of the specified class. The results can be displayed or can undergo any valid operation, such as CH analysis. This ontology-based approach allows CH researchers to associate geospatially referenced data to any other non-spatial information related to the geospatial feature that is expressed on the semantic web.

Existing web service technologies (Remote Procedure Call (RPC) or Representational State Transfer (REST)) are only at the syntactic level and fail to capture enough semantic data, there are semantic gaps in cross-domain resource discovery, heterogeneous resource query, resource translation from one domain to another at the semantic level [13]. Semantic web technology can alleviate this limitation and Semantic Web technologies have been widely used to support automatic service composition. Semantic Web Services deal with such limitation by augmenting the service description with a semantic layer in order to achieve automated discovery, composition, monitoring, and execution, which are all highly desirable processes [14].

The concrete GI services which meet those conceptual needed GIS data and function can be automatically discovered in the semantic repository. Discovered GI services can also be automatically composed as a workflow (service chain) to generate an initial result for users to evaluate. Ontology Web Language for Services (OWL-S) was chosen as a proper workflow description language to enable automatic web service discovery, invocation, composition into a workflow, and interoperation. Automatic workflow chaining utilizes business logic in integrating applications to construct a new application and executes an OWL-S composite process with service groundings.

IV. CONCLUSION AND FUTURE WORK

The geo-ontologies embodied in the geospatial semantic web approach provide a shared understanding and conceptualization of relevant aspects of the CH domain applications. Independent applications that interpret and process CH data with respect to these ontologies can achieve a much higher level of interoperability and information/knowledge sharing. This proposed Knowledge-based Spatial Information Systems and Services and services can play an important role in enabling geospatial-based information and knowledge sharing in the world of interoperable knowledge-based distributed environments.

As ontology development technology evolves, the benefits of ontology use will outweigh the costs of developing them. With the success of this technology, large-scale repositories of ontologies will be available in diverse

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disciplines, and this work has been developed based upon this assumption.

To share and integrate data, information, and knowledge among the constituents of the CH domain, standardized communication protocols, standardized metadata contents, and interoperable programming interfaces are essential for the success of 'the future of the past'.

In addition to developing technical solutions, a series of recommendations and effective management are required for the frictionless workflow of adaptive information, from local fieldworker to regional heritage curator to national agencies and the public, such as how fieldworkers could report surveys, excavations.

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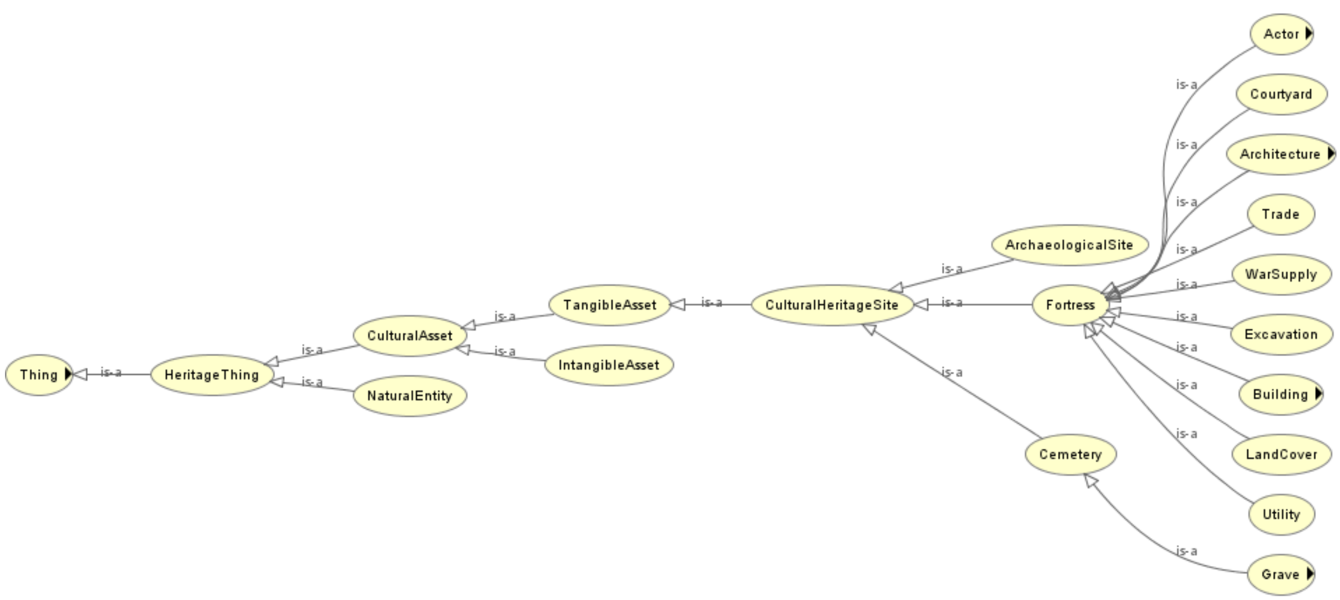

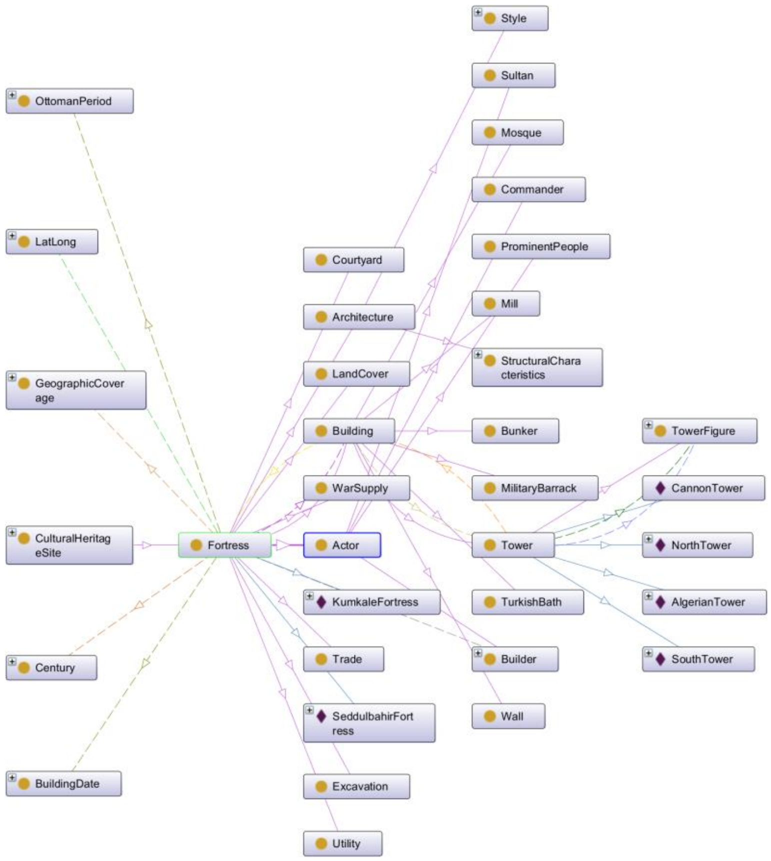

Figure 1. Screen shots of the Protégé-OWL ontology development environment.

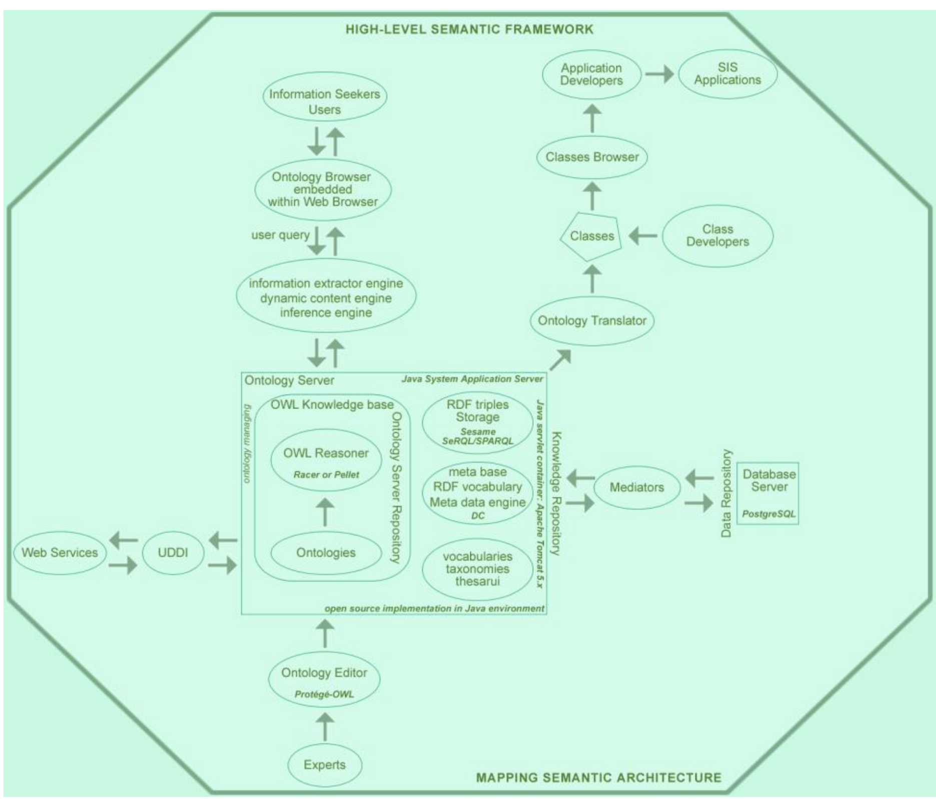

Figure 2. Semantic Architecture of “GeoGCHEAF”.