Geospatial Resource Description Framework (GRDF) and Security Constructs

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Abstract— **The Semantic Web enables an automated, ontology based information aggregation mechanism. In geographic domain, automatic aggregation is a particularly important task in light of the over-abundance of data formats and types. Because the formats and types are not necessarily uniform or adhere to a particular information structure, aggregating geospatial data with differing formats is a challenging task. The aggregation is extremely useful in many areas such as business, academic, homeland security and public awareness. In this paper, we propose a set of geospatial constructs written in Web Ontology Language (OWL) and collectively referred to as Geographic Resource Description Framework (GRDF).Our goal is to propose a broad, semantics-aware and expressive language for geospatial domain. The most important advantage GRDF has over other geospatial languages is the ability to use logical inference and dynamic content aggregation. We also publish our work on security constructs for GRDF that allows domain experts and software developers to address the security concerns as part of the core development process instead of an ad-hoc course of action.**

I. INTRODUCTION

Semantic Web enables an automated, ontology based information aggregation mechanism. In geographic domain, automatic aggregation is a particularly important task in light of the over-abundance of data formats and types. Because the formats and types are not necessarily uniform or adhere to a particular information structure, aggregating geospatial data with differing formats is a challenging task. The aggregation is extremely useful in many areas such as business, academic, homeland security and public awareness. Companies rely on location-specific demographic data to create business strategies, academic research such as development of real-time systems benefits greatly from spatiotemporal visualization, homeland security organizations utilize geographic data to track terrorists' trail and so on. Due to the challenge associated with aggregating heterogeneous geographic data, many of these use cases perform at a sub-optimal level. For instance, the defense application that keeps track of information relating to enemy movement uses a different format for the stored data than the application that stores criminal records. A lot of intelligence data can be extracted or inferred by combining the data from the two applications, but the difference in formats gets in the way of such aggregation.

To solve geographic data heterogeneity and improve interoperability across multiple platforms for the data, standardized encoding languages have been proposed. Geographic Markup Language (GML) [20] is one of the most prominent encoding mechanisms. It is an XML-based meta-data format that contains a set of schemas to encode geospatial knowledge. The schemas define constructs for high-level geospatial concepts such as shape of a house or highway topology. Application developers who need more specific domain concepts derive them from the GML constructs through XML content-derivation model. Because of the standardization process, developers and users can refer to a common definition of geospatial terms, regardless of the particular application or environment they are dealing with. Going back to the defense application, now both movement tracking application and criminal records application can store geospatial component of their data in GML, allowing a much more seamless aggregation process than before.

However, the geospatial schemas in GML solve data heterogeneity and interoperability in geospatial domain only. The problem with information 'silos' remains despite the introduction of common schemas. Information 'silos' refer to individual domains that have become isolated because of cross-domain data heterogeneity. The isolated sources work well as long as there are common schemas such as GML that the domain developers can tie their application to. However, when information starts to flow outside the boundary of the domain, the same heterogeneity and interoperability problem resurfaces. Data from one domain is hard to decipher by users of another domain. This problem is particularly prominent on the web where large databases with volumes of essential information is workable only from within the pertinent domain; they become intractable for outside domains to analyze in an aggregated environment. The ability of geographic applications to inter-operate with other software and databases such as wireless applications and e-commerce is critical for national research needs and benefits [6].

One way to solve the problem is to have a data model for the encoding languages. This way, various domains can define their schemas in a language-independent manner. The node-arc-node model in the Semantic Web languages such as RDF (Resource Description Framework) and OWL (Web Ontology Language) provide the required language neutrality. In this paper, we propose a set of geospatial constructs, similar to those in GML, written in OWL and collectively referred to as Geographic Resource Description Framework.

In this paper, our main contribution is a set of extensible geographic ontologies that aim to cover the entire geospatial domain. The ontologies are extensible so that domain users can develop domain ontologies based on GRDF. The rest of the paper is organized as follows. In section 2, we discuss related topics in geospatial ontology development. Section 3 introduces GRDF and its components. Section 4 and 5 describe the two main elements of GRDF, feature model and geometry model, respectively. Section 6 discusses security aspects of GRDF and the advantages of using the GRDF ontologies to enhance data safety.

II. RELATED WORK

Development of geospatial ontology is an ongoing research issue both in computer sciences and geosciences. However, the current research is aimed at developing application level ontologies that contain very specific and occasionally, contextual concepts. This differs from our approach because GRDF is viewed as a mid-level ontology applicable regardless of a particular application area. Arpinar and Sheth et al [1] have extended a benchmark ontology called SWETO [2] to incorporate geospatial parameters for the concepts in SWETO. However, in their approach, called SWETO-GS, the geospatial concepts are concrete, real-world entities extracted from individual data sources. Unlike GRDF, the concept hierarchy evolves in a bottom-up fashion; they first enumerate specific entities and then generalize them based on similarity criteria.

Information modeling has been used to organize concepts of a particular domain to represent the domain information in a coherent form. Development of geographic ontologies can be viewed as a form of information modeling with a formal underlying framework. The authors of [4] discuss this notion abstractly and define a set of basic theories desirable in a geographic ontology. The theories help to establish a tighter coupling between 'intentional' level (i.e., ontology) and ground facts (i.e., instances) so that when instance data is created and shared, it is more efficient to capture the geospatial objects and their semantics. However, there is no equivalent theoretical proposal in GRDF. Of course, they can be stipulated formally through OWL properties or as rules [5] if needed.

Due to the availability of a number of geospatial ontologies, there is a possibility that a concept is defined using potentially different semantics in different ontologies. Then a geospatial client is presented with a dilemma of which one he or she should choose to use the concept. The semantic heterogeneity can lead back to the same set of problems that ontology mechanism was supposed to solve. Unless the semantics are completely at a discord, this type of heterogeneity problem can be solved with various ontology alignment techniques. Kokla and Kavouras et al [3] discuss concept matching techniques to group geospatial items that refer to the same concept. The matching procedure is largely based on the conventional natural language processing (NLP) methods such as lexical similarity or pattern matching. GRDF will lend itself very well to this work. People using GRDF will create lower level ontologies that belong to separate application domains where similar or overlapping concepts could be specified differently. To reconcile the deviation one can use the ontology alignment techniques ([6], [7], [8], [9], [10]) based on semantics similarity or the NLP methods described in [3].

There are a number of geospatial ontologies ([11], [12], [13], [14]) that define concepts for specific domains or applications. The main difference between GRDF and these works are twofold. First and foremost, GRDF is based on a subset of first-order logic and written in OWL (Web Ontology Language), while the others follow their own unique syntax. For instance, [16] uses XML format to aid querying geographic data stored in a database. Second, GRDF is a mid-level ontology that defines the most general geospatial terms, while the latter ontologies belong to lower-level of the ontology hierarchy. The intent of GRDF is to allow the lower-level ontologies to bootstrap themselves from a common semantic platform. Then they can extend GRDF to define more domain specific concepts.

There are several initiatives ([17], [18]) in the semantic web and geospatial community to define geospatial concepts in a semantic web language (e.g., RDF or OWL). However, some of the initiatives are incomplete or in a theoretical stage. [17] provides a very simple geospatial vocabulary to enable users to tag or embed spatial contents in their documents. GRDF on other hand is a much more complete language that provides a broad range of geospatial constructs. Another related topic in geospatial semantics is geospatial folksonomy (e.g., [19]). Geospatial folksonomy relies on users to tag and annotate data and services so that information can be structured. It is a collaborative way of organizing geospatial contents that allows people to mark information as they see fit without adhering to any particular definition. In contrast, ontologies such as GRDF lay out the top level concepts and then users utilize these concepts to tag their data. Thus, GRDF is a more formal approach to organizing structured geospatial data.

III. GRDF ONTOLOGY

There is a direct correspondence between high-level GML schemas and GRDF ontologies. The specific content organization differs because OWL allows a tighter association between concepts that belong to the same group. Figure 1 shows the GRDF hierarchy. The main elements of the hierarchy are the feature and geometry model. The feature model describes the abstract geographic concepts while geometry model describes the concrete geometric shapes. The individual ontologies are described in the next section.

Before we delve into the details of the ontologies, a discussion about some of the challenges faced in the design process of the ontologies are presented next.

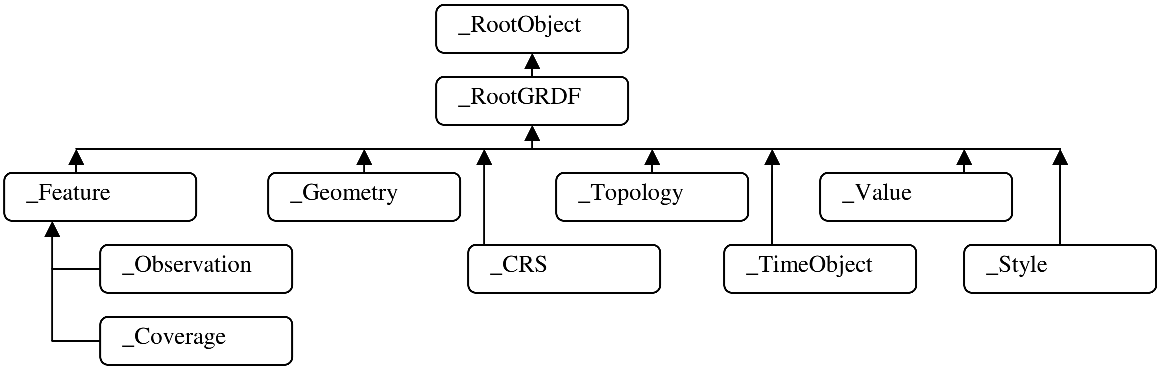

Fig 1: GRDF Ontology diagram

A. *Separation of Knowledge and Instances*

For decoupling and efficiency reasons ontology developers recommend separating the schema or metadata information from the actual data. A strict ontology consists of only metadata, also referred to as knowledge, and no instances. Knowledge refers to a set of abstract concepts while instances refer to their concrete characterization. So 'Shape' would be the knowledge of the 'Square' instance. GML allows non-concept elements such as Null that designate absence or non-applicability of instance data. Such elements are omitted since their corresponding meaning in OWL also is instances. We want to profile only the GML types (simple or complex), which can be mapped to OWL knowledge base (i.e., classes, properties). The elements in the GML schemas are there for user convenience and do not augment any meaning to their containing concepts.

B. *Modelling XML Extension Types*

GML types that derive their content model with the XML 'extension' mechanism (e.g., the extension base can be 'double') present a challenge in their conversion to OWL classes. 'Extension' essentially, creates a subclass of the base (see MeasureType in http://schemas.opengis.net/gml/3.1.1/base/ basicTypes.xsd for a concrete example) which can augmented additional attributes and elements. However, subclassing through 'extension' does not necessarily translate to subclassing in OWL. This is particularly true if the extension base is one of the built-in XML datatypes. For instance, consider the GML type MeasureType in basicTypes.xsd where the extension base is 'double.' An instance of MeasureType is:

```
<Element name="temperature" type="MeasureType">
<temperature uom="http://.../farenheit">
        21.23
</temperature>
```

If we were to model it as OWL subclass of xsd:double (where xsd denotes the namespace for XML schema), then we run into the problem of where to place the element value. Unlike XML, OWL class/type instances cannot assert the temperature value 21.23 in between the open and end-tags of the type. Because of the striping nature of the OWL model, only way to place this in an instance is through a property value. Therefore, it is obvious that the most intuitive way to model XML extension constructs with bases referring to one of the built-in datatypes is by creating property with range restriction set to the base type.

IV. FEATURE MODEL

The basic feature model is given by the Feature ontology in GRDF. A feature is a concrete object belonging to a particular domain (see ISO 19109 for a more detailed definition of 'feature'). A complex object builds on smaller features. A feature is defined using the 'Feature' class and usually associated with its extent through properties. There are several geometric properties that define the minimum extent of a feature. The 'isBoundedBy' property can define the extent in terms of a rectangle. The rectangle represents an imaginary bounding box that is the minimum area occupied by the feature. A non-trivial object may consist of different types of geometric features. The following properties can be used to state the exact type:

```
<owl:ObjectProperty rdf:about="#hasCenterLineOf"/>
<owl:ObjectProperty rdf:about="#hasCenterOf"/>
<owl:ObjectProperty rdf:about="#hasEdgeOf"/>
<owl:ObjectProperty rdf:about="#hasEnvelope"/>
<owl:ObjectProperty rdf:about="#hasExtentOf"/>
```

The content model for Feature adds two specific classes suitable for geographic features to define shapes. First is the 'Envelope' class that allows one to specify a pair of coordinates corresponding to the opposite corners of a feature. The other one is 'EnvelopeWithTimePeriod' that adds a temporal dimension to the envelope. The most basic concept to define the shape of a feature is the 'BoundingShape' class. It can specify the shape in terms of either of two aforementioned envelope classes. A value of GRDF:Null will appear if an extent is not applicable or not available for some reason for a feature.

For envelopes that include a temporal extent, GRDF:EnvelopeWithTimePeriod is defined as follows:

```
<owl:Class rdf:about="#EnvelopeWithTimePeriod">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:cardinality
             rdf:datatype="&xsd;nonNegativeInteger">2
     </owl:cardinality>
     <owl:onProperty>
        <owl:ObjectProperty
about= http://localhost/ temporal#hasTimePosition"/>
      </owl:onProperty>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

This adds two GRDF:timePosition properties which describe the extent of a time-envelope. Since GRDF:EnvelopeWithTimePeriod is derived from GRDF:Envelope, it may be used whenever GRDF:Envelope is valid. The coordinate reference system used for the positions defining the GRDF:Envelope may be indicated using the feature hasSRSName.

V. Geometry Model

Geometry model is defined through the classes and properties in the geometry ontology. As the name suggests, the ontology is placeholder for any concept used to define a feature's geometry. Whether it is a simple feature or a complex object consisting of multiple feature members, geometry ontology provides all the constructs to specify the geometric profile of the object. The ontology is organized in terms of complexity of the geometric forms. A geometric form can be a trivial one-dimensional line or an intricate mesh of connecting curves.

A point is the most basic and indecomposable form of geometry. A curve is a one-dimensional form that is defined in terms of anchor points. A curve can be as simple as a straight-line or a multiple arcs connected at their terminal anchor points. A surface is a two-dimensional form that defines an area with three or more anchor points. The surface class provides the basis for more complicated forms included the three-dimensional geometric forms. The solid class is used to denote a three-dimensional object's geometric shape. However, unlike the classes for the other lower dimensional forms, solid does not have its own composite types. Instead, it relies on two-dimensional classes to construct the shape.

All of the forms mentioned above can be defined as a singular entity or a multipart entity. A multipart form is basically a combination of the base type enumerated in a certain geometric way. How they are arranged indicates the exact nature of the multipart. There are three types of multipart's: 1) Multi 2) Composite 3) Complex. When a multipart entity is composed of the same base type and there is no stipulation as to their mutual relationship, it is called Multi type. A Multi type does not allow nesting since it is a straight enumeration of the individual parts. Composite type is similar to Multi type except the individual parts have to be contiguous and nesting is allowed. So a composite type can have another composite type of the same base form in its content model. A Complex type is the most involved of the three types because it allows arbitrary combination of the types. The atomic parts of a Complex type can be Multi type, Composite type and even Complex type. Complex types are more of a convenience construct for users to define their own types that may not be composed of a unique geometric form.

The individual parts are defined through the range values of properties. In the following example, we illustrate how a curve can take on one of the above multiparts.

```
<owl:Class rdf:about="#Curve"/>
<owl:Class rdf:about="#MultiCurve"/>
<owl:Class rdf:about="#CompositeCurve"/>
<owl:ObjectProperty rdf:about="#curveMember"/>
```

There is no such thing called ComplexCurve since a curve cannot take on a non-curve form. However, an application domain can define a shape that is composed of CompositeCurve and MultiSurface. Geometry ontology also defines a concept called 'Ring' that is similar to Multi type except it is restricted to have straight-lines or curves in its content model.

VI. Security context for GRDF

A significant aspect that can strongly affect the future direction of GIS systems is the security concern for geospatial data. Currently, space satellites can capture images to a level of resolution that can be considered privacy breaches for public. A future is foreseeable when third party integration site will act as the mediator that lets clients access scattered resources in a coherent, intelligent manner. There are sensitive geological data that owning organizations might be reluctant to expose to public use because of potential abuse. A third party can provide a uniform, controlled access to such sites. But this framework requires the third party to be trustworthy, and not everybody would be ready to put such trust on the third party. The emerging data clearinghouse infrastructure also poses a similar security problem. Located across the globe, the clearinghouses contain volumes of data that are highly significant for research and practical applications, yet lack of a coherent security framework reduces the availability of the data to potential users.

The security concerns need to be mitigated through an efficient mechanism without giving up on the powerful capabilities of integrated GIS's. With the evolution of thousands of geospatial clearinghouses, the methods for geospatial data exchange is shifting from localized query retrievals to online process request and response through web services. Geospatial Web Services service client queries to access and modify various kinds of possibly distributed and heterogeneous geographic data sets. The phases of the web service processing such a composition have to be secure. However, securing web services as well as handling data semantic heterogeneity while integrating heterogeneous geospatial data sources is beyond the scope of this proposal.

In general, the user request is processed by the web service and data access is mediated by the policy layer. The security policies have to be enforced and only the authorized data is retrieved and returned to the user. In the case of multiple geospatial data servers, each node may enforce is own set of policies as specified and enforced by the policy framework. Data access by a web service is mediated by some sort of broker and the request is then sent to different locations. If the combination of policies from participating systems is inconsistent, additional rules may be needed to resolve conflicts.

GeoXACML [23] is an emerging security policy framework that can handle client requests to web services over heterogeneous and distributed data. However, it views geographic resources as objects that can be associated with either a class or instance of the class. As such, it is unable to provide a fine-grain access control. For instance, consider granting access to a Building object to a user. The conferred privilege is going to allow a user to access all the Building properties including height, extent, exit doors, and location of telecom towers, some of which should be intended only for building security personnel. Our goal is to propose a security framework that can handle security for geospatial applications in a wide-range of contexts.

A. A Detailed Scenario

The following scenario describes a water contamination incident in a chemical plants zone. This scenario illustrates the need for a comprehensive geospatial security mechanism with fine-grain access control over resources. We use two databases which are populated from two different geospatial data sources. One of them stores hydrology topology information of north central Texas including aggregated streams, creeks and lakes data. The hydrology topology and the associated meta-data are available from North Central Texas Council of Governments ([21]). The other database houses chemical information stored in various chemical facilities located in over twenty states. Chemical sites location, types of chemicals reserved in their repository, chemical codes and contacts of site personnel are the primary sources of data for this data store. Since most of the chemicals are in commercial use, emergency responders require various levels of access to this repository. Unlike the open geography-centric hydrology topology, the nature of chemical data introduces a considerable need for secure access mechanism for the data.

LIST I
SAMPLE HYDROLOGY DATA IN GRDF

```
<rdf: Description about=”#VECTOR.VECTOR.
            HYDRO_STREAMS_CENSUS_line”>
      <app:hasObjectID>11070</ app:hasObjectID >
      <grdf:LineString srsName="http://.../TX83-NCF">
        <grdf:coordinates>2533822.17263276,7108248.
              82783879 …
        </gml:coordinates>
  </grdf:LineString>
</rdf:Description >
```

Since the facilities discharge waste products into the sewage, an on-site investigation is conducted to ascertain which area is affected and in what manner. For a stretch of the area, water mains and waste mains run in a close proximity.

LIST II
SAMPLE CHEMICAL SITE DATA IN GRDF

```
   <app:ChemSite rdf:about=”#NTEnergy>
      <app:hasSiteName> North Texas  Energy
       </app:hasSiteName>
      <app:hasSiteId> 004221</ app:hasSiteId >
      <grdf:BoundedBy srsName="http://.../TX83-
            NCF”>
         <grdf:coordinates> …
          </grdf:coordinates>
 </grdf:BoundedBy>
    <app:hasChemicalInfo
             rdf:resource=”#NTChemInfo”/>
  </app:ChemSite>

  <app:ChemInfo rdf:ID=”NTChemInfo”>
    <app:chemical>
       <app:hasChemName>  Sulfuric Acid
       </app:hasChemName>
       <app:hasChemCode> 121NR
       </app:hasChemCode>
   …
```

An effective response to the incident requires coordination among various groups of people with different roles. One group with ‘main repair’ role would be designated to repair the wastewater pipes, while a second group with ‘hazmat personnel’ role would be assigned to clean up chemical spill on the stream. A third group under ‘emergency response’ role would have to be dispatched to locate and alert the chemical sites to take alternative actions for chemical discharge. All the groups can use middleware/Web-service to extract incident site specific information.

Middleware creates a layered view by combining the two result-sets fetched from hydrology and chemical site data store. However, ‘main repair’ is a low security role that should not be able to view chemical information of the sites. Therefore, before presenting the layered view, middleware needs to eliminate data that violates security with respect to this role. People under ‘hazmat personnel’ role need knowledge of chemicals that were potentially disbursed into the stream to assist in the clean-up work. The chemical database contains more than just chemical names, which necessitates data suppression for the ‘hazmat personnel.’ The access control module presents them a view containing the stream data layered with affected chemical site locations and an aggregate list of chemicals from these sites. ‘emergency response’ team has an administrative role and requires full access to the data.

Table 3 lists a policy for the ‘main repair’ personnel. It uses a security ontology to define the policy rules. The table grants ‘view’ access to the group on a conditional basis. The condition stipulates that only the geographic extent of the sites would be viewable to this group. This is enforced by specifying the 'BoundedBy' property in the condition. This is a very flexible way to have fine-grained control over resources and allow access to them either fully or partially. Another advantage to this semantics-aware access control approach is data merge. Let us assume the chemical site data in table 2 is aggregated with weather data. A reasoning system can still enforce the policy in table 3 against the aggregated data, which would not be possible with a GeoXACML parser.

LIST III
POLICY FOR 'MAIN REPAIR' GROUP

```
<SecOnto:Subject rdf:about="#MainRep">
     <SecOnto:hasPolicy
              rdf:resource="#MainRepPolicy1"/>
</SecOnto:Subject>

<SecOnto:Policy
              rdf:about="# MainRepPolicy1">
   <SecOnto:hasAction
              rdf:resource="#View"/>
    <SecOnto:hasCondition
            rdf:resource="#CondSites"/>
    <SecOnto:hasPolicyDecision
            rdf:resource="#Permit"/>
    <SecOnto:hasResource
              rdf:resource="#BuildingResource"/> </
SecOnto:Policy>

<SecOnto:ConditionValue
              rdf:about="# CondSites">
   < SecOnto:condValDefinition>
     <SecOnto:hasPropertyAccess
              rdf:resource="&grdf;BoundedBy"/>
   </SecOnto:condValDefinition>
</SecOnto:ConditionValue>
```

VII. CONCLUSIONS

In this paper, we discuss the use of geospatial ontologies to mitigate geospatial heterogeneity and format mismatches. To take advantage of the huge amount of geospatial data available through sources such as the Web, sensors, satellites, we need to organize and structure the data in more seamless manner. We need to enable machines to interpret the data uniformly so that information can be linked and produced more efficiently. GRDF provides the basic framework for a geospatial web that understands semantics and can aggregate information on the fly. Moreover, use of GRDF allows reasoning system to not only find existing links, but deduce new data. Because of the world-wide adoption and standardization of GML, GRDF is designed to match GML in its content descriptions and feature relationships. For instance, a polygon in GRDF can be directly mapped to a polygon in GML. However, GRDF is written in OWL-DL, a description logic based language that provides a very powerful and expressive means to attach semantics to the data. One of the most powerful and appealing features of GRDF is the instant integration of the domain language with a security language. A security ontology similar to what we have defined for section 6 can be easily enforced against a GRDF data model without building expensive security applications. Because of the nature of OWL, if base data model changes or aggregated with other data sources, the same security framework will continue to work. For our future work, we plan to implement our idea of a semantics-aware geospatial access control tool that can operate on security ontologies and corresponding policies.

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