Geo Linked Data

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Abstract. The pervasive use of map viewer clients on *Semantic Web* applications shows the juxtaposition of two worlds: the *Semantic Web* and the *Geo Web*. The *Geo Web* is a wide Web community based on the use of a set of specifications and applications with which systems can share and transform data with geographic content. This paper analyzes the powerful role of (x, y) as linker of spatial knowledge, and describes a practice, *Geo Linked Data*, that transforms the juxtaposition into a formal link between two different approaches of representation of the spatial semantics: the formal, represented by the *Semantic Web*, and the configurational, represented by the *Geo Web*.

1 Introduction

A user looking for *hotels in Lisbon* in a Web search engine expects not only information about prices and quality of service but also information about the location. The information conveyed in the search engine's response about the location might modify the user's decision about booking a hotel. Today, a popular way to provide rich informative data about the location is to provide a map with locations markers.

Location markers and maps are a powerful way to convey spatial semantics on the Web but, in the context of the *Semantic Web*, they are just ancillary tools. Today, we can use a URI and the Web, such as the URI `http://dbpedia.org/resource/Lisbon`, to dereference a URI to a formal description of a location, such as Lisbon. However, we should consider how the semantic Web mashups present the spatial content of the result of a user search. The mainstream approach is the extraction of geographic points from the formal description, and then, its conversion in a marker on a map viewer client. Good examples of this approach are Tabulator [6], Falcons [21], DBPedia Mobile [4], and LinkedGeoData [3]. That is, the geospatial semantics of a resource as complex as Lisbon is often:

1. *simplified* in formal descriptions of the *Semantic Web* to (x, y) pairs, and then
2. *overlaid* on a geospatial representation provided by a remote server that gives an interpretative context.

The latter geospatial representation does not proceed from the *Semantic Web* world, but from the *Geo Web* community. The *Geo Web* is about the use of a set of specifications and applications with which systems can share and transform data with geographic content. This includes markup languages, data access services, map services, catalogue services among other. Standardization organizations, non-governmental organizations, and vendors from the Geographic Information Systems (GIS) community are the main developers of these specifications and applications. But what is more important, in the last five years among these specifications and applications there are some of them, such as the markup Language KML [26], that have been developed by Web practitioners for the Web mass market. The Geo Web began in the mid 90's as the integration of functions found in existing desktop GIS, such as the ability to render maps as images, into Web based applications. The standardized Geo Web does not appear until year 2000 with the specification Web Map Server 1.0 (WMS) [10] published by the Open Geospatial Consortium (OGC), an industrial standardization organization. Since the year 2000, OGC has published other geospatial specifications such as the geographic markup language GML [20] and the geodata access service WFS [25]. With the development of the Web mapping technology, the Geo Web was mature to go a step further. The inflection point is the introduction by Google in 2005 of a searchable mapping and satellite imagery application. Google Maps, with an API that enabled an easy integration to existing Web applications, made the Geo Web part of the mainstream Web.

The *Semantic Web* is about the use of a particular set of W3C standards with which we can encode meaning on Web resources in such a way that the intended meaning of the resources is more accessible to machines, and, as by-product, to humans. These standards allow to assign unambiguous names to resources (URI), to express, to link and to query data and metadata (RDF, SPARQL), and to capture semantics with the express purpose of describing data and metadata clearly across a wide audience (RDFS, OWL). These standards are the outcome of the ambitious research programme that the full vision of the Semantic Web envisioned by Berners-Lee [5] has boosted. Furthermore, the full vision requires additional research for the definition and wide adoption of standards for rules, logical proof, cryptography, trust, and user interfaces. Initiatives such as Linked Data interconnect data on the Web data using the Semantic Web standards, which allows linking remote resources. Linked Data promotes a shared agreement on the meaning of some of the messages and status codes of the HTTP protocol that is described by Sauermann and Cyganiak [23]. The Linked Data community has developed a semantic commitment that guarantees a coherent and consistent use of the HTTP protocol to link resources. Unfortunately, the Linked Data community has no formalized this commitment, although there are open research lines, such as the work of Halpin and Presutti [14] on the development of conceptual formalisms for modelling Linked Data.

We analyze in this paper a possible approach to enrich the spatial semantics in the Semantic web applications that intertwines the formal representations with the geospatial representations. This approach generalizes the commitments of the Linked Data to allow data represented in standard geographic formats, such as GML, and georeferenced media, such as the images from a Web mapping service. This approach involves:

1. *specification* of the relation among RDF graphs, standard geographic formats and georeferenced media, and the entities that they are cognitive and computational proxies, and
2. *advertisement* to the user of the existence of the above relations using RDF graphs.

The latter allows users' applications to move seamlessly between different geospatial representations. We use the term *Geo Linked Data* to describe this commitment on that extends the commitments of the Linked Data community.

This paper is organized as follows. Section 2 analyzes the juxtaposition of the spatial semantics between the Semantic Web and the Geo Web and provides hints to intertwine both. Section 3 describes Geo Linked Data and its concepts. Section 4 shows a use case of application of Geo Linked Data. Finally, we present conclusions and future work.

2 Who bears the semantics of (x, y) on the Web?

We use the terms c*onfigurational geographic knowledge* and *declarative geographic knowledge*, coined by Mark [19], to identify two kind of interpretations of the spatial semantics that we can find, for example, in (x, y) pairs. A phrase that asserts simultaneously a basic configuration of a geographic space (*configurational geographic knowledge*), and a declaration of a geographic fact (*declarative geographic knowledge*) is:

> Lisbon is located at *38° 42′ N, 9° 11′*.

But this simultaneous assertion can also be found in:

> Lisbon is part of Portugal.

The configurational knowledge includes not only geometry but also topology. The knowledge about the configuration of a geographic space, for example, allows the estimation of the distances and relations between points. This powerful characteristic is the basis of the manipulation and visualization of points on map viewer clients in semantic Web mashups. The configurational knowledge is a subset of the declarative geographic knowledge. The declarative knowledge about spatial things includes any knowledge about resources located on the geographic space such as name, population or type.

We can find *configurational geographic knowledge* on different kind of representations of the geospatial semantics on the Web. We can use the classification of representation of geospatial semantics for the Web proposed by Egenhofer [11] to analyse how the *configurational geographic knowledge* is conveyed on the Web: *natural language texts with minimum markup*, *simple metadata*, *data models* and *logical (model-theoretic) semantics*. Henceforth, we use the term *formal models* to refer to *logical (model-theoretic) semantics*. *Natural language with minimum markup* representations is exemplified by HTML Web documents with phrases such as *Lisbon is part of Portugal* and includes any resource that can be processed as plain text. It is difficult to retrieve the geographic knowledge from the text. *Simple metadata* that appears as specially designated tags on Web documents, such as the term "spatial", part of the DCMI metadata terms [9], or the tag "ICBM" used by the GeoURL project [24]. *Data models* provide Web resources with an identifiable conceptual structure in terms of primitive objects, entities, relationships and attributes. Data models include geographic markup languages, such as KML and GML, application profiles based on these markup languages, such as GeoRSS [22], and conceptual modelling languages, such as RDF. Data models enable Web users the access to geospatial data and the performing of remote Geoprocessing tasks, which often consist of combining primitive spatial objects to produce new representations. Hence, we can find geospatial semantics in data models instances, such an RDF graph which contains a point description made with the vocabulary Basic Geo [7], and in the outcome of remote Geoprocessing tasks, such as an image map retrieved from a WMS server. The configurational geographic knowledge appears often in the data models represented by semantically well-defined elements, such as coordinates or as a topological relationship between two data elements. *Formal models* allow making an ontological commitment on the correspondence among Web resources and world entities, and automated reasoning tasks. However, the amount of geographic configuration knowledge represented in logical semantics is limited because geometrical geospatial representations make difficult an efficient reasoning [1].

Egenhofer realizes that the main bearers of the spatial semantics in representations in natural language with minimum markup are the documents themselves and the users. Aslo he states that, for simple metadata, data models and formal models, the systems that carry out geospatial processing tasks the bearers are the documents, the users and the systems that carry out geospatial processing tasks. Consider the Figure 1. On the left, the representation in the geographic space of the location of Lisbon that a semantic resource, such as DBPedia, provides. This resource has an URI resource, for example `:Lisbon`, that servers as formal identifier. On the right, a realization of information about the same entity provided by a geospatial processing system, such as a Web mapping service. This realization might be approximate, that is, it might refer to several entities. For example, it may also provide the location of Madrid. On the centre, we present the overlay of one on other. The bearer of the semantics in the first case is the formal document itself, and the server if we are dealing with Linked Data. That is, the application can assert that exists a resource identified with `:Lisbon` located in the coordinates (x, y). The main bearer of the semantics in the second case is the system that has done a geoprocessing task to render a map derived from the data stored in a spatial database. We need to read the metadata of the service in order to understand how the spatial information has been realized into the image. Finally, the chief bearer of the semantics in the third case is the user, because the user is able to understand that both representations can be overlaid: both are spatially compatible, and it realizes that their understanding about the resource identified as `:Lisbon` can be enriched by the content of the map.

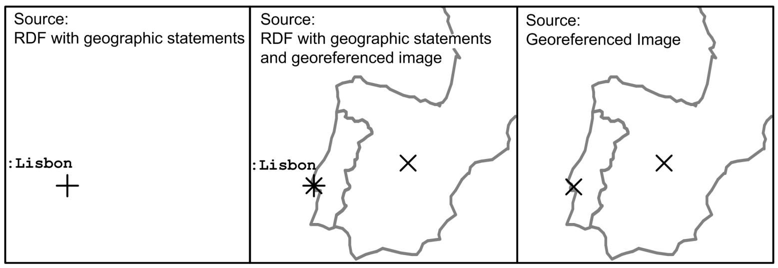

Fig. 1. Realizations of the spatial semantics of a resource identified as Lisbon.

In the context of Linked Data, we should ask if the server as bearer of the geospatial semantics could ease user tasks that deal with geospatial semantics if it has knowledge of the existence or presence alternative representations of the geospatial semantics. For example, when a user does a request with a geospatial bias, such as looking for "a map of rivers of Portugal" on the DBPedia, the answer should not only contain the locations encoded in RDF format but also clues to discover an appropriate Web mapping service where the points can be overlaid. Even, the user and the server should be able to negotiate a different representation of the knowledge when the user knows that knowledge has a spatial nature. That is, the user can start a content negotiation for an image from a Web mapping service instead of a RDF document.

We identify two complementary approaches to extend the representation of configurational knowledge on the Linked Data:

1. *negotiate* the content of alternative geospatial representations, and
2. *advertise* the presence of alternative geospatial representations.

The first approach, described in Kevin et al. [16], requires that the user knows the availability and the media type of the different representations. Then, the user can move seamlessly between different geospatial representations retrieving RDF and Geo Web representations from the same URI when required. The second approach, described in this paper, is to advertise the available representations in the server and its semantics. Then, the user might select the most appropriate representation for its processing requirements. For example, a user looking for a map of the rivers of Portugal can retrieve an RDF description associated to `http://dbpedia.org/page/Category:Rivers_of_Portugal`. Then, discover the fact that a representation as an image is associated with the same URI. To be effective, both approaches require that users and servers have the same commitment about the interpretation of the vocabulary that advertises the existence of the representation.

3 Geo Linked Data Interface

Linked Data provides two mechanisms to identify resources that may exist outside the Web: *hash URIs* and *303 URIs forwarding*. Both involve resources that act as proxy for other resources. The notion of proxy here is similar to the notion of proxy introduced by Gangemi and Presutti [13]: a resource is a proxy only if it realizes an information object about other resource. The first solution that Linked Data provides identifies the resource with a hash URI, a URI that contains a fragment identifier separated by the rest of the URI reference by a # (number sign or hash symbol) character. The procedure is as follows. The user requests a representation encoded in a formal language of a resource identified by a hash URI. This requires first to strip off the fragment from the hash URI, and then dereference the stripped URI to a representation. If the representation retrieved from the server is effectively encoded in a formal language, such as RDF, then the user can assert that the retrieved representation is a formal proxy for resource identified by the hash URI. This solution is the preferred for stable and small sets of resources. The second solution is based on a commitment on the interpretation of the HTTP status code *303 See other*. The procedure is as follows. The user requests a representation encoded in a formal language of a resource identified by a URI. The server responses with a HTTP code *303 See other* and the location of an alternative document. When the user retrieve the alternative document, which must be encoded in a formal language such as RDF, then the user knows that the alternative document is a formal proxy for the resource identified by the URI.

We can identify a special kind of proxy that is related with the spatial semantics. A proxy is identified as a *geospatial proxy* if it realizes an information object that is about the geospatial semantics of other resource. We can identify six possible roles that the geospatial proxy can fulfil (Figure 2):

- *broad*, the proxy describes a wide spatial area where the information about the resource is only a small fraction. For example, world maps or large regional maps are often used as geospatial proxies for the capital cities.
- *close*, the representation in some circumstances can be interchangeable with the spatial semantics of the resource. A geometry that can be employed as a marker on a map, or an overview of the surrounding area are typical close representations.
- *narrow*, the resource describes a small spatial area inside the area of the resource. A good example are landmark maps that are used as metonymic reference for the resource, such as a map that includes the captial city for the country.
- *related*, the representation realizes an information object that spatially interact with the spatial semantics of the entity. For example, a street map often acts as proxy of the town.

- *approximate*, the representation realizes an information object that spatially interact with more than one resource. Image maps of an urban area or a dataset of named places are the approximate representation of a set of resources.
- *exact*, the representation in the context of a geospatial tasks has exactly the same spatial semantics of the resource and only describes that resource. For example, the geometry that define the administrative boundary limits of a political entity.

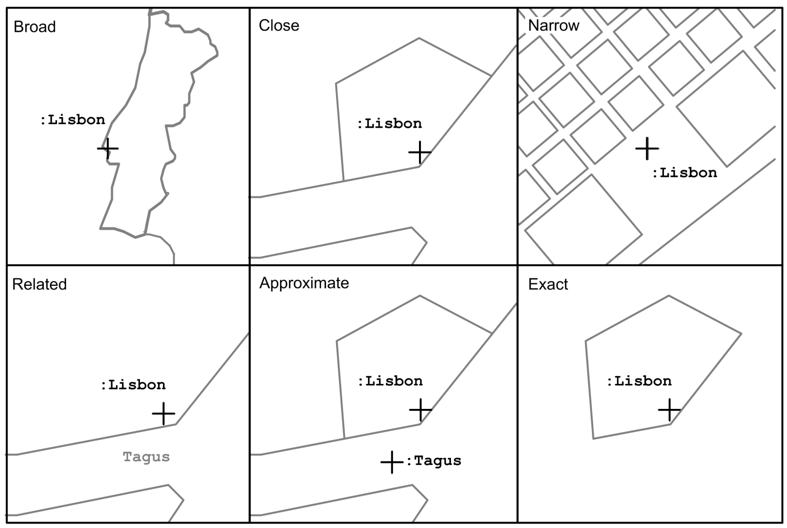

Fig. 2. Different geographic proxies for the official boundary of Lisbon

We use the term *GeoLinked Data* for identifying an extension of the Linked Data mechanisms that takes into account the geospatial proxies. If the user request a representation encoded in a standardized geospatial format of a resource identified by a URI, and through the above mechanisms the user retrieves a document encoded in a standardized geospatial format, then the user knows that the returned document is a geospatial proxy for the resource identified by the URI. That is, the document realizes geospatial semantics about the resource identified by the URI. This realization has a subtle advantage over the conventional Linked Data approach. The spatial semantics might or not be present in formal proxies for resources. With the approach of *GeoLinked Data*, if the resource has a spatial proxy then the spatial semantics must be present on the proxy document. Figure 3 shows how a user can use this extension. If the user has a Semantic web facet, it will request and negotiate the content of a formal representation that might realise or not the spatial semantics of the resource. However, if the user has a Geo web facet, it can retrieve a Geo web document, such as a GML or a georeferenced image, that realizes the spatial semantics of the resource.

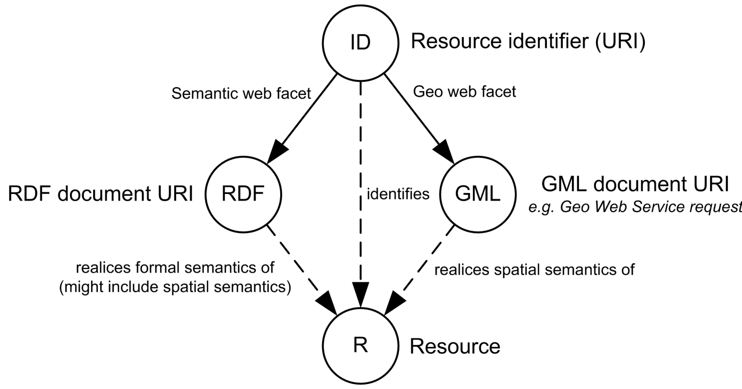

Fig. 3. Two ways to realize the essential spatial characteristics of a non-information resource.

We identify an essential requirement for the implementation of the *GeoLinked Data* interface: the *advertisement* to the user of the existence of geospatial proxies. We identify two ways to advertise the availability of a Geo Web representation:

1. *assert existence* (Figure 4) and
2. *assert location* (Figure 5).

For example, in RDF, as it is based upon the idea of making statements in the form of subject-predicate-object expressions, we can relate a resource URI to a geospatial proxy adding the following statement to its formal proxy:

```
<resource URI> :hasGeoProxyWithContentType <mimeType> .
```

`the predicate :hasGeoProxyWithContentType` is a property defined in a vocabulary whose definition must assert the existence of an additional geospatial representation with range, for example, the list of Internet Media Types. Then the user can dereference again the resource URI but asking for the mime type that was asserted in the statement to retrive a geospatial representation. The server is responsible to forwarding the user the location of the geospatial proxy.

Assert a location is the same as asserting that an information resource exist on a Web address. However, we also assert that the information resource is a geospatial proxy for a resource. Assert a location requires the addition of the following statement to its formal proxy:

```
<resource URI> :hasGeoProxyLocatedAt <document URI> .
```

The predicate `:hasGeoProxyLocatedAt` is a property whose range are valid URLs. To be a valid Geo Linked Data link, the vocabulary must assert that the information object pointed by the document URI is a geospatial proxy of the subject. This approach allows to include additional metadata about the geospatial proxy. For example:

```
<resource URI> :hasGeoProxy <internal URI> .
<internal URI> :locatedAt <document URI> .
<internal URI> :owner <owner URI> .
```

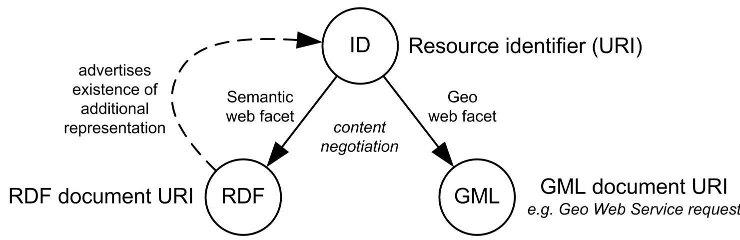

Fig. 4. Advertise the existence of an alternative spatial proxy for the resource.

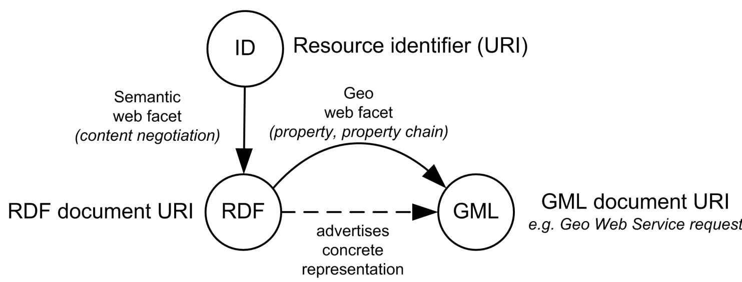

Fig. 5. Advertise the location of a spatial proxy for the resource.

4 Use case: Publication of a national gazetteer

Geo-Net-PT 02 [17]is an authoritative geographic knowledge RDF dataset about named places of Portugal. Geo-Net-PT 02 is available in the XLDB Node of Linguateca (`http://xldb.di.fc.ul.pt/wiki/Geo-Net-PT_02`) under a Creative Commons license (CC-BY) that allows its free use by researchers. Geo-Net-PT 02 defines 701,209 instances, most of them named places and place names. The named places are classified in 81 types. Postal codes, streets and settlements are the most common types. Geo-Net-PT 02 has 21 different sources. A relevant source is the Instituto Geográfico Português (IGP) that provides the Official Administrative Boundaries Map (CAOP) of Portugal for the administrative units. This information is available on the Web through OGC Web Services Geo (WMS and WFS) by SNIG. SNIG is the Portuguese Spatial Data Infrastructure, which enables users to identify, visualise and explore Geographic Information accessible by a geoportal [2]. The CAOP dataset is continuously updated and the versions published on the Web might change. Then Geo-Net-PT 02 faces a problem of obsolescence of the geographic data derived from the updates of the CAOP dataset.

The conceptual model of *Geo-Net-PT 02* extends a previous version [8], based on conceptualizations of Hill [15], Manov et al. [18], and Fu et al. [12]. It is formalized in a vocabulary named Geo-Net. The Geo-Net vocabulary is intended to describe and discover toponymic datasets. By description, we mean the identification of relevant place names and geographic features that they refer to. By discovery, we mean the identification of geographic features that best match a query. he Geo-Net vocabulary defines concepts such as places (class `Feature`), place names (class `PlaceName`), types (class `FeatureType`), relations between pairs of places (class `FeatureRelation`) and locations (class `Footprint`). In order to decouple the Geo-Neo-PT 02 dataset from the actual data representation of the geographic information, the dataset has been enriched with a description of the geographic proxies of the footprints of the administrative units.

Figure 7 shows the main elements involved in the publication as Geo Linked Data: the user, the user clients, the geo linked data server and the geo web service. The user clients can process formal geographic facts embedded in formal representations and can order a Geo Web client to dereference a resource URI to a Geo Web representation. The Geo Linked Data Server is a Web server that implements the Linked Data recipes. However, it has been configured to apply the same recipes to some URIs when the user requests a geographic content type. The Geo Linked Data Server makes accessible a RDF dataset that includes statements that assert that some resource URIs have also a Geo Web representation. These statements are constrained to the administrative units described in the CAOP. The dataset contains statements not intended to be publicly available: the mappings established between URI resources and Geo Web representations. This are used to configure the Geo Linked Data Server and might change is the Geo Web representation change. Finally, the Geo Web server is a WFS that provides the official geometries of the CAOP in GML format.

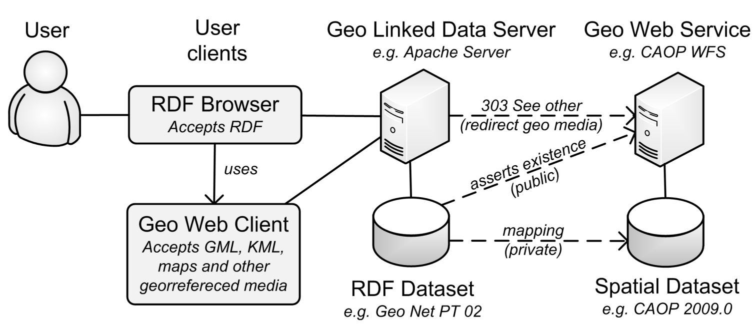

Fig. 6. Use case secenario: geo proxies for Geo-Net-PT 02

The vocabulary Geo-Net has been extended with four properties that describes the spatial proxies. We use the prefix `gn:` to identify the Geo-Net vocabulary.

– `hasGeoProxyWithContentType` and `hasExactGeoProxyWithContentType`, asserts that a resource URI has a spatial proxy representation that can be obtained in the content negotiation. The range of the property are valid MIME types literals. For example, a footprint with geospatial proxy can be advertised as follows:

```
:LisboaFootprint a gn:Footprint .
:LisboaFootprint gn:hasExactGeoProxyWithContentType
  "application/vnd.ogc.gml" .
```

– `hasGeoProxy` and `hasExactGeoProxy`, asserts that a resource URI has a spatial proxy identified by the object. hasExactGeoProxy is a subproperty that signals a perfect match in the geospatial semantics. The effective location of the spatial proxy is asserted as follows:

```
:LisboaFootprint gn:hasExactGeoProxy :LisboaFootprintProxy .
:LisboaFootprintProxy rdfs:seeAlso <effective location> .
```

  This information is intented to be internal. Its purpose is the maintenance of the dataset and the configuration of the Geo Linked Data server.

Figure 7 shows the perspective from the point of view of the user client. First, the client dereferences `:LisboaFootprint` and discovers that a representation as GML is also available. Then, the cliente dereferences again but asking for GML. Then, the client can, for example, display the GML on a map. But, as it formally knows that the GML is a geospatial proxy for `:LisboaFootprint`, can process the geometry and use this information to look for more data in other Linked Data datasets.

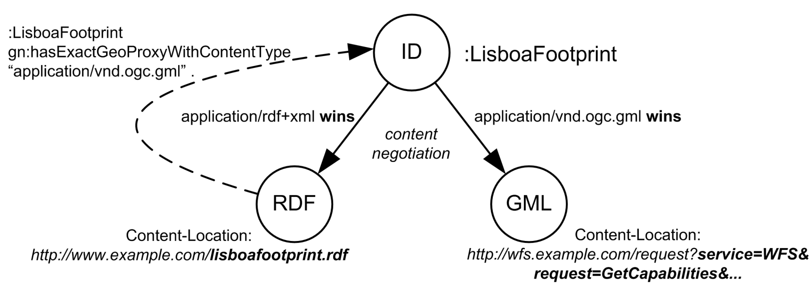

Fig. 7. Use case secenario: geo proxies in action

5 Conclusions

Geo Linked Data provides a way to not overloading RDF datasets with large amounts of highly detailed geographic information. Also, provides a formal basis to link different spatial representations of the a resource with its resource URI. It only requires to advertise the user that there is available additional representations of the resource in a different format. This approach can be generalized to link Linked Data datasets to other media.

This paper has shown its use in the geographic aspect of the information. It can enrich or provide more consistence to existing applications build with Linked Data. Future work will include the formalization of the categorization of spatial proxy representations, and the relation with concepts of the Geo Web.

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