A geo-ontology to support the semantic integration of geoinformation from the National Spatial Data Infrastructure

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Abstract. *The profusion of geoinformation and the diversity of providers increasingly demand availability of integrated geoinformation. The Brazilian National Spatial Data Infrastructure (INDE) and the Web 2.0 technologies provide the existence of such solutions. In this context, geoinformation needs to be discovered and processed, seamlessly and semantically interoperable through the services offered by INDE, independently of the existing technological arrangement. It is essential to have an information model that represents the involved concepts, their characteristics and their relationships. The development of a geo-ontology, in order to consolidate aspects of spatial metadata, spatial features and geographic names, is the challenge addressed by this work.*

1. Introduction

Over the last decades of evolution and exponential growth of geospatial content, there have been increasing demands for interoperability, integration and sharing of geoinformation, and increased ability to provide geospatial knowledge, especially by public organizations to attend multidisciplinary demands.

Recent studies address geospatial semantics through the use of consistent and well formed ontologies, as applied to the semantic objects when querying a heterogeneous geospatial database [Bishr 2008].

In order to provide an effective and efficient access, as well as to make spatial data available for all sociopolitical entities, many governments and public organizations have developed their Spatial Data Infrastructures (SDI), which aggregate the main functions of communication and spatial reasoning [Bishr 2008] of governmental actions and policies, emphasizing transparency and governance [Gimenez et al. 2013] [CONCAR 2010].

An SDI provides the representation of syntactic Web [Janowicz et al. 2012] based on the technology stack from the Open Geospatial Consortium (OGC) standards of geo-services with the architecture defined by the Global Spatial Data Infrastructure Association (GSDI). The services available in an SDI support syntactic and systemic integration describing interfaces for using geospatial data, in contrast to Semantic Web technologies.

The National Spatial Data Infrastructure (INDE) is a Brazilian initiative to set up an SDI, with national scope, bringing together public and private organizations, with focus on dissemination of geoinformation in Brazilian context. Its three key characteristics are the use of standardized metadata, semantic and syntactic interoperability [CONCAR 2010].

The INDE follows the definitions of the e-PING[1] architecture, which in turn references the OGC standards, adding other standards and specifications of the geographical domain in the Brazilian context: (i) MGB (Brazilian Geographic Metadata), a profile of the geospatial metadata standard ISO 19115:2003, which provides facilities for publishing, searching and exploring geospatial data; (ii) ET-EDGV (Technical Specification for Geographic Vector Data Structure), which describes the classes of geographic objects (geo-objects) and their interrelationships, providing a conceptual data model with attributes detailing [Gimenez et al. 2013].

The need for formalization and representation of the geoinformation at the semantic level, to face the challenges of SDI interoperability, was addressed by the OGC [Lieberman 2007]. In that work, the OGC issues regarding geospatiality (features and geometries of features, geographic and non-geographic relationships, systems and coordinates, scales conflicts) and geosemantics (discernment of a feature, spatial reasoning and representation dissonance) were the biggest challenges for semantic integration based on the characteristics of the domain. This field is still open, in that there is an increased availability of geoinformation that amplifies the need for geospatial semantic processing, in order to dynamically provide more elaborate geoinformation without redundancy [Gimenez et al. 2013][Diaz et al. 2012].

The objective of this research is to present an approach to the creation of a geo-ontology for representing geographic objects within the context of the INDE under the ET-EDGV and other associated standards, using the MGB profile and existing geographical names, as well as enabling the discovery and integration of geoinformation.

The remainder of this paper is organized as follows. Section 2 discusses the concepts and technologies applied to the field of geoinformation, the INDE and the development of geo-ontology. Section 3 presents the methodological approach for ontology engineering. Section 4 presents the sets of ontologies defined. Section 5 presents an application scenario of the geo-ontology. Section 6 presents some related works and proposals. Finally, Section 7 concludes and outlines future work.

2. Geoinformation and geo-ontologies: the Brazilian context

A geospatial data is a particular case of spatial data in which the spatial component refers to its position on the Earth and its space in a specific moment or period of time [Soares, Tanaka and Baião 2010]. The term comes from the geospatial association to the geoid concept, which is the physical model for the shape of the Earth or the equipotential surface (surface of constant gravitational potential) obtained by considering the mean value of the average level of the sea. The geoid surface is in fact more irregular than the ellipsoid of revolution usually used to approximate the shape of the planet and represent entities in relation to it [Bédard, Rivest and Proulx 2005].

In this way, expressions and mathematical models are used to derive the shape of the geoid. While there is an international ellipsoid (globally representing the Earth from a

[1] http://www.governoeletronico.gov.br/acoes-e-projetos/e-ping-padroes-de-interoperabilidade

“zero-point”, or point of reference), countries and international organizations are allowed to prepare their own local ellipsoids in order to view their region from an internal central point, thus generating a new geographic reference system. In Brazil, SIRGAS2000[2] is defined as the standard geographic reference system.

Geographic entities can be conceptualized in two different perspectives: geo-field (spatial data as a set of continuous distribution) and geo-object (spatial data that is discrete and identifiable throughout the world) [Fonseca 2008]. A geospatial object (geo-object perspective) is defined by its attributes and their spatial distribution [Zhou 2008].

2.1 The Brazilian context

The National Digital Cartographic Library (MND) [Lunard and Augusto 2006] represents the Brazilian geographic space in three parts: (i) matrix data, (ii) vector data and (iii) metadata.

Matrix data represents the geo-field perspective, and follows the ET-PCDG (Technical Specification for products of Geospatial Datasets) standard [CONCAR 2010].

Vector data represents the geo-object perspective, and follows the ET-EDGV standard [CEMND-CONCAR, 2008]. Its current version (2.1) addresses reference geospatial data for Topographic Systematic Terrestrial Mapping [CONCAR 2010], and a future version will include Cadastral Systematic Terrestrial Mapping.

The metadata structure is defined by the MGB Profile [CEMG-CONCAR 2009], which aims to promote documentation, integration and deployment of geospatial data as well as to enable search and exploration, while avoiding duplications. The MGB profile is structured in sections according to their objectives: (i) to identify the producer and technical production responsibility, (ii) to standardize terminology, (iii) to ensure data sharing and transfer, (iv) to facilitate information integration, (v) to enable quality control, and (vi) to ensure minimum availability requirements. The MGB profile is recommended for the description of geospatial reference data and has two versions: a full version and a summarized version, which is based on "Core Metadata for Geographic Datasets" ISO 19115:2003 with the addition of the Status attribute. Nowadays only includes metadata specification for data sets, does not cover services (ISO 19119), and also the implementation (ISO 19139).

Additionally, the Action Plan for the Implementation of INDE [CONCAR 2010] intends to consider the ET-BNGB standard, that is still under development, but is already being implemented on the Brazilian Geographical Names database [IBGE 2010], which deals with the geographical names used in the Brazilian systematic mapping.

2.2 Geo-ontology

A geo-ontology (or geospatial ontology) is an ontology that aims at describing spatial factors, spatial relationships, physical facts, subjects, collections of data and geospatial computing models [Di and Zhao 2008].

[2] ftp://geoftp.ibge.gov.br/documentos/geodesia/projeto_mudanca_referencial_geodesico/legislacao file rpr_01_25fev2005.pdf

Wang et al. [Wang, Li and Song 2008] proposed the following formulation:

Geo-ontology = {C, R, A, X, I}, where: C is the set of concepts of a geographical object, R is a set of relationships and the description of this set on the concepts, A is the set of attributes of the geographic object, X represents axioms and constraint rules on concepts, relations and attributes, and I is a set of instances.

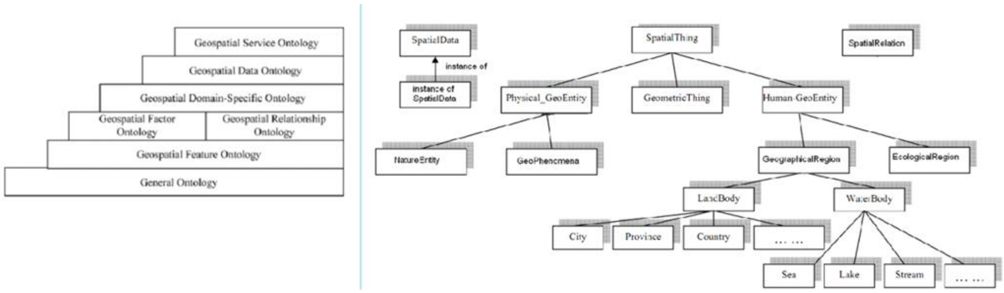

Figure 1: (a) Hierarchy of Geospatial ontologism [Di and Zhao 2008]. (b) Structure of geographic space [Adapted from Wang ET AL. 2007]

The geographic entities defined in the ET-EDGV standard may be arranged according to Wang's proposal [Wang ET AL. 2007] (illustrated in Figure 1(b)). With this arrangement, some concepts, relationships, conditions and attributes can represent geospatial ontologies of different levels as proposed by Di and Zhao [2008] (illustrated in Figure 1(a)).

3. Methodological approach for the construction of the proposed geo-ontology

This section presents the methodological approach we follow for constructing a geo-ontology for INDE. The proposed ontology was built by combining existing methodologies from the literature: the Simple Knowledge-Engineering Methodology defined in [Noy and McGuinness 2001] and the works from Wang, Li and Song [2008] and [Bishr 2008]. The Simple Knowledge-Engineering Methodology was adopted due to its simplicity and efficiency, while the methodologies of Wang, Li and Song [2008] and [Bishr, 2008] were considered to specifically address the geographical domain.

According to the Simple Knowledge-Engineering Methodology, the ontology designer defines a set of competency questions (CQ) to determine the scope of the ontology. After that, he/she follows a set of steps to: (1) determine the domain and scope; (2) reuse existing ontologies; (3) list important terms in the ontology; (4) define classes and class hierarchies; (5) define class properties; (6) define facets of these properties; and (7) create instances.

The methodology from Wang et al. [2008] is composed by the following steps: (i) confirm the scope of geo-ontology, (ii) list ontological properties (properties that describe the object in essence) for the geographical concept, (iii) ensure the relationship between geographical concepts; (iv) collect concepts meaning, their attributes, images and instances, and (v) build the prototype model / geospatial ontology system. Wang's approach uses the "Concept lattice", which is defined as sets of objects and attributes from geographic concepts that represent the main aspects of the geospatial domain: is-a, kind-of, part-whole, dependency, instantiation and member relationships, as well as the relationship between attributes and concepts.

Bishr [Bishr 2008] states that some elements must be observed during the construction of the geo-ontology concepts: (i) the context: establish the set of assertions and conditions considering a restricted vocabulary and spatial-temporal perspectives; (ii) identity criteria: establish sufficient conditions to determine the identity of a concept, organize the taxonomy of concepts and persist in time; (iii) spatial reference system: to represent the location concept for absolute or relative position; (iv) Mereotopology: incorporate relationships between assemblies, parts, parts of parts and boundaries between the parts in space; (v) limits: distinguish boundaries between "bona-fide" (intrinsic things) and "fiat" (marked as human cognitive effect) for the generalization of the concepts and treatment of co-localization of spatial objects; and (vi) the shape and size: characterize qualitatively ("has hole", is hollow, is a piece of something larger, is complete) and quantitatively (may assist in identification) for a feature size.

4. The proposed INDE geo-ontology

This section presents our proposed geo-ontology, following the steps of the methodology presented in the previous section. The proposed geo-ontology will serve as a basis for the semantic integration of spatial data within INDE.

The following competency questions were established, as required by the methodology from [Noy and McGuinness 2001]:

CQ1: Which conditions or characteristics are required by a Geographic name so that it addresses (identifies) a Geographic Feature?

CQ2: Which conditions or characteristics are required by a Geographic Metadata so that it can be associated to a Geographic Name when identifying Geographic Feature?

CQ3: How are the needs for cartographic generalization of geographic features be identified?

CQ4: How can we identify the same object being represented as distinct cartographic features using different scales?

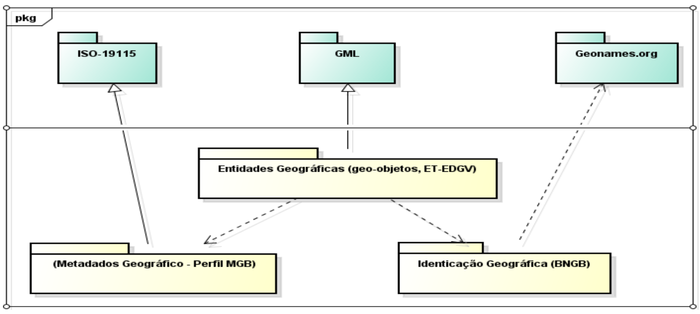

Figure 2: Overview of the INDE geo-ontology

To address these issues and serve as a basis for the semantic integration of different knowledge bases containing geographical data, we propose a geo-ontology composed by three sub-ontologies, as illustrated in Figure 2: (i) geographical names ontology ("*Identificação Geográfica*"); (ii) MGB profile ontology ("Metadados *Geográficos*"); (iii) geographic entities based on geo-objects.

4.1. Geographical Names ontology

This sub-ontology describes the basic features for the representation of Geographic Names, as defined in [IBGE 2010] and in [Lima 2011]. The Geographic name or toponym standard allows the identification of a Geographic Feature or Accident. A toponymic phrase consists of two parts: the element on the geographical entity that receives the name (generic term) and the element that distinguishes the identity of the geographic element (specific term) [IBGE 2010, Lima 2011 apud Dick 1990].

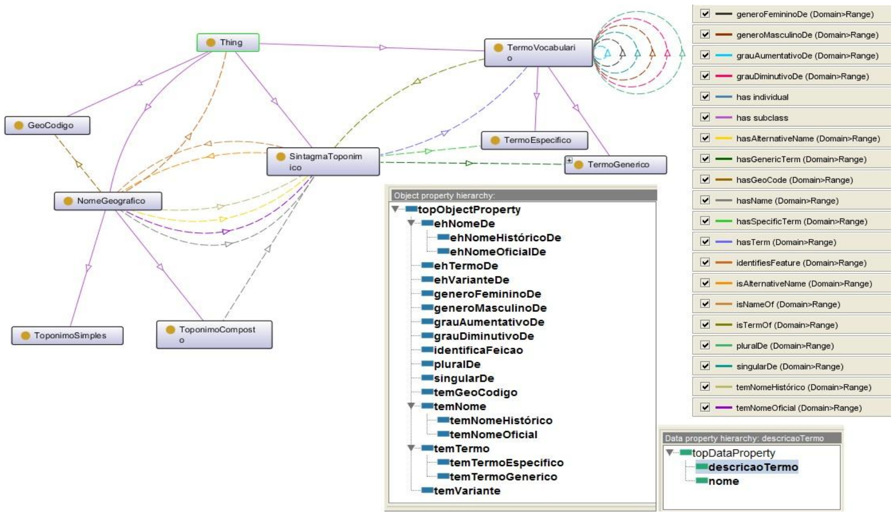

Figure 3: The Geographical Names ontology – basic view

Figure 3 shows the correlation between term and toponyms. It also encompasses lists of generic terms (as proposed in [IBGE 2010]), names denoting variation in gender (male x female) and number (plural x singular), alternative toponymic phrases for a particular geographical area, as well as the possible existence of geographical names composed of multiple toponymic phrases [IBGE 2010] [Lima 2011].

4.2. Brazilian Geographic Metadata Profile ontology

Ontologies for geographic metadata (e.g., ISO 19115 ontology) add semantic meaning and relationship to describe the underlying data [Di and Zhao 2008]. This extends the capability of geospatial data being discovered, used and semantically interoperable from the geo-ontologies of geospatial data or services.

This sub-ontology describes the basic features for the representation of concepts defined in the MGB Profile. The nature of the terms, their interrelations and dependencies, composition and classification between the two versions of the MGB Profile (Summarized and Full) were considered. The sections and entities referred in the profile specification were generally represented as classes in the ontology, while information and elements were typically represented as properties and enumerated lists.

The MGB Profile [CEMG-CONCAR 2009] has several information elements shared among several sections, many of them being referred as distinct terms in different sections. In those cases, we have preserved the distinct terminology and added synonym relationships to the ontology.

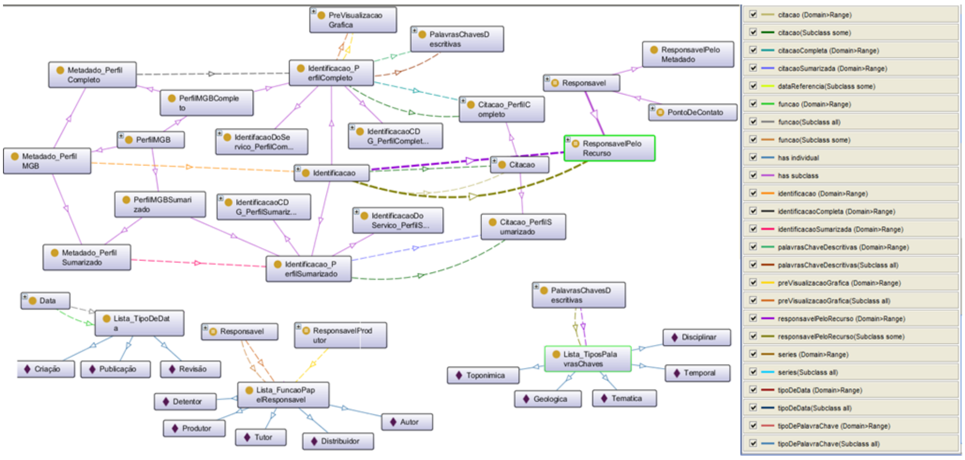

Figure 4: Brazilian Geographic Metadata (MGB Profile) ontology – partial view

As seen in Figure 4, the proposed MGB Profile ontology concepts is based on the ISO-19115 ontology (Metadata Application), which in turn makes use of several other ISO ontologies, including ISO-19103 (Conceptual Schema Language), ISO-19107 (Spatial Schema), GML (Geographic Markup Language), ISO 19111 (Spatial Referencing by Coordinates), ISO 19112 (Spatial Referencing by Geographic Identifier), ISO 19109 (Rules for Application Schema) and ISO-19108 (Temporal Schema). The concepts were all based on the MGB profile, but their characterizations as properties and fields followed the ISO-19115 where not defined by the profile [CEMG-CONCAR 2009] or in cases of distinct definitions [Diniz 2013] [Pascoal, Carvalho and Xavier 2013]. Cardinality restrictions were mapped according to the specifications in Table 1.

Table 1 – Mapping Cardinality for Ontology

MGB Profile		Ontology
Mandatory	**Cardinality**	**Mapping**
Yes	1	[ExactCardinality 1]
Yes	N (multiple)	[someValueFrom]
No	1	[MinCardinality 0 MaxCardinality 1]
No	N (multiple)	[MinCardinality 0]
Conditional	1	[subClasses] hierarchy and/or [ExactCardinality 1] or [MinCardinality 0 MaxCardinality 1]
Conditional	N (multiple)	[subClasses] hierarchy and/or [someValueFrom] or [MinCardinality 0]

4.3. Brazilian Geographic Domain ontology

The ontology of Brazilian Geographic Domain was based on the characteristics of geographic objects, spatial relationships and spatial primitives described in ET-EDGV [CEMND-CONCAR 2008] and the guidelines for the construction of each element and concept defined in ET-ADGV [DSG-EB 2011]. The Relationship, Classes and Objects (RCO) attached to ET-EDGV were also evaluated in order to broaden the semantic level of the concepts involved through class definitions and subtypes described. Additionally, the hierarchical classification of concepts was adjusted to represent the categories provided by their own reference specifications and classifications of geo-concepts proposed by Wang [Wang, Li and Song 2008]. The ontology is partially illustrated in Figure 5.

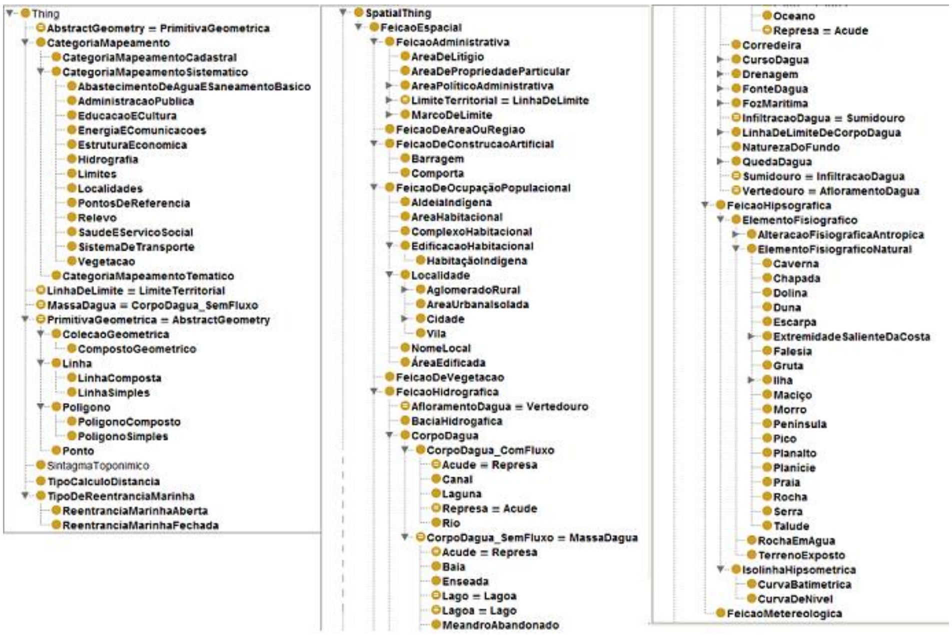

Figure 5: Brazilian Geographic Domain ontology – partial view

As seen in Figure 5 and Figure 2, the proposed ontology represents geo-objects of the domain covered in the ET-EDGV and ET-ADGV specifications, and makes use of the concepts of the ontology specification for GML (Geospatial Markup Language), that defines one geographic feature and the forms of spatial representation for geometric primitives among other characteristics.

The spatial relations and cardinalities presented by reference specifications are mapped to the ontology proposed as shown in Table 2 below:

Table 2 – Mapping Cardinality and Conditionality relations for Ontology

Cardinality and conditions from ET-EDGV	Ontology Mapping
0..1	**[MinCardinality 0] and [MaxCardinality 1]**
0..N (0..*)	**[MinCardinality 0]**
1..N (1..*)	**[someValueFrom]**
1..2	**[MinCardinality 1] and [MaxCardinality 2]**
1..1	**[ExactCardinality 1]**
Condittion {if 'tipoMassaDagua' = “Oceano” or “Baía” or “Enseada”}	**[OnlyValueFrom “Oceano”] or [OnlyValueFrom “Baia”] or [OnlyValueFrom “Enseada”]**

The subtypes are reported in RCO as subclasses of the class hierarchies for original, with consideration of the description of each element and the class itself, the categories were represented as a hierarchy. Figure 6 shows these correspondences demonstrating the case of class "*CorpoDagua*" (water body) and hierarchy of categories ("*CategoriaMapeamentoSistematico*" and others). The conceptual connection with the Brazilian Geographic Metadata Profile ontology is also presented.

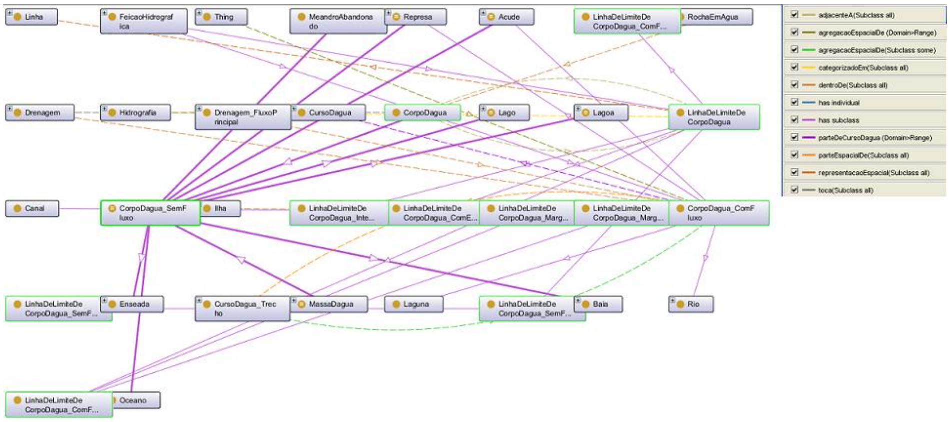

Figure 6: Class hierarchy and relationships to represent subtypes of RCO - case "CorpoDagua"

Whereas @OntoNG, @OntoMG and @ OntoFG respectively as sub-ontologies of Geographical Names, Geographical Metadata and Geographic Domain, the Competency questions listed before in this section could be answered through set of assertions in Table 3 below:

Table 3 – Set of assertions that address the Competency Questions

Set of assertions	CQ addressed

• There is a name x queried.
• There is some GeographicName g:
  • @OntoNG:GeographicName.hasToponym"->Toponym.compositeName(x) OR
  • @OntoNG:GeographicName.hasAlternativeToponym"->Toponym..compositeName(x)
• And there is some GeographicFeature f:
  • @OntoFG:GeographicFeature.identifiedByName(g)
	CQ nº 1

• There is a name **x** queried.
• There is some GeographicName **g**:
  • @OntoNG:GeographicName.hasToponym->Toponym.compositeName(**x**) OR
  • @OntoNG:GeographicName.hasAlternativeToponym->Toponym..compositeName(**x**)
• And there is some GeographicMetadata **m**:
  • @OntoMG:GeographicMetadata.hasIdentifcationOfCDG.hasKeywords(x) OR
  • @OntoMG:GeographicMetadata.hasIdentifcation.hasAbstract(x)
• And there is some GeographicFeature **f**:
  • @OntoFG:GeographicName.identifiesFeature(**f**) AND @OntoFG:GeographicMetadata.describesFeature(**f**)
	CQ nº 2

▪ Considering GeographicFeature **f1** and **f2**. ▪ There is some Resolution **res1** as @ontoMG:GeographicMetadata.describesFeature(**f1**).hasIndentificationOfCDG->IdenticationOfCDF..hasResolution(). ▪ There is some Resolution **res2** as @ontoMG:GeographicMetadata.describesFeature(**f2**).hasIndentificationOfCDG->IdenticationOfCDF..hasResolution(). ▪ And **res2** <> **res1**.	**CQ nº 3**
• Considering GeographicFeature **f1** and **f2**. • There is some Resolution **res1** as @ontoMG:GeographicMetadata.describesFeature(**f1**).hasIndentificationOfCDG->IdenticationOfCDF..hasResolution(). • There is some Resolution **res2** as @ontoMG:GeographicMetadata.describesFeature(**f2**).hasIndentificationOfCDG->IdenticationOfCDF..hasResolution(). • With res2 <> res1 then generalizes f1 as gf1 and f2 as gf2, both using max value between res1 and res2. • And **gf1** is spatially equals **gf2**.	**CQ nº 4**

5. Application of the proposed geo-ontology

The example scenario is presented in Table 4 [Gimenez let al. 2013], where integrated geoinformation is obtained from the basic geoinformation available in INDE. Moreover, integration of the associated metadata and the correlation with the geographical names are also carried out. The final step of the integration comprises the alignment of the ontology that describes the INDE geo-services with the geo-ontology proposed by this work, and then followed by the geo-processing of the retrieved data to compose the integrated geo-information with its resulting metadata.

Table 4 – Application query sample [Gimenez et al. 2013]

Consulta	Um especialista ambiental deseja saber quais são as áreas urbanas de maior risco de deslizamento de encostas por região de interesse.
Recursos requeridos	• Dados de localidades e áreas urbanas. Provedor: IBGE. Temas: Localidades e Malhas Municipal e Estadual. Conceitos principais: Cidades, Municipios, Estados, Áreas Edificadas. • Dados de precipitação pluviométrica histórica por região. Provedor: INPE/CPTEC. Tema: Clima. • Dados de geologia e geomorfologia por região. Provedor CPRM. Temas: Geologia e Geomorfologia. Conceitos: declividade, formação do solo. • Dados de incidência histórica de catástrofes naturais por região. Possível provedor: Ministério das Cidades. Tema: Mapeamento de Áreas de risco. • Dados de relevo. Provedor: IBGE e Estados. Tema: Cartografia – Relevo. Conceitos principais: relevos, curva de nível. • Dados de hidrografia. Provedor IBGE, ANA e Estados. Conceitos principais: hidrografia, bacias hidrográficas, trechos de drenagem, curso d'água, massa d'água.

Thus, to provide the data needs of localities and urban areas, topography and hydrography of the query specified in Table 4, which are covered by the ET-EDGV standard, would require the combination of the corresponding concepts in the sub-ontology of geographic features. This combination is based on the evaluation of the geographical identity of each element, considering the sub-ontology of geographic names, and using the description provided by the geographic metadata sub-ontology.

6. Related works

Some studies have been made to define and specify the possible structuring of geo-ontologies sets to represent geographic space [Bishr 2008] [Di and Zhao 2008] [Kun, Wang and Shuang-Yun 2005] [Wang, Li and Song 2008].

Di and Zhao [Di and Zhao 2008] defines several levels of abstraction for geo-ontologies, as seen in Figure 1(a): (i) General Ontology – the core upper level vocabulary representing the common human consensus reality that all other ontologies must reference; (ii) Geospatial Feature Ontology – defines the geospatial entities and physical phenomena that form ontological foundation for geospatial information; (iii) Geospatial Factor Ontology – describes geospatial location, unit conversions factors and numerical extensions; (iv) Geospatial Relationship Ontology – represents geospatial and logical relationships between geospatial features to enable geospatial topological, proximity and contextual reasoning; (v) Geospatial Domain-Specific Ontology – represents the domain concepts by using proprietary vocabularies; (vi) Geospatial Data Ontology – provide a dataset description including representation, storage, modeling, format, resources, services and distributions; (vii) Geospatial Service Ontology – describes who provides the service, what the service does and other properties that the service has that it discoverable, as well as other characteristics of the service.

Our proposal differs from existing works by being specific to the Brazilian context and to the INDE technological stack of its applied patterns, datasets, MGB profile, and the particular characteristics of the associated Brazilian Geographical Names. We also adopt existing ontologies, such as Geonames.org, ISO 19000 series, GML and so on, in a simplified perspective that covers all applied patterns to INDE.

7. Final Considerations

In this paper we outline the conceptual organization of the geographic entities defined to the Brazilian context based on INDE and ET-EDGV specification about geo-objects, as well as information about BNGB (Brazilian Bank of Geographic Names) and MGB Profile. Much has to be done yet, to achieve a geo-ontology that can be accepted as the basis for semantic integration of several heterogeneous sources as to the themes and producers in the Brazilian context. This work has the intention to (re)open the discussion and the application prospect to maximize the use of basic geoinformation available in INDE. The focus of our current work is to use the geo ontology proposed applied on architecture for semantic integration for INDE.

The main contribution of this proposal is the combination of concepts from the geographic names, metadata and geographic entities, providing support for analysis, applications and multifaceted uses.

Besides promoting the technical and academic contribution for the research centers and the institutions participating in the INDE, in order to mature the geo-ontology proposal, we can envision some future work: (i) extension of the proposed geo-ontology to cover the needs of Systematic Cadastral Mapping as soon as the ET-EDGV specifies them; (ii) extension of geo-ontology to represent metadata of geo-services that are not yet covered by the MGB Profile and adaptation of coded values lists to reflect the national context; (iii) extension of geo-ontology for geo-field in alignment to ET-PCDG[3] under elaboration; (iv) creation of geographic quality control ontology for validation and verification of geospatial data quality for alignment with the future ET-CQPCDG[3] specification; (v) expansion of Brazilian Geographic Domain Ontology to match ET-EDGV specification in a complete way, considering all rules and orientations in there; (vi) expansion of Brazilian Geographic Names Ontology to treat the concepts associated with historical, ethnological and linguistic characteristics of toponyms.

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[3]See more details for these specifications in CONCAR (2010)

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