Data Model for Geographic Ontologies Generation

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Abstract: Structured geographic information has an important role in many applications, such as geographically-aware search engines and named-entity (e.g., proper names) recognizers. This information is compiled from resources like dictionaries, gazetteers and ontologies. The quality of the applications depends critically on the richness of these resources. This article describes a new version of the Geographic Knowledge Base (GKB), an environment for integrating geographic data and generating ontologies. We introduce the new metamodel of GKB and show how the information in its repository is transformed into OWL representations. We also present the data integration process of the administrative and physical domains, which deals with geographic relationships in both domains.

Keywords: modeling, geographic ontologies, ontology generation

1 Introduction

A well-defined model has an important role in any kind of system, facilitating its reuse and extension. The model-driven approach defines relationships among concepts in a domain and precisely specifies the key semantics and constraints associated with these domain concepts [1]. Considering that all information represented in a system is constrained to the model, the modeling phase is crucial to determine what and how is possible to represent within an application.

The modeling becomes more complex when we try to bring together several views of different communities. The geographic knowledge domain is an example in which geographers, geographic engineers and computer scientists (when coping with geographic information) use different terminologies to represent the same information. These terminologies need to be integrated in a model, which must be able to consistently represent the geographic concepts. A consensual notion concerns the existence of two geographic domains: administrative and physical.

Geographic Knowledge Base (GKB), an environment for integrating geographic data and generating ontologies, is implemented based on a model able to support the storage of the information from administrative and physical domains [2,3]. The first version of GKB (GKB 1.0, henceforth) contains two instances: one stores data about the geo-administrative and network (web) domains of Portugal and the other contains data from all over the world.

The information stored in GKB 1.0 is exported to ontologies in the OWL format. One of these ontologies (Geo-Net-PT01) contains the integrated geographic administrative information of Portugal and is freely available from `http://xldb.fc.ul.pt/geonetpt`. Applications using Semantic Web technologies can easily work with the ontologies exported from GKB [4,5]. Other examples of use of the ontologies generated by GKB 1.0 can be found in [6,7].

This article describes a new version of GKB (hereafter GKB 2.0), which supports a couple of new requirements. A more detailed representation of the geographic names and a better control of information sources among other improvements should be provided by GKB 2.0. In addition, full support to the modeling of the physical domain and its integration with the administrative domain should also be present in the next version of GKB.

The main contribution of this article is a detailed description of the model for integrating geographic information from multiple domains and making this knowledge available as ontologies in a Semantic Web format. We are working on data about Portugal, but the model could be applied to represent geographic knowledge from any country or geographic region.

The structure of this article is as follows: Section 2 introduces the GKB requirements and Section 3 details the design of the new GKB model. Section 4 describes the geo-physical domain introducing new physical concepts and relationships. Section 5 shows the conversion of the GKB 2.0 model to OWL ontologies and Section 6 presents related work. Section 7 gives the final remarks.

2 GKB 2.0 Requirements

It is necessary to introduce the notion of the *feature* concept in this work, borrowed from the GIS (Geographic Information System) world, before we describe the requirements for GKB 2.0. A *feature* is "a meaningful object in the selected domain of discourse" as defined in ISO 19109 [8]. Examples of *features* include the `Douro river` and the `Álvares Cabral Avenue`. Feature types, in the above examples are `river` and `avenue`, and their names are `Douro` and `Álvares Cabral`, respectively.

GKB 2.0 is centered on the notion of feature as in GKB 1.0, but includes a number of extensions:

Support for relationships between types: GKB 1.0 only supported relationships between features, such as `Lisbon` is `part-of Portugal`. GKB 2.0 also supports relationships between feature types, such as `rivers` are `part-of continents`.

Support for generic property sets: All the major classes (feature, feature type and name) may now include arbitrary attributes, whose support is defined in the metamodel. For example, attributes to a river include `source`, `outlet` and `length`, while a soil has a `PH level` and a mountain has an `altitude`. GKB 2.0 also provides a more detailed specification of feature names. Attributes of geographic names, like the language in which a name is given can be captured. In addition, it may store other attributes of the geographic names, such as time and demonyms. For example, `Olissipo` is an `historic` name of `Lisbon` and `lisboeta` one of the Portuguese `demonyms` of the inhabitants of `Lisbon`.

Better control of information sources: Data lineage was very simplistic and recorded only at the feature level in GKB 1.0. For example, all information related to the *Municipality of Lisbon* was associated to one information source. In GKB 2.0, each name, type and relationship can be independently associated to a distinct information source. This extension allows us to know, for example, that two types are provided by distinct information sources and the relationship between them is derived from a third information source.

3 GKB Metamodel

A model is an abstraction of phenomena in the real world, and a metamodel is yet another abstraction, highlighting properties of the model itself [9]. In GKB the metamodel describes the classes and relationships that are used to model geographic information. The GKB 2.0 metamodel supports representations of multiple information domains related to geography, such as the administrative and physical domains. In each of these domains, the information is organized using concepts from the metamodel (e.g. features, feature types and their relationships).

3.1 Base Model

The core of the GKB 2.0 metamodel is represented in Figure 1. The class *Feature* is associated with the class *Type*, which stores the types (feature `Douro` is of type `river`). The class *Type-Relationship* captures the relationships between types (a `Municipality` is `part-of` a `Country`).

The class *Relationship-Type* stores the supported relationships, such as `part-of` and other relationships of geographic nature. Considering that a `river` is `part-of` a `continent`, the class *Type-Relationship* stores this relationship.

Features may be specialized by *Feature-Footprints*, which capture coordinate data. Coordinates represent centroids, bounding boxes and polygons. The feature `Serra da Estrela` has a centroid at `40°20N, 7°38W`.

3.2 Attributes and Names Representation

Figure 2 represents the base model of Figure 1 extended with the classes used for representing names and the attributes of types, features and names. Different geographic types have different attributes. A river has a length, a source and a mouth, while a mountain has an altitude and a municipality has population.

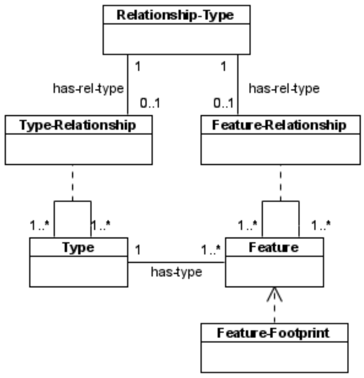

Figure 1. GKB 2.0 base class metamodel.

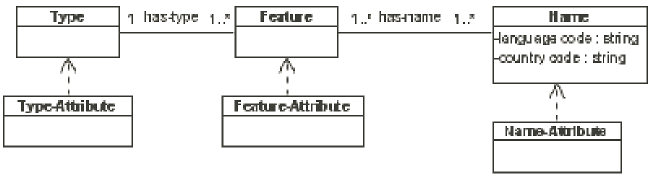

Figure 2. GKB 2.0 names and attributes model.

The classes *Type-Attribute* and *Feature-Attribute* add property sets to the base classes *Type* and *Feature*, respectively.

GKB 2.0 also provides better modeling of the geographic names. Each name is associated with a language and its country code (e.g., PT-BR), which are captured in the class *Name*. The language coding adopted follows the language tag standard <language code"–"country code> defined by RFC 3066 of the IETF [10]. Names can also be extended with sets of attributes capturing preferences (e.g., a name is preferred or alternative), time (e.g., used in the nineteenth century), use (e.g., rare, colloquial) and demonyms. These are stored in the class *Name-Attribute*.

For example, the river `Tajo` has its equivalent in Portuguese `Tejo` and its historic name `Tagus`, from Latin. The attribute historic is captured in the class *Name-Attribute*, whereas the class *Name* stores the names (`Tajo`, `Tejo` and `Tagus`), its languages (ES, PT and LA) and its country codes (ES and PT), respectively.

3.3 Inter-domain Relationships

GKB 2.0 stores information on administrative and physical domains. In addition to modeling relationships between features in the same domain, it supports inter-domain relationships. Figure 3 shows the model representing the inter-domain relationships.

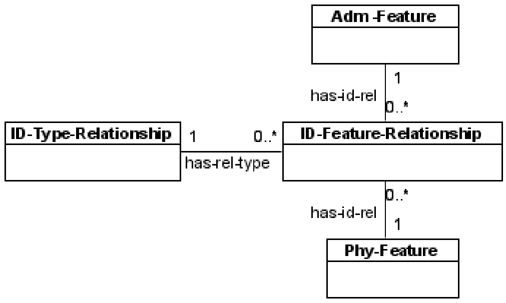

Figure 3. Inter-domain relationships in GKB 2.0.

The class *Adm-Feature* contains information from the administrative domain and the class *Phy-Feature* information from the physical domain. The class *ID-Type-Relationship* (ID stands for inter-domain) stores relationships such as `part-of` and `adjacency`. For example, the `municipalities of Lisboa` and `Setúbal` (administrative domain) are `adjacent` to the `river Tejo` (physical domain). This relationship is stored in the class *ID-Feature-Relationship*.

Other relationships such as `crosses`, `touches` and `intersects` are implicit on the footprint data and are not modeled as *ID-Feature-Relationship* in GKB. For example, the `Douro river crosses` the `municipality of Porto` and `intersects` the `Biótopo Alto Douro Internacional`.

3.4 Data Provenance

In GKB 2.0 the information sources are individually assigned both to types (concepts) and names (instances). Figure 4 shows how instances of the classes type, name and relationship are associated to their information source.

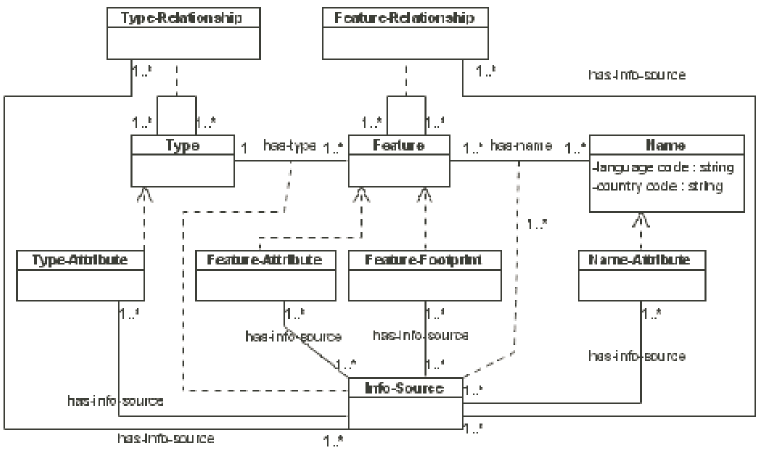

Figure 4. GKB 2.0 information sources model.

Information sources (IS) are now independently associated to each individual attribute and relationship in the model, and to each association between a feature and its names and type.

This approach also allows applications using GKB 2.0 to reason on the credibility of information assigning weights to each piece of data based on the level of authority of the associated information source. For example, a GIS should probably work just with the knowledge associated to coordinates provided by a state authority.

3.4.1 Information Sources

The information being used in this work for the Ontology of Portugal comes from *Ministério do Ambiente* (MA - Ministry of the Environment), *Instituto Geográfico do Exército* (IGeoE - Geographic Institute of the Army), *Instituto Geográfico Português* (IGP - Portuguese Geographic Institute), *Instituto da Água* (IA - Institute of the Water), *Instituto Nacioanal de Estatística* (INE - National Institute of Statistics), *Correios e Telégrafos de Portugal* (CTT - Portuguese Post Office) and *Instituto de Pesquisa da Marinha* (IMAR - Institute of Marine Research).

Information about the uses and occupations of the ground should come from the *Ministério da Economia*, but it is only available in a descriptive form at the moment. Such information will allow us geocoding to municipalities and through extrapolation represent their occupations of the ground. Other possible inferences concern to the ground and population or uses of the ground and climate.

Table 1 presents the geo-physical concepts provided by the information sources and the corresponding number of features (more than 23,000 features). Most of the information in Table 1 comes from IGP, which is the centre of reference to deal with geo-physical information in Portugal. All of these features have coordinate information. These coordinates represent polygons, which define the area occupied by each concept. The datum used in GKB 2.0 will be the European Terrestrial Reference System 1989 (ETRS89) - (`euref.org`). Statistics on data of administrative domain integrated in GKB have been published elsewhere [2].

4 Model of the Physical Domain

The previous sections described the GKB 2.0 metamodel for representing geographic information from multiple domains. This section presents the conceptual representation of the geo-physical domain and its integration with the geo-administrative domain. This last domain was previously presented in detail [2].

The geo-physical domain is harder to model than the administrative domain, because it has a much richer set of associations. This also makes the modeling of inter-domain relationships involving the physical domain more complex.

We divide the geo-physical domain into six sub-domains: hydrography, relief, soil uses and occupations, communication pathways, soils and climate. Figure 5

Table 1. Number of geo-physical features of each type obtained for the geographic ontology of Portugal.

Types	# features	Types	# features	Types	# features
Adega Reconhecida	311	Estabelecimento Dormida	2847	Nascente	220
Albufeira (área)	80	Estação Arqueológica	456	Parque Campismo	150
Albufeira (ponto)	1800	Estância Termal	35	Parque Nacional	55
Aldeia Preservada	217	Ferrovias	103	Parque Natural	12
Aquífero	125	Fortificação	263	Património Mundial	11
Área Paisagem Protegida	18	Gruta	7	Paul	441
Area Protegida	49	Jardim Botânico	7	Praia	591
Bacia de Escoamento	209	Kartódromo	30	RAMSAR	10
Bacia Hidrográfica	129	Lagoa	10	Rede Hidrográfica	7589
Biótopo	120	Litologia	2245	Regadio	90
Campo Golf	65	Local Culto	23	Região Natural	437
Casino	8	Marina	26	Reserva Natural	9
Edifício Notável	3877	Monumento Natural	5	Zona Fito geográfica	278
Espécie Notável	2432	Museu	524		

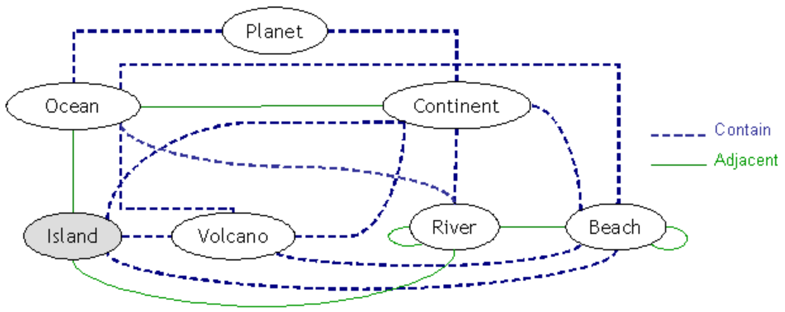

Figure 5. Excerpt of the geo-physical conceptual representation in GKB 2.0.

presents a small excerpt of the geo-physical representation, restricted to concepts from the hydrography and soil sub-domains.

The main problem in the representation of the geo-physical domain is how to correctly model the large number of relationships among the concepts. An example of the complexity of the relationships arise for the `island` concept, which is related to `oceans` and `rivers` under the `adjacency` relationship. However, its relationships are more complex when dealing with the *part-of* relationship. In the example of Figure 5, an `island` may be `part-of` a `continent`, a `beach` or a `volcano`. An `island` may also be related to other physical concepts, which have been omitted for the sake of clarity and space.

Figure 6 shows some instances of the concepts in Figure 5. It is possible to observe the multiplicity of relationships between features. It describes the geo-physical relationships for the `Rio Douro`, which is `adjacent` to `Albufeira Crestuma-Lever`. It also intersects four features: two from the geo-physical domain (`Intensidade Sísmica 6` and the `Biótopo Alto Douro Internacional`), and two from geo-administrative domain (the municipalities of `Porto` and `Vila Real`). The latter are examples of inter-domain relation-

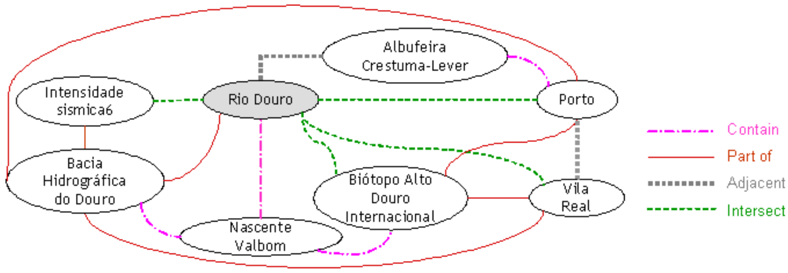

Figure 6. Excerpt of the inter-domain relationships among some geo-physical instances in GKB 2.0.

ships. The `Rio Douro` is also related to other physical instances, which have been omitted for the sake of clarity and space.

5 Publishing GKB contents for Semantic Web Applications

Once integrated in GKB 2.0, geographic knowledge can be exported in OWL, the Semantic Web format, for use by applications working with geographic information. Considering the different needs in the Semantic Web environment, generated ontologies may be organized in different ways. GKB 2.0 may export its stored knowledge with multiple data-structure organizations, corresponding to different visions of the information. It is possible, for example, to generate name-centered or feature-centered views. A named entity recognizer requires a name-centered representation for names look-up, whereas GIS applications are probably more interested in a loading of features satisfying some criteria and their associated attribute.

A name-centered view allows an application to know, for example, how many types a name is related to faster than with a feature-centered view. On the other hand, the feature-centered view enables the capture of the information (e.g., relationships, attributes and footprints) related to every single feature easier than with a name-centered representation.

Figure 7 presents an excerpt of the name-centered OWL format description of the geo-administrative name `Lisboa`. `Lisboa` is a `preferred name` (gn:att="P") provided by the INE `information source` (gn:is="INE") and has two other names. `Lissabon` is an `alternative name` (gn:att="A") in German and `Olissipo` is its `historic name` (gn:att="H"). The Wikipedia information source provides both names. `Lisboa` is also the name of different feature types. It may be a `province` (PRO), a `municipality` (CON), a `street` (RUA) and an `avenue` (AVE), among others.

The geographic knowledge output in OWL ontologies reflects the classes, relationships and the cardinality in the model described along the Section 3. The OWL sub-language used here is OWL-Lite. The restrictions of OWL-DL and OWL-Full are still not necessary in our representation. This fact allows any OWL reasoner handle the generated ontologies.

```
<gn:Geo-Name rdf:ID="GEO_ADM_30">
  <gn:names>
    <rdf:Bag>
      <rdf:li gn:name="Lisboa" xml:lang="PT-PT" gn:att="P" gn:is="INE"/>
      <rdf:li gn:name="Lissabon" xml:lang="DE-DE" gn:att="A" gn:is="WIKI"/>
      <rdf:li gn:name="Olissipo" xml:lang="EL-GR" gn:att="H" gn:is="WIKI"/>
    </rdf:Bag>
  </gn:names>
  <gn:geo_type_id rdf:resource="#PRO"/>
  <gn:geo_type_id rdf:resource="#CON"/>
  <gn:geo_type_id rdf:resource="#RUA"/>
  <gn:geo_type_id rdf:resource="#AVE"/>
</gn:Geo-Name>
```

Figure 7. An excerpt of a name-centered OWL representation from GKB 2.0.

```
<gn:Geo_Feature rdf:ID="GEO_PHY_145">
  <gn:names>
    <rdf:Bag>
      <rdf:li gn:name="Douro" xml:lang="PT-PT" gn:att="P" gn:is="IGeoE"/>
      <rdf:li gn:name="Duero" xml:lang="ES-ES" gn:att="A" gn:is="IGP"/>
    </rdf:Bag>
  </gn:names>
</gn:Geo_Feature>
```

Figure 8. An excerpt of a feature-centered OWL representation from GKB 2.0.

Figure 8 gives an excerpt of geographic names and attributes exported from a GKB 2.0 model to an OWL ontology. The feature `GEO_PHY_145` is describing the names and attributes for the `Douro river`. The `GEO_PHY` prefix represents features from physical domain whereas the `GEO_ADM` prefix encodes the features from administrative domain. The Douro river has a preferred name `Douro` in Portuguese `PT-PT` and an alternative name `Duero`, in Spanish `ES-ES`. Each name is associated with an information source. The first is provided by `IGeoE` whereas the second one is given by `IGP`.

Figure 9 shows an excerpt of how the feature types are represented in OWL. The excerpt describes the details about the Douro river. The type `Rio` and its attributes are provided by `IGeoE`. The source of Douro river is represented by the element `source_river` with a internal link to the feature, which has the identifier `GEO_PHY_120` (*Serra de Urbião* in Spain). The outlet of the river is `GEO_ADM_238` (municipality of Porto). Its tributaries are in number of 10, but Figure 9 just illustrates two of them, whose identifiers are `GEO_PHY_400` (`Paiva river`) and `GEO_PHY_401` (`Sousa river`). The `length` of the `Douro river` is `850 km`.

Figure 10 shows examples of the relationships involving the `Douro river`. The `Douro river intersects` the `municipality of Porto` (GEO_ADM_238) and the `Ribeira da Granja river` (`GEO_PHY_300`). In addition, the Douro river is `adjacent` to `Albufeira do Carrapatelo` (`GEO_PHY_198`) and is `part-of` the `Bacia Hidrográfica do Douro` (`GEO_PHY_100`). In this case, the `intersects`

```
<gn:geo_type_id gn:is="IGEO" rdf:resource="#Rio"/>
<rdfs:comment>Serra de Urbião - Spain</rdfs:comment>
<gn:source_river gn:is="IGEO" rdf:resource="#GEO_PHY_120"/>
<rdfs:comment>Porto - Portugal</rdfs:comment>
<gn:outlet_river gn:is="IGEO" rdf:resource="#GEO_ADM_238"/>
<gn:tributary gn:is="IGEO">
    <rdf:Bag>
        <rdf:li rdf:resource="#GEO_PHY_400"/>
        <rdf:li rdf:resource="#GEO_PHY_401"/>
    </rdf:Bag>
</gn:tributary>
<gn:length unit="km" gn:is="IGEO">850</gn:length>
```

Figure 9. An excerpt of types and its attributes in OWL in Geo-Net-PT02.

```
<rdf:Bag>
    <rdf:li>
        <gn:Geo_Relationship>
            <gn:rel_type_id rdf:resource="#INTERSECTS"/>
            <gn:geo_id>
                <rdf:Bag>
                    <rdf:li rdf:resource="#GEO_ADM_238"/>
                    <rdf:li rdf:resource="#GEO_PHY_300"/>
                </rdf:Bag>
            </gn:geo_id>
        </gn:Geo_Relationship>
    </rdf:li>
    <rdf:li>
        <gn:Geo_Relationship>
            <gn:rel_type_id rdf:resource="#ADJ"/>
            <gn:geo_id rdf:resource="#GEO_PHY_198"/>
        </gn:Geo_Relationship>
    </rdf:li>
    <rdf:li>
        <gn:Geo_Relationship>
            <gn:rel_type_id rdf:resource="#PRT"/>
            <gn:geo_id rdf:resource="#GEO_PHY_100"/>
        </gn:Geo_Relationship>
    </rdf:li>
</rdf:Bag>
```

Figure 10. An excerpt of relationships between geo-administrative and geo-physical domains in OWL in Geo-Net-PT02.

relationship was generated from coordinates, since it is not explicitly represented in GKB 2.0.

Finally, an other important characteristic of GKB 2.0 is that information can also be partially exported. Applications using ontologies generated by GKB 2.0 may have interest only in parts of its contents. For example, one may be interested only in the generation of features containing just historic names, features associated with types above a specific degree of granularity (e.g., localities or streets) or features provided from specific information sources.

Geo-Net-PT02 intends to be a reference for geographic information processing on the Portuguese territory, providing a large (wide and deep) coverage of concepts and instances. Geo-Net-PT01 filled this need for the geo-administrative domain whereas Geo-Net-PT02 is going to be enriched with geo-physical data, coordinates and multilingual names for features.

6 Related Work

Other works dealing with an environment to integrate and export ontologies are often in the scope of private companies or public initiatives. In both cases details about the construction of the resources are omitted or really do not exist. Two geographic information resources that are available for free or at a nominal license fee are the Getty Thesaurus of Geographic Names (TGN) [11] and Geonames (`geonames.org`).

TGN is a structured vocabulary including names and associated information about both current and historical wide-world places. Details about the construction of this resource are not available and the data-integration procedure is also unknown to us. TGN contains about 1 million places over the world, including both political entities (e.g. nations) and physical features (e.g. rivers) [12]. However, TGN lacks detailed information about Portugal (notoriously some of the most important street names).

Geonames is a large public geographical database, which contains a worldwide list of geo-administrative and geo-physical names. For Portugal, it has just 23,503 names in both domains. Historic feature types and names for Portugal (e.g., provinces) are also not provided by Geonames. Considering just the administrative domain, Geo-Net-PT01 has 34,519 distinct names for the geographic types above the level of localities (not including streets names) [13]. This leads us to conclude that the coverage of names supported by Geonames is very limited for Portugal.

7 Final Remarks

This article described ongoing work about the new version of GKB, detailing the data model and ontology format for the exported data. The model enables the generation of geographic ontologies representing knowledge integrated from geo-administrative and geo-physical domains. We also showed different ways for publishing GKB contents for Semantic Web applications, facilitating their parsing. Future work includes the processing (Extraction, Transformation and Loading (ETL)) of geographic data covering the physical domain and generation and release of Geo-Net-PT02.

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