Specification of a Framework for Semantic Annotation of Geospatial Data on the Web

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ABSTRACT

The Web is a huge repository of geospatial information (GI), distributed all over the world. Efficient retrieval of this information is a key factor in planning and decision-making in a variety of domains. However, the proposed standards and specifications for data annotation and exchanging enable only syntactic interoperability. Semantic heterogeneity still presents challenges for GI retrieval. One possible approach to tackle these problems is to elicit knowledge by means of semantic annotations, based on multiple ontologies. This work describes a framework to support management of semantic annotations for digital content on the Web, for agricultural planning and monitoring. This will help end-users (agronomers, farmers, Earth scientists) to work cooperatively in developing integrated practices for land management. Content to be annotated in this context includes, for instance, satellite images, sensor data temporal series (e.g., from ground sensors or weather stations), and all kinds of textual data files.

Categories and Subject Descriptors

H.2 [**Database Management**]: Database Applications—*Spatial databases and GIS*

Keywords

Semantic Annotation, Geospatial data, Semantic Interoperability, Geospatial standards

1. INTRODUCTION

Geospatial data are a basis for decision making in a wide range of domains, in particular agriculture. Their combined use is useful to answer questions such as '*When will be the best time to start harvesting coffee in this area?*' or '*Given a crop productivity pattern, which regions show the same pattern?*'. These questions are important for production planning and definition of public policies concerning agricultural practices, also allowing the environmental control of protected areas.

The Web plays an important role in this scenario, having become a huge repository of geospatial information distributed all over the world. Data are collected and stored by different organizations, which are required to exchange such data. Usually, the search for these data and methods is done by their syntactic content, focusing primarily in keyword matching. This can lead to the retrieval of irrelevant data, disregarding relevant files. Hence, semantic interoperability is a key issue in discovery, access and effective search for data in different application contexts.

Novel solutions must be found to support adequate management and retrieval of geospatial data on the Web, taking all these factors into consideration, with agriculture in mind. There is a large amount of research on the management of geospatial data,including proposals of models, data structures, exchange standards and querying mechanisms. However, relatively few computer scientists are concerned with the specific requirements of applications in agriculture.

Our solution is based on exploring the use of *semantic annotations*. In our work, a semantic annotation is a set of one or more metadata fields, where each field describes a given digital content by ontology terms. An ontology formally describes the elements of a domain and the relationships among them, providing a common understanding of the domain [9]. The goal of this research is to provide a framework for semantic annotations of geospatial, distributed and heterogeneous data available on the Web, for generation of strategic information for agriculture. The work is centered on a framework that will support:(1) creation, validation and management of semantic annotations of geospatial data on the Web, for agricultural planning; and (2) discovery and effective search for data in agricultural contexts.

This research is being conducted within the WebMAPS multidisciplinary project under development at UNICAMP, whose goal is to develop a platform based on Web Services for agro-environmental planning [15].

The rest of this paper is organized as follows. Section 2 introduces concepts used in the rest of the paper. Section 3 presents the proposed annotation framework. Section 4 gives a comparative view of related work. Section 5 describes our conclusions and ongoing work. Most of the text in this paper is extracted from a paper submitted to the Int. J. Metadata, Semantics and Ontology - Special Issue on Agricultural Metadata and Semantics.

2. RELATED CONCEPTS

2.1 Geospatial Semantic Web

The Semantic Web for geographic information, called Geospatial Semantic Web by Egenhofer [6], is a way to process requests involving different kinds of geospatial information. This requires the capture and analysis of such information, grouping data according to criteria that extrapolate their syntactic context. According to the author, this process requires the development of multiple spatial and domain ontologies, their representation in a way that computers can understand and process, the processing of queries considering these ontologies and the evaluation of results based on the required semantics. All of this leads to the search for a geospatial information retrieval framework that relies on ontologies, allowing users to retrieve desired data, based on their semantics.

In spite of extensive research, the Semantic Web is far from becoming a reality [21]. Although several standards have been developed and adopted, there are too many views, interests and needs of people that publish and share content in the Web. Consensual vocabularies and ontologies are hard to establish and maintain. So far, most retrieval engines are restricted to text, and other kinds of media pose countless challenges to the effective implantation of the Semantic Web [3].

2.2 Semantic Annotations

"To annotate" means to add coments, to coment. In computing, an annotation is used to describe a content (usually a textual content) and what it does, by means of formal concepts (e.g., using entities in an ontology)[19]. An annotation is represented by a set of metadata that provide a reference to each annotated entity by its unique Web identifier, like a URI. In other words, annotations formally identify resources (in the text, called "digital content") through the use of concepts and the relationships among them, and can be processed by a machine. A way to promote interoperability is to use the entities of a domain ontology as those concepts. For example, an annotation may relate the word *orange* that occurs in a text to an ontology that identifies this word as an abstract concept *fruit* (as opposed to *color*).

However, names can vary through time, or in their usage, and distinct users may adopt different ontologies. Therefore, the simple adoption of ontologies during the annotation process is not enough. In geographic applications, annotations should also consider the spatial component, since geographic information associates objects and events to localities, through places and geographic object names, spatial relationships and standards. Hence, the geospatial annotation process should be based on geospatial evidences – those that conduct to a geographic locality or phenomenon.

The annotation process should be as automatic as possible, since a manual process can be slow and subject to errors. This remains a challenge that has been addressed by a number of research projects. However, most of the proposed mechanisms consider annotations only of textual content, not taking into account other kinds of content. In the geospatial domain, there is also other information to consider, e.g. satellite images, maps, graphs, data from sensors. There is a scarcity of mechanisms to annotate these data, motivating our research.

3. THE PROPOSED FRAMEWORK

3.1 The WebMAPS Project

WebMAPS [15] is a project that aims to provide a platform based on Web Services to formulate, perform and evaluate policies and activities in agro-environmental planning. It involves state-of-the-art research in specification and implementation of software that relies on heterogeneous, scientific and distributed information, such as satellite images, data from sensors and geographic data. The project caters to two kinds of users – farmers, and domain experts, such as agronomers or earth scientists. They can visualize geospatial variables concerning their properties (farmers), or analyze and monitor crop behavior (scientists). Using satellite images, users can search for an image based on content, such as texture or color. It is also possible to obtain information of the expected behavior of a culture, based on time series similarity on generated and stored NDVI (Normalized Difference Vegetation Index) graphs. The development of WebMAPS combines rapid prototyping with the delivery of tools and content for agriculture experts – see some of these tools at http://www.lis.ic.unicamp.br/projects/webmaps.

Figure 1 gives an overview of WebMAPS' 3-layer architecture, part of which already implemented. The Client Layer is responsible for processing a user request, fowarding it to be processed by the middle layer and presenting the returned result. The Service (middle) Layer provides services such as: textual and geospatial data management and ontology management. The workflow service is still under construction, though isolated experiments have already been conducted [17, 14]. The textual data service is responsible for all operations involving textual data, like input and query processing. Through the geospatial data service it is possible to generate NDVI graphs. It is being expanded to perform queries based on similarity on temporal series [16]. The workflow management service provides means to edit, execute and manage workflows [17]. Ontology management is performed by Aondê [5], an ontology Web Service responsible for handling ontologies. It provides a wide range of operations to store, manage, search, rank, analyze and integrate ontologies.

The Data Layer contains digital content provided by WebMAPS, including primary raw data (e.g., productivity data from Brazilian official sources) and derived data (e.g., NDVI images or yield curves). Geospatial data include satellite images, region boundaries, crop information. Ontologies provide semantics. Other data include information on properties, products and so on. Data is stored in the PostGreSQL/-PostGIS database management system.

Although supporting a wide range of queries, WebMAPS is still limited in terms of semantic support. The goal of this research is to develop the annotation service, providing such a support via semantic annotations. This involves getting information from other data sources and combine them to produce a more meaningful result. The Aondê ontology service will support the semantic annotation service, allowing: a semantic search of the desired data, use of multiple ontologies during the annotation process and refining the queries,

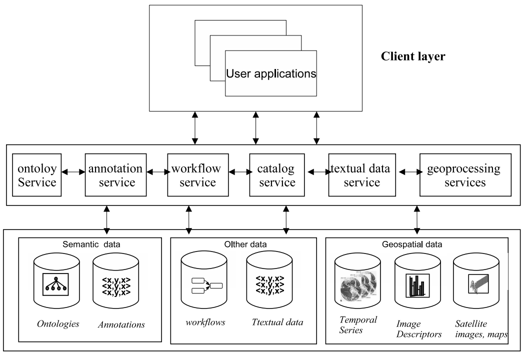

Figure 1: WebMAPS 3-layer Architecture

to eliminate ambiguity of terms. A catalog service, also part of our research, will be responsible for the management and publishing of the produced annotations.

3.2 The Annotation Service

The goal of the annotation service is to semantically annotate different kinds of geospatial data, such as satellite images, maps and graphs. Agosti and Ferro [1] propose a formal model for annotation of different kinds of digital content, such as textual documents, images, and multimedia documents in general. According to them, an annotation model should be as uniform as possible, considering all kinds of content, but also flexible, making it possible to exploit the semantics each content has, providing an effective collaboration tool for users.

Taking this into account, our annotation service should not only be based on explicit geospatial features, like geographic coordinates, but also on features that can be derived from the content, like climate and temperature or productivity trends. We are dealing with different kinds of digital content, each one with distinct geospatial features. The service should consider these differences, defining a specific annotation process for each kind of content. Although expert systems are frequently used in annotation systems [13, 20], not all of our processes can be described by decision systems. Hence, we have decided to use scientific workflows to describe each annotation process [23, 8]. Each workflow contains information on the data annotation schema that will be used during the process, the ontologies that describe these data, which operations must be performed and how to store the generated annotations.

Figure 2 presents a high level view of the workflow that annotates content. For instance, if the content is an image mosaic, it uses information from the graph's metadata (e.g., it is a JPG file), its provenance (e.g., the satellite images used to create it), its creation process (recorded as a scientific workflow), and geospatial evidence (extracted from content, metadata, provenance and process). First, the *annotation schema* is defined (i.e., the metadata fields that will be used in an annotation) and next the schema is filled with ontology terms. Additional annotations are defined manually.

An important issue while constructing the annotation workflow is the nature of the content to annotate. In the example, the image is what the user sees, but it can be stored in many ways. It can, for instance, be one file - and thus the file is annotated. Alternatively, it can be computed dynamically,

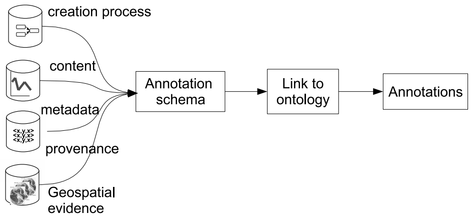

Figure 2: The workflow for content annotation

and only the images used to produce it are stored. At the moment we restrict ourselves to annotations for stored (as opposed to virtual) content.

In WebMAPS, scientific workflows are used to specify models in agriculture (e.g., to analyze erosion trends, or to define areas suitable for a given crop [8]). Workflows may also be used to specify how to create some kinds of content within WebMAPS (e.g., erosion maps or NDVI graphs). These workflows are stored in a database to be subsequently queried and reused [17]. Hence, the annotation service can take advantage of this workflow base to determine information on content.

Figure 3 gives an overview of the annotation service, comprising 3 basic steps. Step 1 selects the annotation workflow to be performed, based on the nature of the content to be annotated. Step 2 comprises the execution of the selected workflow. Finally, once the annotations are generated, in step 3 the framework publishes them in a catalog, enabling the discovery of data and analysis provided by WebMAPS.

Annotation generation will require accessing several data sources, including external data. The desired data will be discovered through metadata catalogs, using WebMAPS catalog service. We will only consider those catalogs that use domain ontologies to semantically describe data they represent. After the new metadata are generated, the framework has to relate them to one or more ontologies, giving them a semantic meaning, thus creating the annotations. The Aondê Web Service plays an important role in the annotation process, looking for and querying appropriate ontologies, or aligning those available within WebMAPS to those used by external sources.

For instance, an external data provider may use its own ontology to classify soil units in a map, whereas we use the soil ontology from Embrapa – the Brazilian Agricultural Research Corporation. In order to annotate the data provided, both ontologies have to be compared and *aligned*, generating a new, extended, ontology. Alignment involves identifying term and structure similarities between ontologies, and in our case is ensured by Aondê. We intend to base our ontology repositories on those defined by FAO (Food and Agriculture Organization of the United Nations) and by the Brazilian Agriculture Ministry, as defined and maintained by Embrapa – e.g., on soil, live animals, vegetation, agroecological relief and other agriculture-related issues. Information on other geographic features will be taken from the National Geographic Institute (IBGE - www.ibge.gov.br). Part of this initial set of ontologies is already being used by WebMAPS (e.g., on produce and on regional and ecological characterizations in Brazil).

Since we are focusing on interoperability, our framework will take advantage of the standards provided by the Open

Geospatial Consortium, like the Geographic Markup Language [18]. The backbone for the annotation schema will probably use FGDC's [7] geospatial metadata standards. Since this is a general purpose standard, we expect that it will be necessary to extend it to support the complex requirements of agricultural applications.

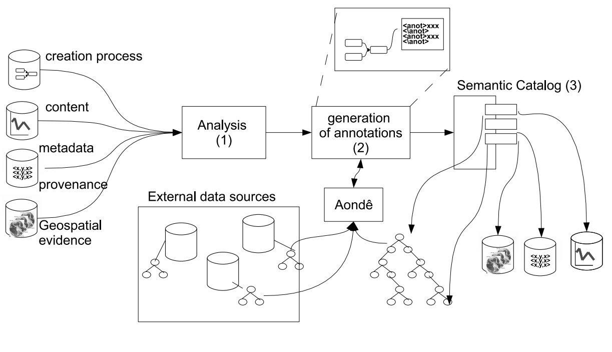

Figure 3: WebMAPS annotation service

3.3 An Illustrating Example

This section presents an example to illustrate the requirements and some challenges of WebMAPS annotation service: annotating an NDVI graph.

Remote sensing has become one of most important research areas in agriculture, taking advantage of satellite imagery. These images require distinct kinds of preprocessing. An example are the so-called NDVI images, whose pixels contain NDVI values, calculated by the difference of the spectral reflectance of red and near-infrared regions and normalized by the sum of both. NDVI represents the biomass conditions of a plant and is widely used in distinct kinds of analysis – e.g. agriculture, biodiversity. An NDVI graph plots the average NDVI pixel value in a region though a temporal series of images. This can be used for crop monitoring and prediction. For example, in the sugar cane culture, a curve with higher values may indicate a product with better quality. Curves can be compared and analyzed for yield forecast, for instance, quality and productivity, or to identify regions with problems. Given an NDVI graph, by its period and locality(latitude and longitude), it is also possible to obtain other information such as season, temperature and climate conditions, geographic region.

Figure 4 illustrates a set of NDVI graphs, together with a few possible semantic annotations that can be generated for them, associated with ontologies. The figure shows two curves, respectively representing graphs for periods with high and low productivity, for the same region and months of a year. Productivity is a kind of semantic annotation that has been added to the curves. One can use tools that mine time series (e.g., see [16]) to determine information on crops for a given region, based on NDVI value or oscillation behavior; here, this resulted in identifying crop = "sugar cane". It is also possible to get the name of the region, through the coordinates provided: annotating county name "Piracicaba". Finally, annotations can identify production phases, like seeding and harvesting. Each of these annotations are linked to ontology terms. These annotations can be used to answer some of the queries mentioned in section 1.

Figure represented by File 1 shows part of an annotation file for one of the NDVI graphs, using the FGDC standard.

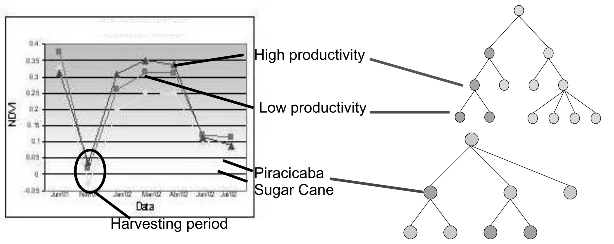

Figure 4: NDVI graph with possible semantic annotations

It is written in XML, according to the FGDC recommendations [7], and including ISO 19115 metadata. The element *Abstract* contains the kind of content being annotated. The comprised period of the content is set on element *Range_of_Dates/Times*. The provenance of data is described in *Native_Data_Set_Environment* as MODIS Vegetation. ISO 19115 metadata is used to identify the category of the data – in our case *agriculture*. Locality information is given in *Place_Keyword*, in *Spatial _Reference_Information*, which considers latitude and longitude, and also in *Spatial_Data_Organization_Information*, which considers the IBGE counties system. We extended FGDC standard to include other annotations, such as *quality_of _production*, *crop* identification and *harvesting_period*. The elements depend on the kind of the content being annotated. In the definition of these elements, we considered the FAOSTAT metadata. The terms used to describe the content come from selected ontologies, supported by mechanisms like thesaurus and gazetteers.

File 1: Annotated NDVI Graph

```
<Identification_Information>
  <Description>
    <Abstract "NDVI_graph"/>
  </Description>
  <Time_Period_of_Content>
    <Time_Period_Information>
      <Range_of_Dates/Times>
        <Beginning_Date "20010701"/>
        <Ending_Date "20020630"/>
      </Range_of_Dates/Times>
    </Time_Period_Information>
  </Time_Period_of_Content>
  <Native_Data_Set_Environment "MODIS Vegetation"/>
  <Keywords>
    <Theme>
      <Theme_Keyword_Thesaurus "ISO 19155 Topic Category"/>
      <Theme_Keyword>
        <farming "agriculture"/>
      </Theme_Keyword>
    <Place>
      <Place_Keyword>
        <county "Piracicaba"/>
        <state "Sao Paulo"/>
        <country "Brazil"/>
      </Place_Keyword>
    </Place>
  </Keywords>
  <Extended_information>
        <crop "sugar cane"/>
        <quality_of_production "high"/>
        <harvesting_period "11"/>
  </Extended_information>
</Identification_Information>
<Spatial_Data_Organization_Information>
  <Indirect_Spatial_Reference>
        <System "IBGE"/>
        <county "Piracicaba"/>
        <state "Sao Paulo"/>
        <country "Brazil"/>
  </Indirect_Spatial_Reference>
</Spatial_Data_Organization_Information>
<Spatial_Reference_Information>
  <Horizontal_Coordinate_System_Definition>
    <Geographic>
      <Latitude_Resolution "-22:43:31"/>
      <Longitude_Resolution "-47:38:57"/>
    </Geographic>
  </Horizontal_Coordinate_System_Definition>
</Spatial_Reference_Information>
```

4. RELATED WORK

Digital content annotation is not an easy task and is also subject to errors. This led to the development of tools, which aim to facilitate the annotation process. We tested these tools – [22], [24], [19], [4], [10], [11], [2], [12], [13] – for their annotation capabilities. Figure 1 shows a comparative analysis of them taking into account the requirements pointed by Reeve and Han [20] for semantic annotation tools, also including the spatial component. *Format* is the format in which annotations are saved. *Ontology* indicates if the annotation tool uses some ontology during the annotation process. Feature *storage* indicates how the annotations are stored: using local files, relational databases or an annotation server. Features *automated* and *annotation method* are related: the first one indicates if the annotation process is automated and, the next one, the annotation technique used (ML stands for machine learning). The kind of data that can be annotated by each tool is considered by the *annotated data* feature. Table 1 shows the features for the analyzed tools, considering the chosen features. Blank slots in the table represent unavailable information.

Tool	Format	Ontology	Storage	Automated	Annotation Method	Annotated data	Spatial Component
Embrapa Information Agency [22]	XML, using Dublin Core metadata	no	Relational data base	no	Manual, using natural language	Textual Web pages, videos, images and documents	no
Amaya [24]	XML, RDF	no	Local files	yes, but very limited	Based on given parameters	Textual Web pages	no
Kim [19]	RDF, OWL	yes	Local files or in an annotation server	yes	String matching and ML	Textual Web pages	no
AKTive Media [4]	RDF	yes	Local files	yes	ML(induction), with continuous manual training	Textual Web pages and images	no
CREAM [10]	RDF, OWL	yes	Local files or in an annotation server	yes, with supervised learned	ML(induction) manual training	Textual Web pages, videos and images	yes, but very limited
E-Culture [11]	RDF, OWL, using VRA metadata	yes		no	Manual, using a structured schema	Images of painting	yes
OnLocus [2]	XML	yes		yes	geospatial evidences (addresses)	Textual Web pages	yes
SPIRIT [12]		yes		yes	geospatial evidences	Textual Web pages	yes
Geodata Annotation [13]	XML, using ISO 19115 metadata	yes		yes	Spatial methods, string matching	Geographic data	yes

Table 1: Evaluated Annotation Tools

Except for the SPIRIT project, all the analyzed tools use a *standard format* to save their annotations. Among them, Embrapa Information Agency [22], E-Culture [10] and Geodata Annotation [13] also adopt standardized metadata, which increases the probability of the annotated content to be found. On the other hand, annotations which are saved on RDF or OWL enable the annotated content to be found during a semantic search, through the use of ontologies. We observe that features *Format* and *Ontology* are linked, since all tools that use ontologies during the annotation process, save the annotations using an ontology definition language. Furthermore the *Ontology* feature seems to be also related to the *Automated* one. This indicate that the use of an ontology helps the automation of the process, since it works as a controlled vocabulary. We also observe that when the *Annotated data* is mainly textual data, without taking the *spatial component* into account, the annotation method is based on machine learning. In this case, since the identification of annotations in the content is based on string matching, the use of an ontology is essential for the disambiguation. The same occurs when the *spatial component* is taken into account: if the process is automated, the use of ontologies is a key factor for the correct identification of spatial evidences. However, if the content is an image or a video the content has to be manually annotated. The analyzed tools did not consider other kinds of content, like maps and graphs, for annotation. Finally, *Storage* is also an important feature, since the efficiency of the annotation process is measure by the results of a content search. Annotations stored in an annotation server, like a catalog, facilitate content discovery, different from those stored in local files. On the other hand, annotations stored in a relational database will not enable content discovery, unless they are also published in another media.

Given this analysis, and considering the geospatial domain, we point out as an important research issue the automation of the annotation process for non textual geographical content, like satellite images, maps, graphs and data from sensors. This motivates our research.

5. CONCLUSIONS AND FUTURE WORK

This text (except for the example about File 1 in section 3) is extracted from a paper submitted on June to the Int. J. Metadata, Semantics and Ontology - Special Issue on Agricultural Metadata and Semantics. It presents a proposal of a framework for semantic annotations of geospatial data available on the Web, geared towards agricultural planning and monitoring. Unlike related research, that focuses on annotation of textual resources, we also consider the spatial component and other kinds of digital content like satellite images, maps and graphs, and content derived from these information sources.

The main contributions of our research are: (1) specification of an annotation mechanism directed to the agricultural context; (2) specification of processes describing the generation of semantic annotations for geospatial data; and (3) the annotation framework.

Our framework will be implemented as a web service within WebMAPS. It will consider the automation of the annotation process, the integration of heterogeneous data to generate annotations and the queries that will be posed on the annotated data. In this context, the main challenges we are facing involve the following issues: how to combine the available data? how to deal with heterogeneity questions? how to obtain the data? which annotation method is best for geospatial data? how to cope with distinct user profiles and requirements? how to yield the desired results, using distinct filtering and aggregation criteria?

Section 4 shows part of our test of existing annotation tools, which indicate the need for novel solutions. Section 3 describes the preliminary model for our annotation process. We are specifying several scientific workflows for models and processes in agriculture, taking into account the issues posed by agriculture experts. We are also manually generating annotations for different kinds of content, to serve as templates for our framework. This will serve as requirements definitions for the implementation phase. The framework validation will be done by these experts, using real data.

6. ACKNOWLEDGMENTS

We would like to thank Embrapa, FAPESP, CNPq and CAPES for the financial support for this work.

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