Modeling an Ontology for Amazonian Biodiversity

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Abstract. Biodiversity information is essential for supporting environmental studies leading to conservation and sustainable development. It presents a high degree of complexity which includes: spatiotemporal parameters, undefined structure, multidimensionality, a not well-known or agreed vocabulary, large volume and dynamic evolution. To produce results of positive impact for biodiversity, automatic tools and models must interoperate. Due to the variety of data format and predictive models available, to achieve effective interoperability is challenging. To cope with such demand, semantic web and ontology has proved to present the necessary resources for data integration and interoperability. Particularly, ontology can drive knowledge acquisition processes for the purpose of comprehensive, portable machine understanding and knowledge management. This work presents domain ontology technique, developed with INPA's biological data and information as object of study, which was adopted to support biodiversity monitoring systems in Amazonia.

Categories and Subject Descriptors. Knowledge Management and Modeling: Ontologies.

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1. INTRODUCTION

The Semantic Web (SW) aims to contribute to the next generation of Web technology by adding semantics to the Web (Berners-Lee *et al.*, 2001; Albuquerque and Campos dos Santos, 2005). For this, it makes use of ontology to associate meaning to data. To develop ontology it is necessary engineering technology and domain experts. Regarding biology, ontologies have contributed to major advances in the area, enabling integration of various sources of data and consequently knowledge, a new approach to delineate experiments for transdiciplinary analysis and synthesis.

Research in biology is characterized by an intrinsic heterogeneity, not only on data and conceptual models used, but also on the needs and profiles of specialists who collect and analyze data. Massive data sets and diversity of specimens act as factors that bring complexity to this scenario. Many branches of biology have their domain described by consensual ontologies (reflecting a consensual knowledge accepted by a group, community), such as Gene Ontology (Ashburner *et al.*, 2000) (genetics) and Transparent Access to Multiple Bioinformatics Information Sources-TAMBIS Ontology (Baker *et al.*, 1998) (molecular biology). In biodiversity and monitoring, however, there is no consensus, although there are several research groups involved in global initiatives (Albuquerque, 2011).

This paper presents a domain ontology developed with real-world biological scenario as object of study, which has been adopted to support biodiversity monitoring systems at INPA. Section 2 provides information about the methods used to develop the ontology. Section 3 presents SABIO systematic approach, definition of competence questions and the biodiversity ontology. Section 4 presents the tools adopted for the implementation and Section 5 concludes by presenting some remarks and what come next.

2. REQUIREMENTS ELICITATION: THE BIODIVERSITY DOMAIN

To model a biodiversity domain, ontology designers need to produce the requirements elicitation, following two steps:

i. Data Collect, which consisted of collecting documents/records from field collects and notes. Also, there were used data available on the Web from projects and institutes; and from a search at INPA and Museu Paraense Emílio Goeldi (MPEG), that resulted in electronic documents (mostly text files) and information about the conceptual schema CLOSi (Clustered Object Schema for INPA's Biodiversity Collections Data) described by Campos dos Santos (2003).

ii. Requirements Elicitation, based on (***i***), where common aspects of most documents acquired for modeling the ontology were identified. At this stage, a generic document was defined to record field data collecting following a specific collect protocol.

These two steps can provide the understanding of a domain application.

2.1 Collecting Protocol

Biodiversity studies imply sampling as material witness for identification, or for collections and future studies. Through these activities it is possible to manipulate data that can be used for other analyzes such as biogeography, distribution patterns and potential ecological niches, description of new species, among others.

Collecting aims to acquire and record any biological material. During collecting, in addition to biological material of interest, information on the site, physical characteristics of the local, as well as information regarding the material collected is essential. Data collected will generally contain information about morphometry, morphology and development stage. Records of the collect localities, geographical coordinates, ecosystem, abiotic aspects are important for guiding future analysis and comparisons made with other studies. In research sites, plants collected are indexed by a botanical assistant. After gathering, the pre-sorted material is then taxonomically identified by specialists. The same procedure is adopted for faun.

2.2 Analysis and Data Treatment

Data collected during a field mission to record species, are divided into two types: (1) *general*, which are information important in all studies (e.g. day, hour, description of location) and; (2) *specific*, that correspond to the scientific interest of a study. Interviewing scientists working in different studies and areas, help to classify information that is common to all and those used only by a few scientists. The results of the interviews along with other data collected were separated by functions and grouped as type of objects (Campos dos Santos, 2003). The use of data schemas (e.g. CLOSi) to support ontology development becomes recommended, since the schema used had been already validated.

3. THE ONTOLOGICAL ENGINEERING APPROACH

Despite various attempts to create methodologies for developing ontologies, practice shows that most research groups create their own method of development, according to their application characteristics.

Based on various methods used for building ontologies, (Falbo *et al.*, 1998) proposed a systematic approach to build domain ontologies, adopted within this research called Systematic Approach for Building Ontologies (SABIO). This approach comprises the following activities: (i) identification of the ontology purpose by means of competence questions; (ii) capture of concepts of a domain as well as its relations and properties; (iii) ontology formalization, which is the definition of formal axioms by using First-Order Logic (FOL); (iv) search for ontologies with reuse and integration resources; (v) ontology evaluation by identifying inconsistency as well as verifying the truthfulness with its purpose; and (vi) ontology documentation. It is important to emphasize that competence questions play an essential role in this methodology by: (1) defining the scope and purpose of the domain conceptualization; and (2) serving as a testbed for ontology evaluation – 'competence questions' are those that the ontology is supposed to answer (Falbo *et al.*, 1998).

As presented in (Guizzardi, 2007), ontology engineering must include phases of conceptual modeling, design and codification. These phases will produce different artifacts and objectives and, as consequence, will require different types of modeling languages and methods with specific characteristics. In a conceptual modeling phase, ontology should strive for expressivity, clarity and truthfulness. In this context, Ontology Web Language (OWL and OWL2) and Resource Description Framework (RDF) are not suitable for ontology conceptual modeling. Once obtained formal ontology is often desirable to make it operational. To do so, two other activities should be completed: design and coding. In the design, the concepts, relations and axioms of formal ontology should be placed in a compatible format with the implementation language.

To model OntoBio it was used an ontologically well-founded UML modeling profile named OntoUML. This profile comprises a number of stereotyped classes and relations representing a metamodel that reflects the structure and axiomatization of a foundational (and, thus, domain independent) ontology named UFO (Unified Foundation Ontology) (Guizzardi, 2005). Based on SABIO, OntoBio is composed by (i) structural conceptual models, (ii) FOL axioms and (iii) a terms' dictionary.

3.1 Competence Questions (CQs)

Whereas the main purpose of our ontology is to provide a clear and precise conceptualization of the issues raised in biodiversity data collect, independent of a specific application, CQs tend to reflect this purpose and the expected uses for it, that is, the ontology competence. The competence of a representation is about the coverage of issues that this representation can answer or tasks that it can support; it delimits the scope of the ontology developed. When establishing competence, is defined what is relevant to the ontology and what is not. It is also helpful to identify potential users and the scenarios that motivated the development of the ontology. CQs are answered using FOL, which validates the design of the ontology. Part of CQs defined by this ontology is listed in Table 1. A complete list can be found at Albuquerque (2011).

Table 1: OntoBio's Competence Questions.

CQ_1. Which institution is responsible for the collect?
CQ_2. What is the type of collection: manual or instrumented?
CQ_3. What are the species of the objects in a collect?
CQ_4. Who is responsible for the collect?
CQ_5. Who classifies the object of the collect?
…
CQ_n

3.2 Biodiversity Ontology - OntoBio

The modeling phase had prioritized OntoBio into five sub-ontologies, integrated by relationships between the concepts and axioms. They are presented in Figure 1: Collect; Material Entity; Spatial Location; Ecosystem; and Environment. The axioms respond to CQs and allow: (i) a rich semantic expressiveness that cannot be reached only by using the graphical model, (ii) the inferences (for encoding the ontology), (iii) an evaluation of the reliability of the presented with the purpose of the ontology, and (iv) identify inconsistencies.

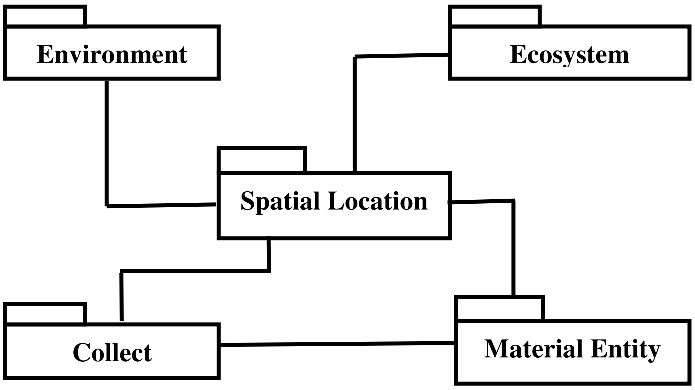

Figure 1. OntoBio's sub-ontologies.

The complete ontology is presented in details at (Albuquerque, 2011). The implementation is open to use and reuse on a global scale at http://www.inpa.gov.br/cti/nbgi/lis/biodiversity_ontology/.

SUB-ONTOLOGY COLLECT

This sub-ontology captures the structure of a collect protocol in a high level of abstraction, as presented in Figure 2. Due to limited space on this paper, other sub-ontologies' tables and figures were suppressed.

A *Collect* must necessarily be associated to a *CollectLocal* (Sub-Ontology Spatial Location), to a *CollectResponsibleInstitution*, to a *CollectParticipant* (Sub-Ontology Biotic Entity), to a *CollectResponsible* (Sub-Ontology Biotic Entity) and to a *CollectedObject* (Sub-Ontology Biotic Entity), characterizing a ***formal relation*** of all ***roles*** mentioned above. The *Collect* is stereotyped as a ***relator*** (represents a type of property that mediates two or more sortals, and it is existentially dependent on them), that mediates the ***formal relation*** between the ***roles*** played by *CollectLocal*, *CollectResponsibleInstitution*, *CollectParticipant*, *CollectResponsible*, and *CollectObject*. Similarly, *InstitutionalLink*, as a **relator**, mediates the ***material relation*** (*isLinkedTo*) between *ResearchInstitution* and *Researcher* (Sub-Ontology Biotic Entity). *Collect* can be specialized according to the area, or to the instruments used.

Collect also establishes a ***formal relation*** (isClassifiedAs) with ***powertype*** *CollectType*. The classes of the supertype Collect are instances of the ***powertype*** *CollectType*.

The ***kind*** *Tool* plays the ***role*** of *CollectTool*. This, in turn, maintains a ***formal relation*** of mediation with the ***relator*** *InstrumentedCollect*.

Axiom 1 indicates that all collect will be associated with an institution responsible for collect and a researcher responsible for the collect.

Axiom 1	$\forall$x,y,z [*CollectResponsible*(x) $\wedge$ *Collect*(y) $\wedge$ media(y,x) $\rightarrow$ $\exists$z [*CollectResponsibleInstitution*(z) $\wedge$ media(y,z)]]

The Competence Questions are answered by the axioms A_n (FOL). A_1, A_2 and A_3 are presented below.

A_1	$\forall$x [*Collect*(x) $\rightarrow$ $\exists$y [*CollectResponsibleInstitution*(y) $\wedge$ media(y,x)]]
A_2	$\forall$x [*Collect* (x) $\rightarrow$ $\exists$y [*TypeCollect*(y) $\wedge$ *instanceOf*(x,y)]]
A_3	$\forall$x,y,z [*Collect* (x) $\wedge$ *CollectedObject*(y) $\wedge$ media(x,y) $\wedge$ *ClassifiedObject*(y) $\wedge$ *Classification*(z) $\wedge$ media(z,y) $\rightarrow$ $\exists$w [*Specie*(w) $\wedge$ media(z,w)]]

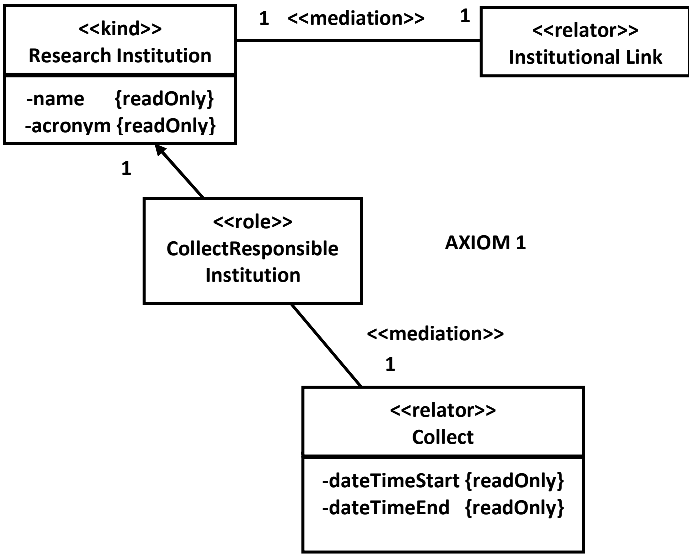

Figure 2. Sub-Ontology Collect.

SUB-ONTOLOGY MATERIAL ENTITY

●SUB-ONTOLOGY ABIOTIC ENTITY

This sub-ontology conceptualizes material entities that are part of a *Collect*. *MaterialEntity* is a category that generalizes two sub-ontologies: Abiotic Entity and Biotic Entity. *MaterialEntity* establishes two ***formal relations*** with sub-ontology Spatial Location: *locatedAt* and *localization* with *SpatialLocation* and *GeographicCoordinate* respectively.

AbioticEntity is a categorization from *MaterialEntity* that represents all non-living physical factors and is specialized in the ***quantities*** *Water*, *Soil* and *Air*. *Water* and *Soil* establish a ***formal relation*** (*isClassifiedAs*) with the ***powertypes*** *TypeWater* and *TypeSoil* respectively. Classes *Water* and *Soil* will instantiate the ***powertypes*** *TypeWater* and *TypeSoil*.

●SUB-ONTOLOGY BIOTIC ENTITY

BioticEntity is a categorization from *MaterialEntity* that represents all the physical and living factors and is represented by the ***categories*** *Plant*, *Animal* and *MicroOrganism*. They establish a whole-part relation (*memberOf*) shareable with ***collectives*** *Flora*, *Fauna* and *Microbiota* since they can instantiate them more than once.

The ***kind*** *Vegetation* establishes a *formal relation* (*isConstitutedBy*) with the ***collective*** *Flora*. This ***kind*** is specialized in ***subkinds*** and establishes a ***formal relation*** (*isClassifiedAs*) with the ***powertype*** *TypeVegetation*. The ***subkinds*** of ***kind*** *Vegetation* will instantiate the *powertype TypeVegetation*. *Vegetation* also establishes a ***formal relation*** (*localizedAt*) with the ***category*** *GeographicSpace*.

Kind *Person* specializes the category *Animal*. *Person* may play the ***roles*** *Researcher*, *CollectParticipant* and *Classifier* **in an overlapped way** since *Classifier* can optionally be both a *Researcher* and a *CollectParticipant* or not. *CollectParticipant* can play the ***roles*** *ParticipantResearcher* and *CollectAssistant*. *Researcher* also specializes in ***role*** *ParticipantResearcher*, which in turn specializes into *CollectResponsible*. Briefly, all *CollectParticipant* or is a *ParticipantResearcher* or *CollectAssistant* and the *CollectAssistant* will necessarily be a *ParticipantResearcher*.

The *BioticEntity* also establishes ***formal relations*** with the ***category*** *Sex* and the ***mixin*** *StageOfLife* that also specializes and enrichs the vocabulary of this ontology schema. *Sex* and *StageOfLife* establish a ***formal relation*** (isClassifiedAs) with ***powertypes*** *TypeSex* and *TypeStageOfLife* respectively. The classes *Sex* and *StageOfLife* and their subclasses will instantiate the ***powertypes*** *TypeSex* and *TypeStageOfLife*.

StageOfLife cannot be a ***category*** because it is not rigid, the stereotype used is ***mixin*** which has as specializations, phases, that is, a single *BioticEntity* can be sorted by different life stages during its life.

The *BioticEntity* plays the role *ObjectUnderStudy* **that is specialized in a superimposed and incomplete form in** *ClassfiedObject* and *CollectedObject*. *Classification* is stereotyped as a ***relator***, that mediates the ***formal relation*** between the ***roles*** played by *ClassifiedObject*, *Classifier* and the ***powertype*** *Specie*.

Axiom 2 means that if a *ClassifiedObject* is associated to a ranked taxonomic classification and *Specie* is also associated with the same classification, then the *ClassifiedObject* is instance of *Specie*.

The ***category*** *BioticEntity* establishes a ***formal relation*** (*instanceOf*) with ***powertype*** *Specie*, that is, the subclasses of *BioticEntity* will instantiate *Specie*. At first it may be said that every *BioticEntity* instanciates a single *Specie*. However, in some situations (peculiar to the domain under consideration), a *BioticEntity* can be classified in more than one way, that is, a *BioticEntity* can instantiate more than one *Specie* (typical problem of taxonomic classification, sometimes associated with the local or beliefs of who ranks), which leads to a reflexive formal relation (identityOfSpecie).

Axiom 3 tells us that if a *BioticEntity* is (*instanceOf*) two differently classified *Specie*, then the two *Specie* are equal.

Axiom 4, in turn, shows us that if two SPECIES maintains a ***formal relation*** (*identityOfSpecie*), both are instance of the same *BioticEntity*.

The ***powertype*** *Specie* establishes a ***formal relation*** (subtypeOf) with ***powertype*** Genus, which establishes a ***formal relation*** (*subtypeOf*) with ***powertype*** *Family*. These ***formal relations***, semantically, represent the taxonomic hierarchy between family, genus and species in a classification system. *Family*, *Genus* and *Specie* specialize ***powertype*** the *Taxon*. The ***category*** *BioticEntity* establishes a *formal relation* (instanceOf) with ***powertype*** *Taxon*, the subclasses of *BioticEntity* instantiate *Taxon*. Nine competence questions (CQ_4 to CQ_{12} and their answers A_4 to A_{12}) were defined for sub-ontology Material Entity.

SUB-ONTOLOGY ECOSYSTEM

This sub-ontology conceptualizes the relations of the ecosystem within the scope of a collect protocol for biodiversity data.

An ecosystem is a natural unit consisting of all plants, animals and micro-organisms (biotic factors) in an area functioning together with the entire physical non-living (abiotic) environment.

The ***kind*** *Ecosystem* establishes ***whole-part relation*** (*componentOf*) shareable with Sub-Ontology Material Entity through ***categories*** *BioticEntity* and *AbioticEntity*. Another option would be to model the ***whole-part relation*** (*componentOf*) shareable directly with ***category*** MaterialEntity.

Ecosystem establishes a ***formal relation*** (isClassifiedAs) with ***powertype*** *TypeEcosystem*. Classes *MacroEcosystem, MesoEcosystem* and *MicroEcosystem* will instantiate the ***powertype*** *TypeEcosystem*. Another ***formal relation*** (*containedAt*) is established with ***category*** *SpatialLocation*.

Ecosystem establishes a self-relationship through a ***whole-part relation*** (*componentOf*) shareable, since *Ecosystem* is not applied to a particular geographic area, ie it is associated with various dimensions (it explains the specialization *MacroEcosystem*, *MesoEcosyatem* and *MicroEcosystem*) and each *Ecosystem* can be composed of several *Ecosystem*. In this context, we observe a ***whole-part relation*** (*componentOf*) between *MicroEcosystem* and *MesoEcosystem*, in which a *MesoEcosystem* may be composed of two or more *MicroEcosystem*. Likewise there is the ***whole-part relation*** (*componentOf*) between *MesoEcosystem* and *MacroEcosystem*. One Competence Question (CQ_{13} and its answer A_{13}) was defined for sub-ontology Ecosystem.

SUB-ONTOLOGY SPATIAL LOCATION

Category *SpatialLocation* (as reported by a GPS system) is specialized in *GeographicSpace* and *GeographicPoint* (latitude, longitude and altitude). *GeographicSpace* may be associated with geographical coordinates of various locations, but also different *GeographicSpace* may be associated with a particular set of coordinates in different circumstances. Thus, the formal relation (*spatialyContainedAt*) indicates that a *GeographicSpace* may contain spatially another *GeographicSpace* (adapted from (Guizzardi, 2005)).

GeographicCoordinate is a ***datatype*** that provides an array of three elements which represent altitude, latitude and longitude. *GeographicCoordinate* maintains ***formal relations*** (*localization*) with ***categories*** *SpatialLocation*, *GeographicSpace* and *GeographicPoint*.

GeographicSpace is specialized according to social-political, climatic and phytophysiognomic aspects. The ***categories*** *ClimaticRegion* and *PhitophisiognomicRegion* maintain a ***formal relation*** (*isClassifiedAs*) associated with a ***powertype***. These ***powertypes*** are instantiated by the specialization of subclasses *ClimaticRegion* and *PhitophisiognomicRegion*. *GeographicSpace* also plays the role *CollectLocal*.

The kind *Locality* establishes a ***formal relation*** (*spatialyContainedAt*) with the ***kind*** *County*, which in turn establishes a ***formal relation*** (*spatialyContainedAt*) with ***kind*** *State*, which establishes a ***formal relation*** (*spatialyContainedAt*) with the ***kind*** *Country*. These ***formal relation***, semantically, represent the hierarchy and relationships between localities and the federal units recognized in the political and social context of a country. *Locality* is specialized according to the property and the type of locality. The ***kind*** *Locality* establishes a ***formal relation*** (*isClassifiedAs*) with ***powertype*** *TypeLocality*, ie, instances of *Locality* will instantiate *TypeLocality*. Four competence questions (CQ_{14} to CQ_{17} and their answers A_{14} to A_{17}) were defined for sub-ontology Spatial Locality.

SUB-ONTOLOGY ENVIRONMENT

Environment is everything that directly affects the metabolism or behavior of a living being or species, including light, climate, water, moon phases, soil or other living beings that cohabit with it.

Environment was stereotyped as ***mode*** which can be described as an intrinsic individual moment. By definition (OntoUML), must be connected in combination with at least one relationship type ***characterization***.

Environment is specialized in ***modes*** *MacroEnvironment* and *MicroEnvironment*. Both *MacroEnvironment* and *MicroEnvironment* establish a ***formal relation*** (*isClassifiedAs*) with ***powertypes*** *TypeMacroEnvironment* and *TypeMicroEnvironment*. Subclasses of *MacroEnvironment* and *MicroEnvironment* will instantiate and the ***powertypes*** *TypeMacroEnvironment* and *TypeMicroEnvironment* respectively.

Environment maintains relations of ***characterization*** with ***modes*** of the type *ClimaticCondition*, *Luminosity*, *MoonPhase* and is specialized in *MacroEnvironment* and *MicroEnvironment*. *Environment*, *MacroEnvironment* and *MicroEnvironment* maintain relations of ***characterization*** with ***categories*** *SpatialLocation*, *GeographicSpace* and *GeographicPoint* respectively from Sub- Ontology Spatial

Location. Two competence questions (CQ_{18} to CQ_{19} and their answers A_{18} to A_{19}) were defined for sub-ontology Environment.

4. TOOLS FOR DEVELOPMENT

To implement OntoBio, it was used *Protégé* ontology editor with implementation and modeling based on Ontology Web Language (OWL). We have extended the functionality of *Protégé* through two plugins: *Racer Pro* for consistency checking, and *Jess*, for inference support with SWRL (Semantic Web Rule Language) to deals with competence questions.

For supporting the creation of conceptual models and domain ontologies in a philosophically and cognitively well-founded modeling language named was adopted OntoUML and its graphical editor (Benevides and Guizzardi, 2009).

5. CONCLUDING REMARKS

A main difficulty in developing ontologies resides in the process of defining the set of knowledge that it must contains. The difficulty level grows with the task of developing generic ontology covering rich and complex domains and requiring investigation of a large number of services, documents and different understandings of the various communities of a domain. When dealing with ontology engineering process, various structures/stereotypes found in languages, at the level of analysis, cannot be mapped to a language at the implementation level.

OntoBio was modeled using OntoUML as its formal language for ontology conceptual modeling, allowing us to capture complex aspects of biodiversity domain. Despite all resources available (methods and tools), ontology development is expert dependent. OntoBio has succeeded due to high expert capacity available at INPA willing to contribute to the project.

Although several issues still need to be tackled, for example reusability and integration of ontologies and the associated differences in semantic expressiveness being one of them, OntoBio has contributed to a better knowledge organization and has been used in real-world situations at INPA, specifically in the biological collection program with bird and fish collections.

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