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CONCEPTUAL MODELING OF FORMAL AND MATERIAL RELATIONS APPLIED TO ONTOLOGIES

Dissertação apresentada como requisito parcial para a obtenção do grau de Mestre em Ciência da Computação

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ABSTRACT

Ontologies represent a shared conceptualization of a knowledge community. They are built from the description of the meaning of concepts, expressed through their attributes and their relationships. Concepts refer to the object of conceptualization, the universe of discourse. They are characterized by their attributes and domains of possible values. Relationships are used to describe how the concepts are structured in the world. In ontologies all concepts are hierarchically defined, however there are other relationships that are definitional, giving identity to the concepts and meaning to the world.

In addition to the subsumption relationships that build the taxonomies of concepts, other formal and material relations assist in structuring the domain and the conceptual definition. The modeling tools, however, are still deficient in differentiating the various types of formal and material relationships in order to assign the possibilities of automated reasoning. In particular, mereological and partonomic relationships lack of implementation options that allow extracting the semantic potential when modeling.

This research project takes as a starting point the study of the literature on ontologies and relations, especially on formal and material relations, including mereological and partonomic relations, reviewing the principles found on ontologies. Furthermore, we identify the theoretical foundations of the relations and analyze the application of the relations concepts to the main foundational ontologies in use nowadays. Following, from the raised proposals, this work proposes an alternative for the conceptual modeling of these relations in a visual domain ontology. This alternative has been made available on the ontology building tool of the Obaitá Project, which is under development by the Intelligent Databases Research Group (BDI) from UFRGS.

Key-words: Foundational Ontologies, Formal Relations, Material Relations, Ontology Building Tools, Visual Domain Ontology.

MODELAGEM CONCEITUAL DAS RELAÇÕES FORMAIS E MATERIAIS APLICADAS A ONTOLOGIAS

RESUMO

Ontologias representam uma conceitualização compartilhada de uma comunidade de conhecimento. São construídas a partir da descrição dos significados dos conceitos, descritos através de seus atributos e dos relacionamentos entre os conceitos. Conceitos se referem ao objeto da conceitualização, o universo do discurso. São caracterizados por seus atributos e domínios de valores possíveis. Relacionamentos são utilizados para descreverem de que forma os conceitos se estruturam no mundo. Nas ontologias todos os conceitos são hierarquicamente definidos, porém existem outros relacionamentos que são definicionais, dando identidade aos conceitos e sentido ao mundo.

Além dos relacionamentos de subsunção que constroem as taxonomias de conceitos, outras relações formais e materiais auxiliam na estruturação do domínio e na definição conceitual. As ferramentas de modelagem, no entanto, ainda são falhas em diferenciar os vários tipos de relacionamentos formais e materiais para atribuir as possibilidades de raciocínio automático. Em especial, relacionamentos mereológicos e partonômicos carecem de opções de implementação que permitam extrair o potencial semântico da modelagem.

Este projeto de pesquisa tem como ponto de partida o estudo da literatura sobre ontologias e relações, em especial sobre relações formais e materiais, incluindo relações mereológicas e partonômicas, revisando os princípios encontrados nas ontologias. Além disso, nós identificamos os fundamentos teóricos das relações e analisamos a aplicação dos conceitos das relações sobre as principais ontologias de fundamentação em prática na atualidade. Na sequência, a partir das propostas levantadas, este trabalho propõe uma alternativa para a modelagem conceitual destas relações em uma ontologia de domínio visual. Esta alternativa foi disponibilizada na ferramenta de construção de ontologias do Projeto Obaitá, a qual está sendo desenvolvida pelo Grupo de Pesquisa de Bancos de Dados Inteligentes (BDI) da UFRGS.

Palavras-chave: Ontologias de Fundamentação, Relações Formais, Relações Materiais, Ferramentas de Construção de Ontologias, Ontologia de Domínio Visual.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

BFO	*Basic Formal Ontology*
BWW	*Bunge-Wand-Weber*
DOLCE	*Descriptive Ontology for Linguistic and Cognitive Engineering*
GFO	*General Formal Ontology*
GOL	*General Ontological Language*
IEEE	*Institute of Electrical and Electronics Engineers*
IFOMIS	*Institute for Formal Ontology and Medical Information Science*
IMISE	*Institute of Medical Informatics*
MVC	*Model View Controller*
NL	*Natural Language*
OCML	*Operational Conceptual Modelling Language*
Onto-Med	*Ontologies in Medicine*
OWL	*Web Ontology Language*
RDF	*Resource Description Framework*
SUMO	*Suggested Upper Merged Ontology*
UFO	*Unified Foundational Ontology*
UML	*Unified Modeling Language*

SUMMARY

1 INTRODUCTION

This work falls in the area of Conceptual Modeling and Knowledge Engineering, focusing on the ontological foundations and conceptual modeling of relations applied to ontologies. Ontologies are used for knowledge representation, providing a framework for organizing and giving a general view of the world.

The concept of ontology was initially originated from the philosophical field and can be traced back to ancient Greek philosopher Aristotle BC. It is defined in the philosophy as the systematic description of the objective existence, namely ontology. It is meant as a systematic explanation and illustration about the objective existence (Du et al., 2010).

Studer defines ontology in (Studer, Benjamins and Fensel, 1998) as a formal and explicit specification of a shared conceptualization. An important distinction that we have to emphasize is between foundational ontology and domain ontology.

A foundational ontology, sometimes also called upper level ontology, defines a range of top-level domain-independent ontological categories, which form a general foundation for more elaborated domain-specific ontologies. In other words, foundational ontologies provide the basic concepts upon which any domain-specific ontology is built (Guizzardi and Wagner, 2005). Among the main existing foundational ontologies we may include UFO, OntoClean/DOLCE, GOL/GFO, BWW, SUMO, BFO, Cyc and Sowa.

Domain ontologies aim at capturing a consensual knowledge, not individual, to be formalized and shared in a community of interest, minimizing the domain ambiguities. Thus, the ontological models describe abstract concepts, but not domain instances. They are strongly implementation independent and their languages look for a formalism that is rich enough to express the semantics of the concepts, being able to be processed and reused by many different types of systems (Abel et al., 2008).

Ontology represents a shared conceptualization that includes concepts, its attributes and the relationships between the concepts. In addition to the subsumption relationships that build the taxonomies of concepts, other formal and material relations assist in structuring the domain and the conceptual definition. The main existing modeling tools, such as Protégé, NeOn Toolkit, WebOnto, WebODE and OntoEdit, however, are still deficient in differentiating the various types of formal and material relationships in order to assign the possibilities of automated reasoning. In particular, mereological and partonomic relationships lack of implementation options that allow extracting the semantic potential when modeling.

Knowledge Engineering has shown to be challenged regarding to knowledge modeling requirements. Part-whole relations, topological and functional models, different kinds of physical constraints and different views have to be taken into account. (Tudorache, 2004).

Some ongoing researches are discussing the introduced issues. On his PhD Thesis (Guizzardi, 2005), Guizzardi has proposed ontological foundations for structural conceptual models and, a few years later, Guizzardi and Wagner presented a foundational ontology to provide real world semantics and sound modeling guidelines using conceptual modeling. The approach found in the literature that is closest to this last one presented here is the so called BWW (Bunge-Wand-Weber) approach (Guizzardi and Wagner, 2008).

The results concerning the formal ontological distinctions among unary and binary relations have been recapped in (Guarino, 2009), sketching a basic ontology of meta-level category representation languages and discussing the role of such distinctions in the current practice of knowledge engineering.

We noticed that most of the available ontology building tools do not provide enough constructs for capturing knowledge about the meaning of the concepts and their relationships, therefore, they may induce the development of incomplete, ambiguous or redundant knowledge models.

In order to capture the correct meaning of a relationship between the ontology concepts, it is necessary to allow people to express their understanding through the use of properties that have concrete meaning to them. This is the role of the foundational ontologies: they express the inherent properties that provide identity to the objects and their relationships. This work proposes to provide support to the ontological foundations of the relations among the ontology concepts in order to obtain better accuracy in their formalization.

Among the human senses, sight constitutes the first and most important sense to capture information from the external world in order to generate conceptualizations. This becomes more evident when we deal with imagistic domains such as Geology and Medicine, in which the recognition of visual patterns is the initial process for capturing information and supporting the problem solving. This work also proposes to support the experts taking advantage of the visual representation, helping them to express the complete meaning of the relations in visual domains.

The use of metadata to describe the ontological meta-constructs and the visual representations of the relations, regardless of domain, allows us to create an environment for defining the domain ontology concept relations without requiring users to have any prior knowledge about ontology representation languages (that is what happens with most of the current solutions), providing mechanisms to work with visual and symbolic information.

Obaitá Portal is a tool for collaborative construction of visual domain ontologies based on foundational ontology. In its previous version, the Obaitá portal did not include any ontological consistency checking regarding the relationships. In this work, we extend Obaitá portal by including the required ontological consistency checking and by providing visual content support for the ontology relations.

The main contributions of this work are:

- providing ontologically well-founded constructs to support the ontological choices of types of the binary relations, especially the formal and material relations, considering the semantic expressiveness of a foundational ontology;

- providing support to the inference of the ontological meta-type of the part-whole relations based on the meta-types of the respective related concepts;

- providing visual components to represent the visual knowledge about the spatial relations among the ontology concepts, supporting visual domains;

- providing an interface to support assistance, not requiring users to have prior knowledge of ontological representation formal languages.

Following, in Section 2, we present a review on the main principles of ontology; in Section 3, we present the foundations of parts and wholes, studying mereology (theory of parts) and integral wholes; in Section 4, we present a discussion about relations, analyzing their classification, meaning and importance for ontologies; in Section 5, we present the application of relations to the main foundational ontologies; in Section 6, we present an analysis on the use of relations on some of the main ontology building tools; in Section 7, we present a review on visual knowledge; in Section 8, we present the Obaitá Portal: the ontology building tool that was extended in this project; in Section 9, we present the conceptual modeling of ontological relations that is proposed in this work; in Section 10, we present the implemented solution as part of the development of this research project; in Section 11, we present the project case study; and finally, in Section 12, we present our conclusions and some open possibilities for future improvement of this work.

2 ONTOLOGIES

Ontology (with-a-capital-O) is an ancient philosophical discipline which can be traced back to the Ancient Greeks. It is a branch of metaphysics and its subject matter is the objective existence and its nature. On the other hand, central to an ontology (with-a-small-o) is an inventory of the types of objects that exist and their categorization by the types of existence they have (Partridge, 2002a).

One of the first definitions of ontology was given in (Neches et al., 1991), stating that an ontology defines the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary. Later on, Gruber defined ontology in (Gruber, 1993a) as an explicit specification of a conceptualization. Based on Gruber's definition, Borst stated in (Borst, 1997) that ontology is defined as a formal specification of a shared conceptualization. Studer merged Gruber's and Borst's definitions in (Studer, Benjamins and Fensel, 1998) by defining ontology as a formal and explicit specification of a shared conceptualization. Conceptualization refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon. Explicit means that the type of concepts used, and the constraints on their use, should be explicitly defined. Formal refers to the fact that the ontology should be machine-readable. Shared reflects the notion that an ontology captures consensual knowledge, that is, it is not private of some individual, but accepted by a group (Du et al., 2010).

In Artificial Intelligence, ontology refers to an engineering artifact, constituted by a specific vocabulary used to describe a certain reality, plus a set of explicit assumptions regarding the intended meaning of the vocabulary words. This set of assumptions has usually the form of a first-order logical theory, where vocabulary words appear as unary or binary predicate names, respectively called concepts and relations (Guarino, 1998).

From a knowledge-based systems point of view, ontology is defined in (Mizoguchi, Sano and Kitamura, 1999) as a theory (system) of concepts/vocabulary used as building blocks of information processing systems. In the context of knowledge-based problem solving, ontologies are divided into two types: task ontology for problem solving process, and domain ontology for domains where the task is performed.

The target of ontology is to study the knowledge of related domain, providing the common understanding of the domain, determining the common-recognized vocabularies in this domain, and giving an explicit definition of the interrelation between vocabularies from different levels of formalization. Ontology can determine the precise meaning of the concepts through the strict definitions and the relations between the concepts, expressing the commonly recognized and shared knowledge (Du et al., 2010).

According to (Guarino, 1998), the philosophical perspective and the computational perspective are related to each other. However, he proposes a terminological distinction where the engineering artifact is defined as ontology while the philosophical point of view is defined as conceptualization. Thus, two ontologies may have different vocabularies and share a common conceptualization.

2.1 Ontology Classification

In the literature there are some different types of ontology classifications.

In (Gómez-Pérez, Fernández-López and Corcho, 2004) ontologies are basically classified in four types as follow:

- Knowledge Representation ontology: aims to model primitives that can be used to formalize the knowledge. Among the modeling primitives there are classes, relations and attributes; these primitives allow to build taxonomies of classes, set properties of relations, range of values, types of attributes, and so on;

- Meta-ontology: describes the general concepts that are common to various domains. For this reason, sometimes meta-ontologies are used for the construction of domain ontologies;

- Linguistic ontology: aims to describe semantic constructs instead of modeling a specific domain, offering a set of features used more often in natural language processing. This type of ontology is related to the grammar unit semantics, such as words, nominal groups, adjectives;

- Domain ontology: it is a reusable vocabulary of concepts and their relationships within a domain, including activities, theories and principles that belong to the domain.

Guarino proposes in (Guarino, 1998) a classification of ontology kinds based on their level of dependence on a particular task or point of view:

- Top-level ontologies: describe very general concepts like space, time, matter, object, event, action, etc., which are independent of a particular problem or domain;

- Domain ontologies and task ontologies: describe, respectively, the vocabulary related to a generic domain (like medicine or automobiles) or a generic task or activity (like diagnosing or selling) by specializing the terms introduced in a top-level ontology;

- Application ontologies: describe concepts that depend both on a particular domain and task, and often combine specializations of both the corresponding domain and task ontologies. These concepts often correspond to roles played by domain entities while performing a certain task, like replaceable unit or spare component.

Different types of ontologies, according to their level of generality, are shown in Figure 1.

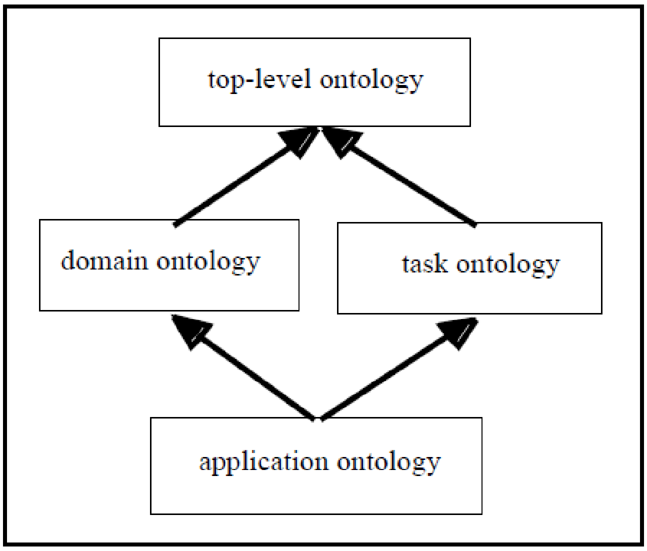


Figure 1 A classification of different types of ontologies (Guarino, 1998).

Core ontologies (Obrst, 2010), not present in the classification above, can be viewed as mid-level ontologies, positioned between top-level and domain ontologies, providing a common definition for the main concepts in some large domain, to which all other concepts are usually related.

In recent years, there has been a growing interest in the use of foundational ontologies (also known as upper level or top-level ontologies) for evaluating conceptual modeling languages, developing guidelines for their use and providing real-world semantics for their modeling constructs (Guizzardi and Wagner, 2010). As one of the main foundational ontologies in use nowadays, the following section presents UFO, the Unified Foundational Ontology.

2.2 UFO

The Unified Foundational Ontology (UFO) was initially proposed by Giancarlo Guizzardi and Gerd Wagner in (Guizzardi and Wagner, 2004). UFO is derived from a synthesis of two other foundational ontologies, GOL/GFO (Section 5.2) and OntoClean/DOLCE (Section 5.1). While their main areas of application are the natural sciences and linguistics/cognitive engineering, respectively, the main purpose of UFO is to provide a foundation for conceptual modeling, including agent oriented modeling (Guizzardi and Wagner, 2005).

As summarized in (Carbonera, 2012), the most generic UFO concept is Thing, which is specialized in two fundamental entities: Urelement and Set (Figure 2). Urelement is an entity that is not a set. The first distinction that is made between the specializations of Urelement is the fundamental distinction between the categories of Individuals and Universals. Individuals are entities that exist in reality, such as a person, an apple, etc. Universals, in turn, are standard features that can be instantiated in a number of different individuals; it can be understood as high-level abstractions that characterize different classes of individuals. In general, for each of the specializations for Universals, UFO also provides a corresponding specialization for Individuals.

UFO Universals are specialized in Endurant and Perdurant (Event). This distinction can be understood in terms of the behavior of the individuals of these universals in function of time. Endurant Universals are those whose individuals are always fully present whenever they are present, in the sense that they preserve their identity thru time (e.g., Person, Chair, Planet). Moreover, Perdurant Universals are those whose individuals extend in time accumulating temporal parts, in the sense that they occur in time (e.g., War, Party, Meeting).

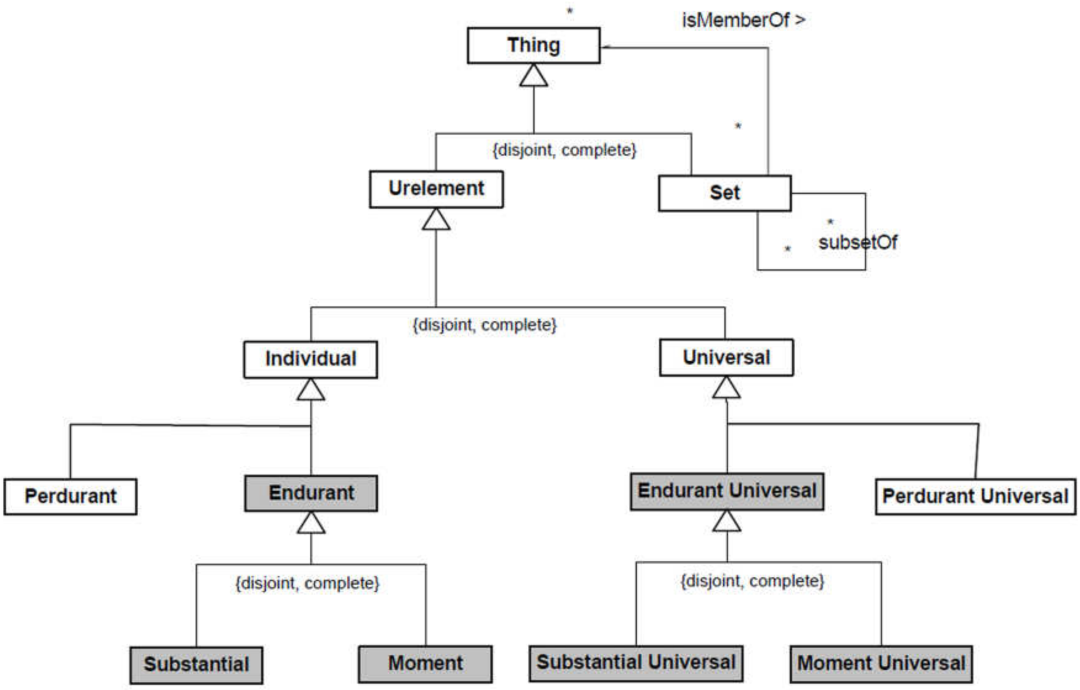


Figure 2 A Fragment of the Unified Foundational Ontology (UFO) (Guizzardi, 2005).

The UFO ontology is divided into three incrementally layered compliance sets:

- UFO-A defines the core of UFO, as a comprehensive ontology of endurants;

- UFO-B defines, as an increment to UFO-A, terms related to perdurants;

- UFO-C defines, as an increment to UFO-A and UFO-B, terms related to the spheres of intentional and social entities (Guizzardi et al., 2007).

2.2.1 UFO-A: An Ontology of Endurants

UFO-A defines the core of UFO, presenting the structuring concepts of the physical objects. According to (Guizzardi, Falbo and Guizzardi, 2008), a fundamental distinction in this ontology is between the categories of Individual (Particular) and Universal (Type). The former are real entities possessing a unique identity. The later are pattern of features, which can be realized in a number of different particulars.

The distinction between universal and particular (or individual) is analogous to the distinction between types (classes) and their instances in conceptual modeling. Thus, UFO provides a set of categories of particulars and a set of categories of universals. The categories of universals can be viewed as meta-types, since they are “types of types”. These meta-types are organized in a taxonomy according to some ontological meta-properties, such as *identity*, *rigidity*, *existential dependence*, and so on. They are used for classifying concepts in domain conceptual models according to its ontological properties. That is, concepts in domain ontologies are instances of the meta-types provided by UFO. A domain ontology whose concepts are classified by the UFO meta-types, and follow the ontological constraints provided by UFO, complies with the well-founded meta-conceptualization embedded in UFO.

Endurant Universals are specialized in Substantial Universals and Moment Universals according to their existential dependency, as presented in Figure 3 (Guizzardi, 2005).

Substantial Universals are those whose individuals are existentially independent, having spatio-temporal properties and being founded on matter. Every instance of a Substantial Universal is an instance of a single Substance Sortal.

Substance Sortals are rigid, relationally independent universals that supply a principle of identity to their instances; they are specialized as kind, quantity or collective.

Kind represents a rigid sortal that supplies principles of identity and individualization to its instances; it represents the class of individuals whose instances are functional complexes; for example: a person, a tree, a chair.

Quantity represents individuals that refer to amounts of matter; for example: water, earth.

Collective represents collections of complexes that have a uniform structure; for example: a deck of cards, a forest, a group of people.

Subkind represents the class of individuals that carries the principle of identity supplied by a Substance Sortal; for example: man and woman are subkinds of person (kind).

Phase represents part of a partition of a Substance Sortal, where certain of its properties may change during its existence while remaining the same entity; for example: when a child (phase) becomes an adult (phase), the person (kind) is still the same person.

Role represents the class of individuals relationally dependent on a Substance Sortal; for example: the role student is played by a person (kind) when she/he is enrolled in an educational institution.

Category represents a dispersive universal that aggregates essential properties which are common to different Substance Sortals; for example: a rational entity (category) is a generalization of person (kind) and computer (kind).

RoleMixin represents a dispersive universal that aggregates properties which are common to different roles; for example: customer (roleMixin) is a generalization of personal customer (role) and corporate customer (role).

Mixin represents properties that are essential to some of its instances and accidental to others; for example: seatable (mixin) represents a property that can be considered essential to chair (kind) but accidental to bottle crate (kind).

Moment Universals are those whose individuals are existentially dependent, so that they only can exist in other individuals; they are inherent to these other individuals. Color, for example, whose individuals can only exist in other individuals, is a Moment Universal. Existential dependence can also be used to differentiate intrinsic and relational moments. While intrinsic moments are dependent of one single individual, such as a color (quality universal) or a headache (mode universal), relational moments (relators) depend on a plurality of individuals (e.g., a medical treatment, a marriage). Relators are individuals with the power of connecting (mediate) entities. For example, a medical treatment connects a patient with a medical unit.

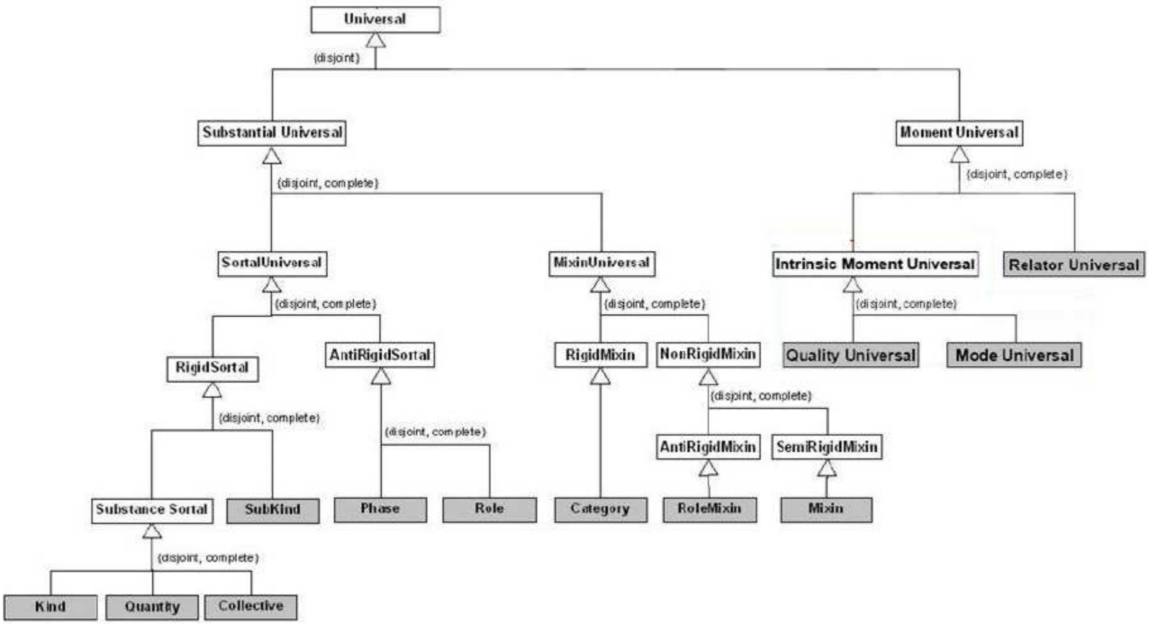


Figure 3 A Fragment of UFO-A (Guizzardi, 2005).

2.2.2 UFO-B: An Ontology of Perdurants

UFO-B, described in (Guizzardi, Falbo and Guizzardi, 2008), discerns endurants and perdurants, which are enduring and perduring individuals, respectively. This distinction is made in terms of their behavior regarding time. Endurants (e.g., a car, a person) preserve their identity over time. Perdurants (e.g., a business process, a conversation), conversely, are individuals composed of temporal parts, which do not retain their identity through time.

Events (Perdurants, Occurrents) are possible changes from a portion of reality to another, i.e., they may transform reality by changing the state of affairs from one pre-state situation to a post-state situation. Events are existentially dependent on their participants in order to exist. Each participation is itself an event that can be atomic (with no improper parts) or complex (composed of at least two events that can themselves be atomic or complex), but that existentially depends on a single substantial. In this ontology, being atomic and being instantaneous are orthogonal notions, i.e., the former can be time-extended as well as the latter can be composed of multiple (instantaneous) participations (Baiôco et al., 2009).

2.2.3 UFO-C: An Ontology of Social Entities

UFO-C, presented in (Guizzardi, Falbo and Guizzardi, 2008), is an ontology of social entities (both endurants and perdurants) built on top of UFO-A and UFO-B. The first distinction to be understood in this ontology is the one between Agentive and Nonagentive substantial particulars, termed Agents and Objects, respectively. Agents can be physical (e.g., a person) or social (e.g., an organization, a society). Objects can also be further categorized in physical (e.g., a book) or social (e.g., money, language). A

Normative Description is a social object which defines one or more rules/norms recognized by at least one social agent. It also defines nominal universals such as social moment universals (e.g., social commitment types), social objects (the crown of the queen of UK) and social roles such as president. Examples of normative descriptions include the Brazilian Constitution, as well as a set of directives on how to perform some actions within an organization.

As cited in (Baiôco et al., 2009), agents are substantials that can bear special types of moments termed Intentional Moments. Every intentional moment has a type (e.g., Belief, Desire, Intention) and a propositional content (an abstract representation of a class of situations referred by that intentional moment). It is important to highlight that intentionality should be understood in a broader context than the notion of “intending something”, but as the capacity of some properties of certain individuals to refer to possible situations of reality. In this sense, “intending something” is a specific type of intentionality, namely Intention. The propositional content of an Intention is a Goal. Beliefs can be justified by situations in reality. Desires express a will of an agent towards a state of affairs in reality. Intentions, in its turn, are desired state of affairs for which the agent commits at pursuing (internal commitment). Therefore, intentions cause the agent to perform Actions. Actions (e.g., a business process, a communicative act) can be understood as events which instantiate a Plan (Action Universal) with the specific purpose of satisfying (the propositional content of) some intention. Thus, actions are intentional events. As events, actions can be atomic or complex (composed of two or more participations). Participations can be intentional (being, therefore, themselves actions, named Action Contributions) or unintentional events. For instance, carpenters collaborating to build a house include the intentional participation of carpenters and the unintentional participation of the house, as well as the tools and raw materials used to create it, named Resources. In particular, this example reflects an Interaction, i.e., a complex action composed of different agents’ action contributions. Objects can participate in actions (Resource Participation) in different ways, i.e., Creation, Termination, Change or Usage.

Social moments are types of intentional moments that are created by the exchange of communicative acts and the consequences of these exchanges (e.g., goal adoption, delegation). A Social Relator is an example of a relator composed of two or more pairs of associated commitments/claims (social moments). An internal or a social commitment is fulfilled by an agent if this agent performs an action that the post-state of this action is a situation that satisfies that commitment.

3 PARTS AND WHOLES

In the previous sections we introduced the principles found on ontologies, relating the philosophical and the computational perspectives, and then presented UFO, one of the main foundational ontologies in use nowadays. Here, in the next sections, we change our focus, presenting the foundations of parts and wholes, in other words, studying the theory of parts and integral wholes.

3.1 Mereology

Mereology is considered as a mature discipline with well-defined and formally characterized theories, which in fact form a lattice of theories such that there is not one single formal meaning of part in mereology, but several alternative axiomatizations of parthood that extend each other. Mapping modeling primitives representing part-whole relations to these theories can indeed provide an important contribution to conceptual modeling (Guizzardi, 2011).

According to (Varzi, 2007), the word "part" has many different meanings in ordinary language, not all of which correspond to the same relation. In a way, it can be used to indicate any portion of a given entity, regardless of whether the portion itself is attached to the remainder or undetached; cognitively salient or arbitrarily demarcated; self-connected or disconnected; homogeneous or gerrymandered; material or immaterial; extended or unextended; spatial or temporal; and so on.

The analysis of parthood relations (mereology, from the Greek μερος, 'part') has for a long time been a major focus of philosophical investigation, beginning as early as with atomists and continuing throughout the writings of ancient and medieval ontologists. As a formal theory, mereology is simply an attempt to set out the general principles underlying the relationships between a whole and its constituent parts, just like set theory is an attempt to set out the principles underlying the relationships between a class and its constituent members. However, unlike set theory, mereology is not committed to the existence of abstract entities; the whole can be just as concrete as the parts (Varzi, 1996).

Parthood is a relation of fundamental importance in conceptual modeling, being present as a modeling primitive in practically all major conceptual modeling languages (Guizzardi, 2011). Mereology provides a sound formal basis for the analysis and representation of the relations between parts and wholes, and among parts that compose a whole, regardless of their specific nature (Guizzardi, 2005). It has shown itself useful for many purposes in mathematics and philosophy (Varzi, 1996).

A theory elaborated by Leonard and Goodman in 1940, The Calculus of Individuals, describes relations among individuals, irrespective of their ontological nature or the meta-level category to which they belong. In other words, the relata can be as different as material bodies, events, geographical regions or abstract entities. Mereologies are formal (i.e., domain independent) theories, which formally characterize the principles underlying the relations between an entity and its constituent parts, just like set theory formally characterizes the underlying relationships between a class and its members (Guizzardi, 2005).

As underlined in (Artale et al., 1996), this theory basically introduces a proper-part-of binary relation as a strict ordering relation on the domain, satisfying a set of additional principles. The most important of them may be informally summarized as follows:

- Supplementation (Minimal or Ground Mereology): if an individual is a proper-part-of a second individual, then a different third individual exists which is the missing part from that second individual;

- Extensionality (Extensional Mereology): two individuals are identical if, and only if, they have the same parts;

- Principle of Sum (Classical Mereology): there always exists the individual composed by any two individuals of the theory, i.e., the mereological sum.

As discussed in (Guizzardi, 2005; Guizzardi, 2011), mereology, the Minimal or Ground Mereology, has been extended in different ways, such as the Extensional Mereology and the Classical Mereology, for dealing with different perspectives of reality. In practically all philosophical theories of parts, the relation of (proper) parthood stands for a strict partial ordering, i.e., an asymmetric and transitive relation from which irreflexivity follows. These axioms amount to what is referred in the literature by the name of Minimal Mereology, which is the core of any theory of parts, i.e., the axioms define the minimal (partial ordering) constraints that every relation must fulfill to be considered a parthood relation.

An important relation in the theories of parts is the existence of overlapping. Two individuals overlap if they have a part in common; this includes the case in which one is part of another, considering the case of identity. Overlapping is the mereological counterpart of the intersect relation in set theory. If, and only if, two individuals do not overlap, they are said to be disjoint. In other words, two individuals are disjoint if, and only if, they have no parts in common.

The first extension to the Minimal Mereology has been created by strengthening the supplementation principle. Two objects are identical if, and only if, they have the same (proper) parts. This is the mereological counterpart of the extensionality principle in set theory, which states that two sets are identical if, and only if, they have the same members. The philosophical controversy of the Extensional Mereology arises exactly because of this axiom. To use an example, a statue and a lump of clay can be composed of the same parts. They are, nonetheless, diverse, since they possess incompatible meta-properties. As pointed out in (Fiorini, 2014), the similarity between wholes takes into account which parts are actually similar and how parts are structured, on else a house would be similar to a pile of bricks.

Although Extensional Mereology describes the basic meaning of parthood for some types of entities (e.g., quantities and events), this is not the case for entities of all ontological categories. In particular for functional complexes, while some of their parts are essential (some parts are inseparable), not all of them are essential (some parts are separable).

A second way that the Minimal Mereology has been extended is with the aim of providing a number of closure operations to the mereological domain, known as the Classical Mereology:

- Sum: also named mereological fusion. The sum z of two objects x and y is the entity such that every object that overlaps with z, overlaps either with x or with y (or with both);

- Product: also named superposition. The product of two objects x and y is the entity z such that every part of z is either part of x or y;

- Difference: the difference of two objects x and y is the entity z such that every part of z is part of x and does not overlap with y;

- Complement: the complement of an entity x is the entity z such that every part of z does not overlap with x.

These operations are the mereological counterpart of the set theoretical operations of union, intersection, set difference and complement of a set, respectively. In the presence of the extensionality principle, the z's that are the results of these operations are unique. Thus, for example, in an extensional mereology, if two objects x and y overlap, then there is a unique entity z that is composed of the common parts of x and y. Furthermore, the classical mereological theories focus solely on the relation from the parts to the wholes.

3.2 Part-Whole Relations

On the basis of linguistic and cognitive studies, it is proposed in (Winston, Chaffin and Herrmann, 1987) a distinction among various kinds of specialized part-whole relations in order to overcome the apparent transitivity paradoxes, which are ascribed to the mixing of different kinds of part-whole relations. The main idea is to capture the different ways in which parts contribute to the structure of the whole, by introducing six different types of meronymic relations as follow:

- Component/Integral-Object: integral objects are characterized by having a structure, while their components are separable and have a specific functionality. For example, wheels are parts of cars;

- Member/Collection: captures the notion of membership in a collection. Members do not play any functional role with respect to the whole they are part of, but they can be separated from it. For example, a tree is part of a forest;

- Portion/Mass: the whole is considered as a homogeneous aggregate and its portions are similar to it (homeomerous) and separable, as in “this slice is part of a pie”;

- Stuff/Object: expresses constituency of things, as in “the bike is partly steel” or “the bike is made of steel”. Essentially, in order to distinguish these part relations from the other ones, the argument is that the stuff of which a thing is made of cannot be separated from the object; it does not have any functional role nor it is homeomerous;

- Feature/Activity: designates a phase of an activity. A phase, like a component, has a functional role, but it is not separable. For example, we can say that grasping is part of stacking objects;

- Place/Area: it is a spatial relation among regions occupied by different objects. Like the portion/mass relation, the place/area is homeomerous since every part of a region is similar to the whole region, but they cannot be separated. For example, we can say that an oasis is part of a desert.

A notion of different views on the entities was added by (Gerstl and Pribbenow, 1995) in the sense that from one viewpoint a complex may be just a collection, which can be a source of problems for semantic interoperability. Although they provide linguistic motivations by showing various examples supporting the existence of three types of meronymic relations, they do not provide ontologically rigorous definitions for them (Keet and Artale, 2008).

They present a common-sense theory of part-whole relations, which is motivated by differences in the compositional structure of the whole, proposing three different types of relations:

- a homogeneous mass with quantities;

- a collection of uniform elements;

- a complex of heterogeneous components.

Odell proposes in (Odell, 1998) a list of six types of part-whole relations, providing descriptions and examples:

- Component-integral object: discrete type of part-whole relation with atoms;

- Material-object: constitution of objects;

- Portion-object: some amount of matter is part of the whole; Scale-based partonomic relations;

- Place-area: where part-place cannot be separated from the whole-area;

- Member-bunch: whole bunch is generally denoted with a collective noun and its members can change over time;

- Member-partnership: like member-bunch, but changing a member destroys the whole.

Guizzardi also proposes in (Guizzardi, 2005) four different types of part-whole relations, on which we present a deeper analysis in Section 4.1:

- Component-of: a car engine is part of a car;

- Member-of: a tree is part of a forest;

- Subcollection-of: the north part of the Black Forest is part of the Black Forest;

- Subquantity-of: alcohol is part of wine.

These distinctions among different kinds of part-whole relations offer a reason to the apparent lack of transitivity in examples like the ones cited in Section 3.4. The particular behaviour of the different part-whole relations may lie, among other things, in the ontological nature of both the whole, including notions like integrity, and the part (Artale et al., 1996).

The distinction between essential and mandatory parts is discussed in (Artale and Keet, 2008), where they state that it can be intuitively explained in terms of a specific versus generic dependence relationship, respectively between the class that describes the whole and the one that describes the part. Mandatory parts express a generic dependence relationship in the sense that, although a part of a certain kind must be always present when the whole exists, the particular part can be different at different moments of time (the part can be replaced). On the other hand, essential parts express a specific dependence relationship, that is, the whole must be always associated with the very same part, and the part must be the same along the entire lifetime of the whole. As an example of mandatory and essential parts, we assume that each person has necessarily a specific brain (essential part) while not necessarily a specific heart, thanks to heart transplantation (mandatory part).

Recollecting (Guizzardi, 2005) contribution on the formalization of the difference between mandatory and essential parts and wholes, we can say that: a part is mandatory if the whole cannot exist without it, which can also be verbalized as “the whole has a mandatory part", i.e., a standard mandatory constraint on the role played by the whole in a part-whole relation. In a symmetric way we can define mandatory wholes. A part is essential if it is mandatory and cannot change without destroying the whole, i.e., “the whole has an essential part"; in an analogous way we can define essential wholes. Furthermore, we say that a part is exclusive if it can be part of at most one whole, similarly for exclusive wholes (Artale and Keet, 2009).

Simons underlined in (Simons, 1987a) that the essential attributes of an object are not a brute fact about it as a particular; an object has the essential properties it has in virtue of being exactly the kind of object it is. These essential parts may have parts which are not essential to them, or to their wholes, but an essential part of an essential part is an essential part of the whole.

As pointed out in (Artale and Keet, 2009), considering the possible interactions between the part-whole relations and shareability, one directly can note that if something is physically a proper part of a whole, such as that a car engine is a proper part of the car, then this proper part cannot physically be directly part of another whole at the same time, and likewise for its subtypes proper containment and proper location. In contrast, a proper subprocess can be simultaneously involved-in (part-of) several grander processes; e.g., a key chemical reaction intersecting in two metabolic pathways.

As elaborated in (Simons, 1987a), cases where an object has an essential proper part are, as a consequence, cases of ontological dependence. Ontological or existencial dependence concerns the relationship between objects, where the dependence of one object on another is a necessity, meaning that the object itself could not exist without the existence of the other. The causal dependence of events and states on other events and states seems to be less constraining, however, it is very common cases of causal dependence which are also cases of ontological dependence in the strict sense. Considering the distinction among the different types of relations, we have to consider some other relevant properties, known as logical properties.

3.3 Logical Properties

The logical properties of the relations have been subject of extensive study in philosophy, linguistics, knowledge representation, among others. Binary relations and their main basic logical properties are mathematically defined in (Rajagopal and Mason, 1992).

Relations: Let U be a set, $U \times U$ the product set of U and U. Any subset R of $U \times U$ is called a relation on U. For any (x, y) that belongs to $U \times U$, if (x, y) belongs to R, then x has relation R with y and denotes this relationship as xRy. For any x that belongs to U, the set $\{y$ belongs to $U|xRy\}$ is the right neighborhood of x in R and it is denoted as $RNr(x)$. For any x that belongs to U, the set $\{y$ belongs to $U|yRx\}$ is the left neighborhood of *x* in *R* and it is denoted as *LNr*(*x*). When the definition is not ambiguous, the lowercase "*r*" may be omitted.

Reflexive relations: Let *R* be a relation on *U*. If for any *x* that belongs to *U*, *xRx*, then *R* is reflexive. In other words, if for any *x* that belongs to *U*, *x* belongs to *RN*(*x*), then *R* is reflexive.

Symmetric relations: Let *R* be a relation on *U*. If for any *x*, *y* that belongs to *U*, *xRy* → *yRx*, then *R* is symmetric. In other words, if for any *x*, *y* that belongs to *U*, *y* belongs to *RN*(*x*) → *x* belongs to *RN*(*y*), then *R* is symmetric.

Transitive relations: Let *R* be a relation on *U*. If for any *x*, *y*, *z* that belongs to *U*, *xRy*, and *yRz* → *xRz*, then *R* is transitive.

Equivalent relations: Let *R* be a relation on *U*. If *R* is reflexive, symmetric and transitive, then *R* is equivalent relation on *U*.

Reflexivity classifies the relations as reflexive, nonreflexive or irreflexive; symmetry classifies the relations as symmetric, asymmetric or antisymmetric; transitivity classifies the relations as transitive, nontransitive or intransitive.

A relation is reflexive when every element is related to itself; it is irreflexive when no element is related to itself; and it is nonreflexive if it is neither reflexive nor irreflexive. A relation is symmetric when, for every element, if *x* is related to *y*, then *y* is related to *x*; it is asymmetric when, for every element, if *x* is related to *y*, then *y* is not related to *x*; and it is antisymmetric when, for every element, if *x* is related to *y* and *y* is related to *x*, then *x* is equal to *y*. A relation is transitive when, for every element, if *x* is related to *y* and *y* is related to *z*, then *x* is related to *z*; it is intransitive when, for every element, if *x* is related to *y* and *y* is related to *z*, then *x* is not related to *z*; and it is nontransitive if it is neither transitive nor intransitive.

For instance, a person cannot be its own ancestor (the ancestor-of relation is irreflexive); if a person *x* is an ancestor-of person *y*, then *y* cannot be an ancestor-of *x* (the ancestor-of relation is asymmetric); if a person *x* is an ancestor-of person *y* and *y* is an ancestor-of person *z*, then *x* is an ancestor-of *z* (the ancestor-of relation is transitive).

Some authors also discuss other relevant properties for part-whole relations, such as the shareability and the supplementation properties.

Shareability is evaluated in respect to the exclusiveness of the part to the whole; if the part is exclusive to its whole, then the relation is said to be nonshareable, but if the part is not exclusive to its whole, then the relation is said to be shareable.

Supplementation may be classified as weak or strong.

The weak supplementation, as defined in (Guizzardi, 2005), is related to the Minimal Mereology: if *x* is part of *y*, then there must be a *z* disjoint of *x*, which also is part of *y*. According to the discussion in (Smith, 2009), the weak supplementation happens when an object with a proper part *p* has another distinct proper part that does not overlap *p*. As formalized in (Sider, 2007), in the weak supplementation if an object *x* is part of an object *y*, and *x* is not equal to *y*, then *y* has a part that does not overlap *x*. In (Bittner and Donnelly, 2007), the relation *R* is said to have the weak supplementation property if and only if, for all *x*, *y* that belongs to *D*(*R*), if *R*(*x*, *y*) then there is a *z* that belongs to *D*(*R*) such that *R*(*z*, *y*), but not *Ro*(*z*, *x*). The weak supplementation property tells us that if the spatial object *x* is a proper part of the spatial object *y*, then there is a proper part *z* of *y* that does not overlap *x*. For example, since the left side of Joe's body is a proper part of his body, there is some proper part of his body (e.g., the right side of his body, such as his right hand) which does not overlap the left side of his body.

The strong supplementation, as defined in (Guizzardi, 2005), is related to the Extensional Mereology: the objects are completely defined by their parts. As proposed in (Smith, 2009), in the strong supplementation if an object *x* does not have an object *y* as part, then there is another object *z* that is a part of *x* and does not overlap *y*. According to (Sider, 2007), in the strong supplementation if an object *y* is not part of an object *x*, then *y* has a part that does not overlap *x*.

For instance, the partonomic component-of relation is nontransitive, irreflexive, asymmetric and weak supplementation; the partonomic member-of relation is intransitive, irreflexive, asymmetric and weak supplementation; the partonomic subcollection-of relation is transitive, irreflexive, asymmetric and weak supplementation; the partonomic subquantity-of relation is transitive, irreflexive, asymmetric, strong supplementation and nonshareable.

3.4 Problem of Transitivity

The problem of transitivity of part-whole relations is a much debated topic not only in conceptual modeling, but also in the linguistic and cognitive science literature. In many conceptual modeling languages (e.g., UML), part-whole relations are always considered transitive. However, as presented in (Guizzardi, 2005; Guizzardi, 2006), examples of fallacious cases of transitivity among part-whole relations abound.

Among the algebraic properties peculiar to the notion of part, the most discussed one is transitivity. We can say, for example, that the finger is part of the hand, the hand is part of the human body, and then inferring that the finger is also part of the human body. However, transitivity does not always hold; as an example, consider the following case: an arm is part of a musician, the musician is part of an orchestra, but it would sound a bit strange to state that the arm is part of the orchestra (Artale et al., 1996). As discussed in (Fiorini, 2014), one of the accepted solutions is to consider ontologically distinct types of part-whole relations, which are naturally not transitive between themselves.

Member collection relations are never transitive, i.e., they are intransitive. This can be understood in our analysis in the following way. To say that a member must be a singular entity coincides in this case with this entity being an atom of a given context. Or to put it differently, the unifying relation underlying membership cannot be further refined.

In (Guizzardi, 2006), it is presented (Figure 4) a meronymic relation between a Human Heart and a Band Member, and the relation between a Band Member and a Band. As this specification shows, the relation between a Human Heart and a Band Member is one of indirect functional parthood (i1), and the relation between a Band Member and a Band is one of direct functional parthood (d1). Transitivity does not hold across indirect and direct functional parthoods. Thus, in this particular specification, a Human Heart is not part of a Band.

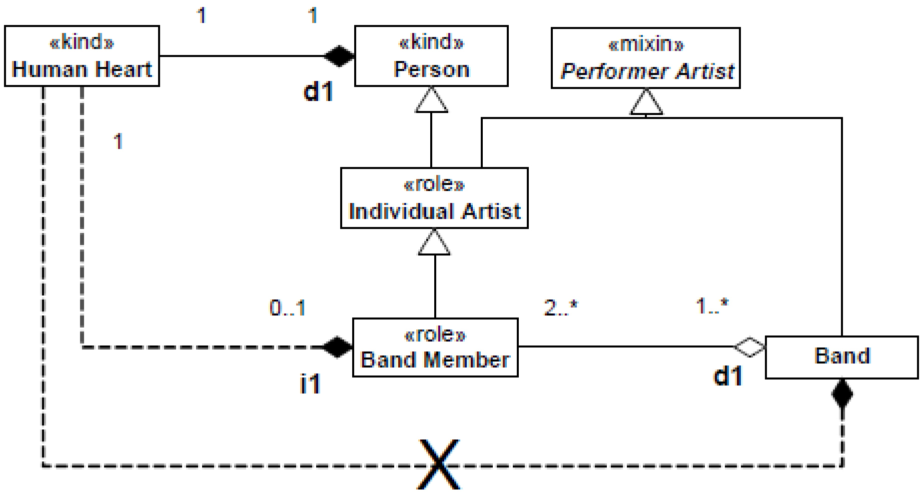


Figure 4 A situation where transitivity does not hold across functional parthood relations (Guizzardi, 2006).

The particular behaviour of the different part-whole relations may also present some problems concerning the evolution of the objects through time, leading to an evaluation on the categories of continuants and occurrents.

3.5 Continuants and Occurrents

Spatio-temporal objects fall into two major categories: continuants and occurrents (Simons, 1987a). Continuants (endurants) change over time by, for example, gaining or losing parts, growing older, changing their location, but they still remain the same thing. Occurrents (perdurants) do not change over time, they just occur. The existence of an occurrent always depends on the existence of some continuant (Bittner, 2002).

The ontological distinction between continuants (objects which persist through time) and occurrents (states or events which are bounded in time) leads to some problems when considering change, specifically over rigid parts or properties (Cohn and Hazarika, 2001). This can even entail paradoxes. This problem may be solved by considering all material objects as occurrents, since properties become relative to temporal parts of these objects (Simons, 1987a).

As discussed in (Bittner, 2002), there are continuants that have different spatial locations at different times. We say that these objects change their spatial location. If we consider a temporal region (a period of time) during which the spatio-temporal object exists, then it may be either located in the same region of space over a period of time, or its spatial location may change by being located in different regions of space at different time-instants during this period.

There is a fundamental philosophical controversy concerning the evolution of concepts in time, namely the perdurantist and the endurantist approaches. This controversy also applies to the generalized spatio-temporal representation (Grenon and Smith, 2004). It is related to issues such as the identity of objects as they evolve in time and, either they endure in time, although their properties may change, implying a fundamental distinction between objects and events, or they perdure in time by relating properties in time and space in a form of a generalized event (perdurantist approach).

According to the perdurantist approach every object is in fact a generalized event having specific spatial and temporal extensions (Sotirios, 2011).

As underlined in (Salamat and Zahzah, 2012), spatio-temporal relations can be defined in the way that spatial relation holds for a certain time interval, and it does not change. In the spatio-temporal object theory, it is defined in the way that a spatial relation is a relation holding between all temporal slices of two entities during a relevant period of time.

Bittner described in (Bittner, 2002) the relationship between occurrents and continuants as very complex in the sense that a single occurrent may depend on multiple continuants, and the set of continuants it depends on can change, losing or gaining members. Considering the relationship between occurrents and the continuants they depend on, we can distinguish two major categories of occurrents: events and processes. Events are spatio-temporal objects that correspond to the occurrence of a certain continuant in a certain state, e.g., the occurrent “John’s childhood” corresponds to the continuant John in the state of being a child. Processes, on the other hand, correspond to the occurrence of the change of some continuant. For example, the process of “John’s growing up” corresponds to certain patterns of changes of the continuant John.

Simons discusses in (Simons, 1987a) the principles of parts for occurrents and continuants. The interaction of part-whole issues with those of time varies according as we consider occurrents on the one hand or continuants on the other hand.

Occurrents comprise events, processes, happenings, occurrences and states. They are, like continuants, in time, but they are distinguished from continuants precisely for having temporal parts. A continuant, at any time at which it exists, is present as a whole, and not just in part. In general, neither occurrents nor continuants have any ontological, epistemological or referential priority over the other, we need both.

The relation of occurrents to time is direct and intimate. Their relation to space is usually less direct, in that their location is given by that of the continuants which participate in them. By virtue of involving extended continuants, occurrents may be scattered and have spatial and temporal parts. The location of an occurrent can be only determined from the location of the related continuants.

Where occurrents have both duration and spatial extents, they may have some parts which are neither purely spatial nor purely temporal, in addition to their spatial and temporal parts. A temporal part of an occurrent is a part including all simultaneously occurring parts of it.

Occurrents are not mere occupiers of space-time. Like continuants, they may be natural or artificial, which rules out their classification in pure mereological or spatio-temporal terms.

Typical continuants come into existence at a certain moment, continue to exist for a period of time and then cease to exist. Not everything that is a continuant is a material thing, object or substance. In particular, there are numerous continuants, such as smiles and waves, which are disturbances in substances rather than substances. Nevertheless, typical continuants, those which do not exist only momentarily, display an important formal property.

Many material objects may gain or lose parts without prejudice to their identity and continued existence; these objects are called mereologically variable. In contrast, objects which cannot gain or lose parts without affecting their identity and continued existence are called mereologically constant.

As described in (Sowa, 2000), a continuant has stable attributes or characteristics that enable its various appearances at different times to be recognized as the same individual. An occurrent is in a state of flux that prevents it from being recognized by a stable set of attributes. Instead, it can only be identified by its location in some region of space-time.

3.6 Integral Wholes

A particular kind of whole, which is called an integral object, is divided into components. Integral objects all exhibit some kind of patterned organization or structure. Their components are also patterned and usually bear specific structural and functional relationships to one another and to the wholes which they compose. These structural relations define the particular natures of integral wholes and their components (Winston, Chaffin and Herrmann, 1987).

For every whole there is a set of (possibly potential) parts; for every specifiable set of parts (arbitrary objects) there is, in principle, a complete whole, its mereological sum, or fusion (Varzi, 1996). The integrity of something in some respect is clearly a matter of certain specific relations among the parts of the object, these relations being characteristic of the respect in which the object is integrated (Simons, 1987a).

As stated in (Guizzardi, 2005), one of the major conceptual problems with Classical Extensional Mereology comes from the generalized fusion axiom, which allows for the existence of a sum (or fusion) for any arbitrary nonempty set of entities. For example, it allows for the definition of an aggregate composed by the state of California and the number 3. According to (Simons, 1987b), the difference between purely formal mereological sums and integral wholes is an ontological one, which can be understood by comparing their existence conditions. For sums, these conditions are minimal: the sum exists just when the constituent parts exist. By contrast, for an integral whole (composed of the same parts of the corresponding sum) to exist, a further unifying condition among the constituent parts must be fulfilled.

Deciding what is the integral whole that should persist is therefore the very task of the principle of application. This supports the thesis that the principle of unity of an individual is also strongly related to its principles of application and identity. In order to individuate something we must decide what its parts are, i.e., we must see it as an integral whole. Thus counting presupposes individuation, individuation presupposes unity and unity presupposes application. Therefore, it is no coincidence that the universals that carry principles of identity, persistence, individuation and counting are also exactly those that also carry a principle of unity, namely sortal universals (Guizzardi, 2005).

As discussed in (Gangemi et al., 2001), a conceptual theory of parthood should also countenance a theory of wholes in which the relations that tie the parts of a whole together are also considered. The composite objects in which we are interested in conceptual modeling are not mere aggregations of arbitrary entities, but complex entities suitably unified by proper binding relations (Guizzardi, 2011).

The kind of integration of integrated wholes may vary. A centralized whole is one where the integrating relation consists in all the parts having a common relation to some part, whereas a network of relations may be without such a center. Between these extremes there is a variety of intermediate cases (Simons, 1987a).

Rescher and Oppenheim analyze the meaning of a whole, suggesting three basic conditions for its existence (Rescher and Oppenheim, 1955):

- The whole must have some peculiar and characteristic attribute in virtue of its status as a whole;

- The parts of the whole must stand in some special and characteristic relation of dependence with each other, satisfying some special condition in virtue of their status as parts of a whole;

- The whole must have some kind of structure in virtue of which certain specifically structural characteristics pertain to it.

As underlined in (Simons, 1987a), the relative proximity in time of parts of a temporal whole, even if it is not temporally continuous, may be crucial in holding it together. For temporal wholes, as for spatial wholes, the variation of these determinables produces different degrees of temporal integrity. The kind and degree of integrity which an individual continuant has at a time is a matter of the interrelations of the parts of the object which exist at that time. For occurrents, integrity over time has exactly the same concerning about which parts may take place at different times.

The conceptualization of parts and wholes are expressed in knowledge models and ontologies through relations, which express the different connections between a whole and its parts. Following, in the next sections, we present, in a more general view, a discussion about relations, analyzing their classification, meaning and importance for ontologies.

4 RELATIONS

Ontology represents a shared conceptualization that includes concepts, its attributes and the relationships between the concepts. Relationships are used to structure the concepts in the ontology. In ontology, all the concepts are hierarchically defined. Without the relationships, ontology has no meaning; they help the system to achieve a better understanding about what the concepts are. They also represent the dependency between concepts in the domain (Tudorache, 2004).

The importance of relationships is highlighted by (Bala and Aghila, 2011) when they state that relationship plays a vital role in the development of ontology for a domain. Relationships are fundamental to express semantics in ontology in order to associate concepts and their instances. Relationships are defined according to their properties (Section 3.3), like symmetry (symmetric, asymmetric, antisymmetric), reflexivity (reflexive, irreflexive, nonreflexive), transitivity (transitive, intransitive, nontransitive). In addition, there are functional, inverse functional and ordering (total order, partial order, no order) characteristics. Most of the formal relations satisfy transitive relations, but materialized relations depend on semantics of the relation.

As addressed in (Cardeñosa et al., 2008), ontological relations describe the interaction between two or more concepts. They are classified into two types: vertical relations, which organize concepts into a hierarchical tree (a concept is a subclass, a specialization of another concept), and horizontal relations, which link concepts along a tree of hierarchies. Some horizontal relations examples are meronymic, location in space and time, and causal relations.

In (Guizzardi, 2005), relations are defined as entities that glue together other entities. Every relation has a number of relata as arguments, which are connected or related by it. Relations are divided into two broad categories, called material and formal relations.

Formal relations hold between two or more entities directly, without any further intervening individual. Examples include *taller than*, *heavier than*, *older than*, etc.

Material relations, conversely, have material structure on their own and include examples such as *employments*, *enrollments* and *flight connections*. The relata of a material relation are mediated by individuals that are called relators. Relators are individuals with the power of connecting entities.

Guarino also assumes a distinction between formal and material relations in (Guarino, 2009), where a formal relation is said to yield just because of the very existence of its relata, while a material relation needs another “grounding” entity. Suppose, for example, that John is older than Mary and John loves Mary; the Older-than relationship is a formal one, while the Loves relationship is a material one, since, besides the existence of John and Mary, it requires an extra entity, namely the event consisting of the love between John and Mary.

Grenon distinguishes between internal and material relations in (Grenon, 2003b). Internal relations (named as formal relations by Guarino and Guizzardi) are grounded in their relata, they are such that no extra entity is needed in order for them to be obtained. Material relations require additional entities linking their relata, they are grounded in an extra relational entity.

As addressed in (Guizzardi, 2005), perhaps a stronger and more general way to characterize the difference between formal and material relations is based on their foundation. There is a fundamental distinction between formal and material relations. While the former hold directly between two entities without any further intervening individual, the latter are induced by mediating entities called relators. Moreover, material relations are founded by material entities in reality, typically perdurants, which are external to their relata. Comparative formal relations, in contrast, are founded in qualities which are intrinsic to their relata and, hence, can be reduced to relations between these qualities.

Comparative formal relations are completely founded on certain intrinsic moments, and material relations are founded on relators. In the case of formal relations, they are derived from the meta-properties of relations among qualia in the underlying conceptual space. In the case of material relations, they are derived from their founding relators and mediated entities (Guizzardi, 2005).

In Figure 5, an example of a formal relation given in (Guizzardi and Wagner, 2008) shows the relation of temporal precedence between Symptoms. In this model, the classes Patient and Medical Unit represent object universals; the quality universal Symptom is represented by a class with the corresponding stereotype. Finally, the intrinsic property start date of a symptom (a universal whose instances are qualities of a quality) is not represented directly, but, instead, it is represented by its associated quality structure, the DateDomain. Formal relations are discussed in Section 4.1.

For material relations, take for instance the relation treatedIn between Patient and Medical Unit in Figure 5. This relation requires the existence of a third entity, namely an individual Treatment, mediating a particular Patient and a particular Medical Unit in order for the relation to hold. Material relations are discussed in Section 4.2.

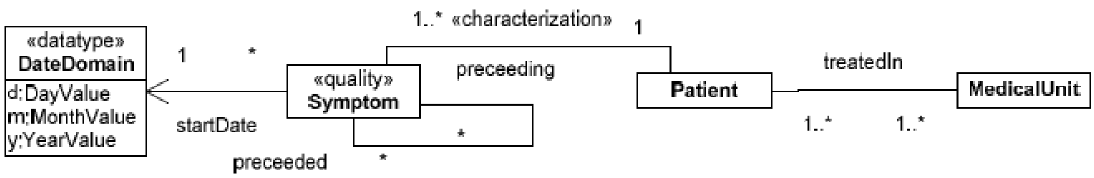


Figure 5 Representing Formal and Material Relations (Guizzardi and Wagner, 2008).

Grenon summarizes relations based on their eight most relevant points in (Grenon, 2007):

- Relations are entities;

- Relations are particulars;

- Relations relate entities which are not relations;

- Relations are not related to themselves (neither to related entities nor to other relations);

- Relations may or may not instantiate universals (but if they do, these universals are not relations);

- Relations are specific to the entities they relate;

- Relations are existentially dependent on the entities they relate;

- Relations are essentially directed.

The main relation ontological elements, which are discussed in the following sections about formal and material relations, are depicted in Figure 6.

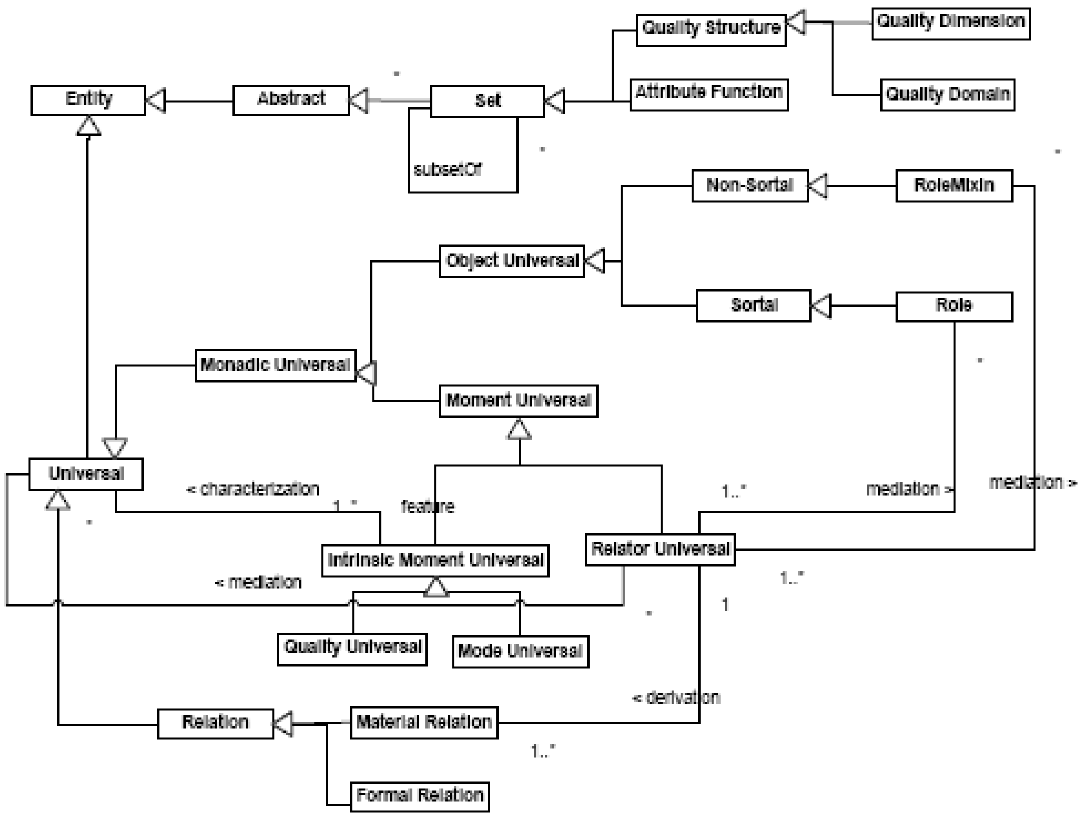


Figure 6 Formal and material relations structure (Guizzardi, 2005).

4.1 Formal Relations

Formal relations hold between two or more entities directly, without any further intervening particular. In principle, the category of formal relations includes part-whole (part-of, parthood, partonomic), taxonomic (is-a, subclass-of, subsumption), existential dependence, inherence, subset-of, instantiation, characterization, exemplification, among others. These relations are named basic formal relations or internal relations. However, those domain relations that exhibit similar characteristics are also classified as formal, i.e., those relations of comparison such as: is taller than, is older than, knows more Greek than. These relations are named comparative formal relations. As pointed out in (Mulligan and Smith, 1986), the entities that are immediate relata of such relations are not objects, but intrinsic moments. For instance, the relation heavier-than between two atoms is a formal relation that holds directly as soon as the relata (atoms) are given (Guizzardi and Wagner, 2010). The truth-value of a predicate representing this relation depends solely on the atomic number (a quality) of each atom and on the material content of heavier-than as distributed between the two relata (Guizzardi and Wagner, 2008).

Figure 7 exemplifies a formal relation between alcohol and wine, where alcohol is part of wine.

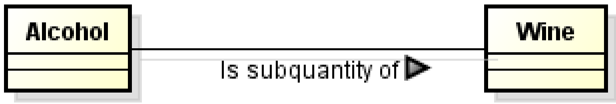


Figure 7 An example of formal relation.

In (Guizzardi, 2006), the comparison relations are also described as logical constructions which are completely reducible to intrinsic moments, to the values these moments take in a certain quality structure, and to the relations between these values induced by the properties of these structures. In general, we can state that the meta-properties of a comparative formal relation can be derived from the meta-properties of the relations between the qualia associated with the qualities founding this relation (Guizzardi, 2005).

As illustrated in (Guarino, 2009), within formal relations there are some distinctions between the internal and the external ones. For internal relation there is an existential dependence relationship between the relata, while for external relation the relationship is not essential for the relata.

The basic kinds of internal relationships are parthood, constitution, quality inherence, and participation, shown in Figure 8. There are, however, some technical problems concerning parthood and constitution (shown with an asterisk), since, if we take time into account, a specific parthood or constitution relationship can be understood as an internal relation only if it holds necessarily (concerning an essential part), otherwise we cannot simply say that such relationship holds without specifying the time frame (the event) where this happens (Guarino, 2009).

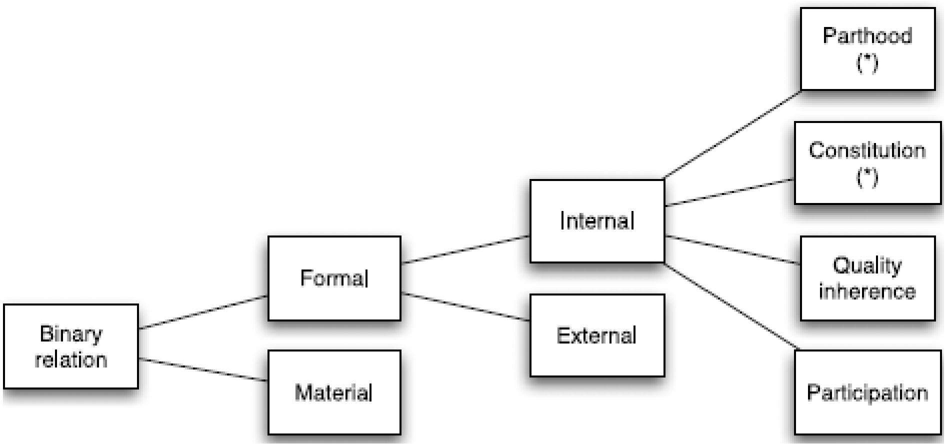


Figure 8 Basic distinctions within binary relations (Guarino, 2009).

As defined in (Guizzardi et al., 2007), a formal relation is either an internal relation holding directly between two entities (e.g., instantiation, parthood, inherence), or it is reducible to an internal relation between intrinsic moments of the involved relata. As examples of formal relations of the latter type, Lisa “is older than” Mike, and John “is taller than” Mary. In both cases, these relations are reducible to comparative formal relations between intrinsic moments of the involved relata (individual ages and heights).

Relations are defined with different semantics according to the ontological categories of the objects, which are the basic categories of existence. In other words, it is possible to distinguish the type of the relations based on the type of entities that they relate.

As formalized in (Partridge, 2002b), the most basic categories are types and elements; types are also called universals or classes, while elements are also called particulars. They are connected by the formal relation instance_of.

Elements and types are disjoint and an element is typically an instance_of a type but cannot have instances, whereas types typically have a number of instances. This gives rise to a classical characterization of types as objects that can have instances, and elements as objects that cannot have. Types also may be instances of types; for example, George is (an instance_of) an Accountant, and Accountant (a type) is (an instance_of) profession. Profession, whose instances are types, is an example of higher-order type.

The identity for the instance_of relation is dependent upon its two relata and the role they play in the relation: in other words, if two descriptions refer to instance_of relations with the same relata in the same roles, then they refer to the same relation.

As well as these basic categories of existence, there are three structural hierarchies built from basic formal relations into which objects must fit: typonomy, taxonomy and partonomy.

Typonomy is the hierarchy generated by the instance-type (instance_of) relation. Instances instantiate types; instances are in an instance-type relation with types. For example, my pet Fido is an instance_of the type dogs. Every object fits into the typonomy.

Taxonomy is the hierarchy generated by the super-sub-type (sub-type_of) relation. The sub-type_of relation is extensional; in other words, saying that type *A* is a sub-type_of type *B* means that all possible instances_of type *A* are also instances_of type *B*; and vice versa, if all possible instances_of type *A* are also instantiations of type *B*, *A* is a sub-type_of *B*. For example, “dog is a sub-type_of animal” means that every possible instance_of a dog is also an instance_of an animal; and if every possible instance_of a dog is also an instance_of an animal, then dog is a sub-type_of animal. As with the instance_of relation, the identity of the sub-type_of relation is dependent upon its two relata and their roles. Every type fits in the taxonomy.

Partonomy (or mereonomy) is the hierarchy generated by the whole-part (part_of) relation. Wholes are composed of parts; the whole has a whole-part relation with the part. Partonomy, in the first instance, is the hierarchy created by the whole-part relations between elements: for example, Fido’s foot (an element) is part_of his leg (another element) and Fido’s leg is part_of his body. The part_of relation is transitive, so Fido’s foot is part_of his body. It is possible to generalize the part_of relation from the “element” to its “type”; in this example, it is possible to generalize that dog’s bodies typically have legs as parts, and the legs typically have feet as parts.

As addressed in (Bittner, Donnelly and Smith, 2004), we distinguish three categories of entities: individuals, universals and collections, providing an axiomatic theory that formalizes relations between the entities in these categories in such a way as to make explicit their different temporal behavior.

Individuals, universals, and collections have different temporal properties. Individuals can gain and lose parts (for example, organisms gain and lose cells); universals gain and lose instances (for example, the universal human being gains or loses instances every time a person is born or dies); and collections are identified through their members and thus cannot have different members at different times.

While individuals are tied to universals through the instantiation relation, certain collections are tied to universals through the extension-of relation. The extension of a universal at a given time is the collection of all individuals which instantiate that universal at that time. Not every universal has an extension at every time, such as some extinct species.

Besides the extensions of universals, other important collections are those that consist of disjoint parts of an individual *y* which jointly sum up to *y*. We call such collections partitions of *y*. An example is a partition of a human body into its constituent cells. Many partitions consist of fiat parts like the head, neck, torso, and limbs of a human body or the right and left hemispheres of a brain.

Given the three categories, individuals, universals and collections, we can distinguish the following relations according to the kinds of entities they relate:

Relation between Individual and Individual: individual-part-of; for example, my heart is part of me.

Relation between Individual and Universal: instance-of; for example, I am an instance of human being.

Relation between Individual and Collection: member-of; for example, this finger is a member of the collection of my fingers.

Relation between Universal and Universal: taxonomic inclusion (is-a); for example, human being is-a mammal.

Relation between Universal and Universal: partonomic inclusion of universals; for example, every instance of the universal human brain is part of an instance of the universal human being.

Relation between Collection and Universal: extension-of; for example, the collection of all instances of the universal human being at a given time is the extension of the universal human being at that time.

Relation between Collection and Collection: partonomic inclusion of collections; for example, the collection of my hands is part of the collection of my arms.

Relation between Collection and Individual: partition-of (subdivision-of); for example, the collection of the subdivision of my body (head, neck, trunk, legs, arms) forms a subdivision of me.

According to (Guizzardi, 2005), every instance of a Substantial Universal is an instance of a Substance Sortal: Kind, Collective or Quantity, as presented in Section 2.2.1. In other words, the related entities participating in the partonomic formal relations are functional complexes, collectives or quantities.

Functional complex:

a) if the universal is a “sortal universal”, then it must be a “kind” or a subtype of a “kind”;

b) if the universal is a subtype of a “mixin universal”, then it cannot be a “quantity”, a subtype of a “quantity”, a “collective”, or a subtype of a “collective”.

Collective:

a) if the universal is a “sortal universal”, then it must be a “collective” or a subtype of a “collective”;

b) if the universal is a subtype of a “mixin universal”, then it cannot be a “kind”, a subtype of a “kind”, a “quantity”, or a subtype of a “quantity”.

Quantity:

a) if the universal is a “sortal universal”, then it must be a “quantity” or a subtype of a “quantity”;

b) if the universal is a subtype of a “mixin universal”, then it cannot be a “kind”, a subtype of a “kind”, a “collective”, or a subtype of a “collective”.

Given these categories, we can distinguish the following relations according to the kinds of entities they relate:

Relation between Functional Complex and Functional Complex: component-of; for example, a car engine is part of a car. This relation is nontransitive, irreflexive, asymmetric, weak supplementation.

Relation between Collective and Collective: subcollection-of; for example, the Brazilian part of the Amazon Forest is part of the Amazon Forest. This relation is transitive, irreflexive, asymmetric, weak supplementation.

Relation between Functional Complex or Collective “considered as a unity” (as part) and Collective (as whole): member-of; for example, a tree is part of a forest, the group of students from this class is member of the university. This relation is intransitive, irreflexive, asymmetric, weak supplementation.

Relation between Quantity and Quantity: subquantity-of; for example, alcohol is part of wine. This relation is transitive, irreflexive, asymmetric, strong supplementation, nonshareable.

4.2 Material Relations

Unlike formal relations, material relations have material structure of their own and include examples such as working at, being enrolled at, and being connected to. While a formal relation between Paul and his knowledge of Greek holds directly as soon as Paul and knowledge of Greek exist, for a material relation of being treated in between Paul and a medical unit to exist, another entity must exist which mediates Paul and the medical unit. These entities are named relators. Relators are particulars with the power of connecting entities (Guizzardi and Wagner, 2010).

Figure 9 depicts an example of material relation between employee and company, where, if an employee works for a company, another entity (employment) must exist in order to mediate them.

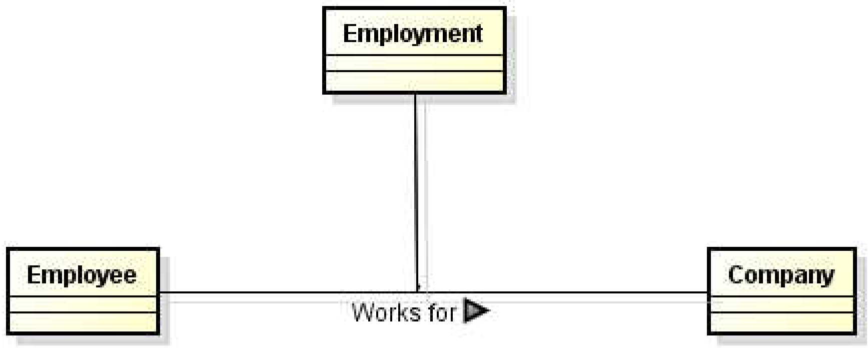


Figure 9 An example of material relation.

Material relations are not founded on intrinsic moments of the involved relata. Material relations are induced by mediating entities called relators. Thus, in order to define a material relation between two entities (relata), another entity must exist, namely an instance of a relator (relational moment), which is existentially dependent on both related entities, hence, connecting these two individuals (Guizzardi, 2006). Material relations hold their material structure; some examples include working-at, has-contact, is-connected-to (Guizzardi and Wagner, 2008). In other words, the relata of a material relation are mediated by relators (Guizzardi, 2005). Another example is the relation being married to between John and Mary. This relation cannot be reduced to intrinsic properties of John and Mary. For this relation to hold, a certain wedding event involving John and Mary must have taken place which creates an individual relator marriage connecting the two. It is important to emphasize that a relator such as the marriage between John and Mary is considered here a genuine ontological entity and can be thought as the aggregation of all social rights and responsibilities that John and Mary acquire by virtue of their participation in that relation (Guizzardi, 2006).

As underlined in (Guizzardi et al., 2007), moments can be specialized into intrinsic moments and relators. The former refers to a moment that is existentially dependent on one single individual. In contrast, a relator is a moment that is existentially dependent on more than one individual (e.g., a marriage, an enrollment between a student and an educational institution). A relator is an individual capable of connecting (mediating) entities. For example, we can say that John is married to Mary because there is an individual marriage relator that existentially depends on both John and Mary, thus, mediating the two.

Relators are special types of (relational) moments, i.e., particularized relational properties that are composed of certain externally dependent modes (Guizzardi, 2005). An externally dependent moment is a special kind of intrinsic moment that although inhering in a specific individual, it also existentially depends on another one. The employee identifier is an example of externally dependent moment, since although inherent to the employee, it is also dependent on the organization where this employee works (Guizzardi et al., 2007).

In (Guizzardi and Wagner, 2008), a relator is said to mediate (or connect) the relata of a material relation. Mediation is a special type of existential dependence relation or, more specifically, a sort of nonexclusive inherence. It is required that a relator mediates at least two distinct individuals. The notion of relator (relational tropes) is supported by several works in the philosophical literature, and they play an important role in answering questions such as: what does it mean to say that John is married to Mary? Why is it true to say that Bill works for Company *X* but not for Company *Y*?

An important notion for the characterization of relators (and, hence, for the characterization of material relations) is the notion of foundation. Foundation can be seen as a type of historical dependence (Ferrario and Oltramari, 2004) in the way that, for example, an instance of being kissed is founded on an individual kiss, an instance of being punched by is founded on an individual punch, an instance of being connected to between airports is founded on a particular flight connection. Suppose that John is married to Mary; in this case, we can assume that there is a particular relator (relational moment) of type marriage that mediates John and Mary; the foundation of this relator can be, for instance, a wedding event or the signing of a social contract between the involved parties (Guizzardi and Wagner, 2010).

In other words, for instance, a certain event in which John and Mary participate can create an individual marriage which existentially depends on John and Mary, and which mediates them. The event in this case is the foundation of the relator (Guizzardi and Wagner, 2008).

Using this example, Guizzardi and Wagner elaborate on the nature of this relator in (Guizzardi and Wagner, 2010). There are many moments that John acquires by virtue of being married to Mary. For example, imagine all the legal responsibilities that John has in the context of this relation. These newly acquired properties are intrinsic moments of John which, therefore, inhere and are existentially dependent on him. However, these moments also depend on the existence of Mary. This type of moment is named externally dependent moment, i.e., externally dependent moments are intrinsic moments that inhere in a single particular but that are existentially dependent on (possibly a multitude of) other particulars.

In the same way, there are also a number of individual qualities (e.g., rights and responsibilities) that Mary acquires by virtue of being married to John (Guizzardi and Wagner, 2008).

Now, it is possible to define a particular that bears all externally dependent moments of John that share the same external dependencies and the same foundation. We term this particular a qua individual (Masolo et al., 2005). Qua individuals are, thus, treated as a special type of complex externally dependent modes. In this case, the complex mode inhering in John that bears all responsibilities that John acquires by virtue of a given wedding event can be named John-qua-husband (Guizzardi and Wagner, 2010).

Qua individuals (special types of externally dependent modes) are defined in (Guizzardi, 2005) as instances of a rigid classifier and as one-side existentially dependent of objects, which are related to their “players” via a contingent sort of existential dependence relation. Furthermore, a qua individual is a complex of externally dependent modes (e.g., in Figure 10, student id and average grade) exemplifying all the properties that an individual has in the scope of a certain material relation, which, by definition, depends also on the existence of another object extrinsic to its bearer. Qua individuals stand in parthood relationship with a unique relator in the scope of a material relation. Since relators consist of at least two distinct qua individuals, we conclude that the qua individuals composing a relator are existentially dependent on each other.

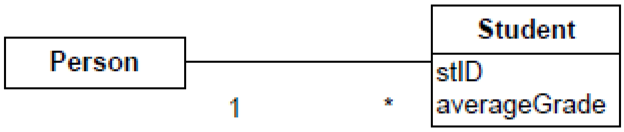


Figure 10 Example with Role and Role Player Universals (Guizzardi, 2005).

In order to continue with the same example, in (Guizzardi and Wagner, 2010) is presented another qua individual Mary-qua-wife, which is a complex mode bearing all the responsibilities that Mary acquires by virtue of the same foundation and that, although inhering in Mary, are also existentially dependent on John. The qua individuals John-qua-husband and Mary-qua-wife are existentially dependent on each other.

Now, it is possible to define an aggregate composed of these two qua individuals that share the same foundation, i.e., John-qua-husband and Mary-qua-wife. This is exactly the instance of the relational property marriage that mediates John and Mary and that makes true propositions such as “John is married to Mary”, “Mary is married to John”, “John is the husband of Mary”, and “Mary is the wife of John”. In this example, a particular instance of the relational property marriage (i.e., a particular marriage relator) is the sum of all instantiated responsibilities that the involved parties acquire by virtue of a common foundation. In general, a relator can be defined as the aggregation of a number of qua individuals that share the same foundation (Guizzardi and Wagner, 2010). The material relation entities interrelationship is exemplified in Figure 11.

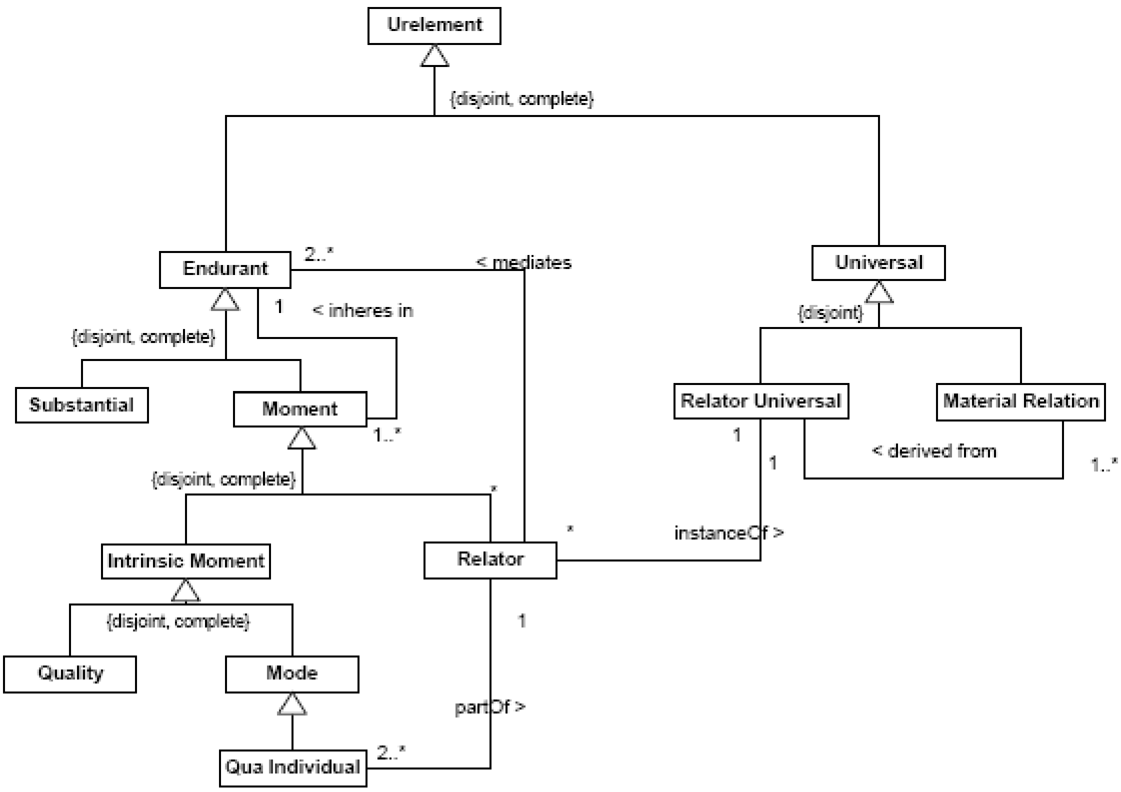


Figure 11 Material Relation entities interrelationship (Guizzardi, 2005).

Following our discussion about relations, the next section describes in which way the concepts presented in this chapter are being used in modeling ontologies, constructing a comparative analysis about the use of relations among the main foundational ontologies.

5 RELATIONS IN FOUNDATIONAL ONTOLOGIES

In the previous sections we have studied the principles found on ontologies, followed by the identification of the theoretical foundations of the relations. Now we analyze the application of the relations concepts to the main foundational ontologies in use nowadays.

Relations in UFO are defined within the same approach as described in Section 4 (Relations). In the next sections we analyze the application of relations to some other important foundational ontologies.

5.1 Relations in OntoClean/DOLCE

OntoClean is a methodology for ontology-driven conceptual analysis proposed by Nicola Guarino and Chris Welty, which has been described in (Guarino and Welty, 2002; Guarino and Welty, 2009).

OntoClean is a methodology for validating the ontological adequacy and logical consistency of taxonomic relationships. It is based on highly general ontological notions drawn from philosophy, like essence, identity, unity and dependence, which are used to elicit and characterize the intended meaning of properties, classes, and relations making up an ontology. These aspects are represented by formal meta-properties, which impose several constraints on the taxonomic relationships between concepts.

According to (Gangemi et al., 2002), the first version of OntoClean was based on an ontology of properties (unary universals), characterized by means of meta-properties. In the sequence, OntoClean was complemented with an ontology of particulars called DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering).

DOLCE has been constructed with a clear cognitive bias: the categories have been explicitly characterized as cognitive artifacts ultimately depending on human perception, cultural imprints and social conventions (Masolo et al., 2003).

DOLCE belongs to the WonderWeb library of foundational ontologies. It is intended to act as a starting point for comparing and elucidating the relationships with other ontologies of the library and also for clarifying the hidden assumptions underlying existing ontologies or linguistic resources such as WordNet. It has been successfully applied in different domains, such as law, biomedicine and agriculture (Oberle et al., 2007).

DOLCE is based on the fundamental distinction between enduring and perduring entities. The main relation between Endurants (objects or substances) and Perdurants (events or processes) is that of participation: an Endurant lives in time by participating in a Perdurant. For example, a natural person, which is an Endurant, participates in his or her life, which is a Perdurant. DOLCE introduces Qualities as another category that can be seen as the basic entities we can perceive or measure: shapes, colors, sizes, sounds, smells, weights, lengths, electrical charges. Spatial locations (a special kind of physical quality) and temporal qualities encode the spatio-temporal attributes of objects or events. Abstracts do not have spatial or temporal qualities and they are not qualities themselves. As example, Regions used to encode the measurement of qualities as conventionalized in some metric or conceptual space (Gangemi et al., 2002).

The main basic ontological relations in OntoClean/DOLCE between domain categories are described in (Masolo et al., 2003):

Is-A: This primitive describes a hierarchical relationship that occurs between a super-class (entity) and a sub-class (entity), usually occurring in taxonomies, where the sub-class inherits the properties of the super-class.

Inherent-in: A physical quality is inherent in a physical endurant.

Has-quality: A temporal quality is inherent in a perdurant.

Part-of: A parthood relation applies to a pair of endurants, or a pair of perdurants. For pairs of endurants the relation of parthood is temporalized, having a third argument for time objects since an endurant may lose and gain parts throughout its existence.

Temporary-part-of: Temporary parthood is a relation between two endurants where one is part of the other at a particular time.

Generic-constituent: Constitution depends on some layering of the world described by the ontology. A constituent is an entity belonging to a lower layer. Constituents are not properly classified as parts, although this affinity can be intuitive for common sense. Example of specific constant constituents are the entities constituting a setting (a situation), while the entities constituting a collection are examples of generic constant constituents.

Has-participant or participant-in: This relation holds between the endurants and the perdurants. Participation is time-indexed in order to account for varieties of participation in time. Participation can be constant or temporary. A functional participant is specialized for those forms of participation that depend on the nature of the participants, processes or intentionality of the agentive participants, constraining participation within the scope of a description, that is, a perdurant is participated by an object according to a description and its components.

Use-of or used-in: A functional participation between an action and an endurant that supports the goals of a performer. It catches the everyday language notion of being exploited during an action by something that initiates or leads it.

Product or product-of: A functional participation that assumes a meet relation between an activity and the life of an endurant. This relation is hard to be formalized, in general, because it is sensible to the particular project that drives the action.

Generically-dependent-on: A particular x is generically dependent on a particular y if whenever y is present x will also be present. In other words, the generation of x depends on the presence of y.

Specifically-constantly-dependent-on: This primitive relation is dependent on both modality and time, that is, a particular x is specifically constantly dependent on another particular y if, at any time, x cannot be present unless y also is present at the same time.

References or referenced-by: A relation holding between nonphysical objects and entities whatsoever, thus including nonphysical objects themselves. An intuition for the references relation could be that a nonphysical object adds information to an entity. In fact, nonphysical objects depend on a communication setting. In most cases, this is the characteristic relation that provides a unity criterion to objects, events, etc.

Classifies or classified-by: The referencing relation between concepts defined by descriptions, and constituents of situations. It can be understood as a reification of a relation holding between elements of theories and elements of models. It has a time index, but time only refers to a part of the classified particular life or extension.

Sequences or sequenced-by: This is the immediate relation between courses and perdurants. A course can be either atomic, being a simple perdurant role, or it can be complex, thus creating an abstract ordering over a temporal or causal sequence of processes or actions.

Plays or played-by: This is the immediate relation between roles and endurants. A role classifies the position of an endurant within a context. Roles can be ordered, interdependent at different layers.

Setting or setting-for: The relation between a situation and the entities that are referenced by it. At least some, or all, of such entities must be classified by concepts defined by the description that the situation is supposed to satisfy.

Causes or caused-by: A perdurant x causes another perdurant y to happen. This is usually related to a temporal precedence of x to y, and a common temporal border. A causal relationship is usually defined by experience, which gives evidence that y usually follows after x.

5.2 Relations in GOL/GFO

As described in (Heller and Herre, 2004), GOL (General Ontological Language) is a formal framework for representing and building ontologies. The purpose of GOL is to provide a system of formalized and axiomatized top-level ontologies which can be used as a framework for building more specific ontologies, such as domain ontologies. GOL is part of the work of the research group Ontologies in Medicine (Onto-Med) (Heinrich Herre, Barbara Heller and collaborators) at the University of Leipzig which is based on collaborative work of the Institute of Medical Informatics (IMISE) and the Institute for Computer Science. GOL consists of a syntax and an axiomatic core which captures the meaning of the introduced ontological categories. The system of top-level ontologies of GOL is called GFO (General Formal Ontology).

GFO has a three-layered meta-ontological architecture comprised of a basic level consisting of all relevant GFO categories, a meta-level, called abstract core level, containing meta-categories over the basic level, and an abstract top level including set and item (urelement) as the only meta-meta-categories (Herre et al., 2006).

Relations in GOL/GFO, in general, are defined within the same approach as described in Section 4 (Relations). These relations are summarized in (Guizzardi, Herre and Wagner, 2002) and (Herre et al., 2006).

There are relations between sets, between individuals, and between universals, but there are also cross-categorical relations, for example, between urelements and sets, or between sets and universals.

Relations are divided into two broad categories, called material and formal relations. The relata of a material relation are mediated by individuals, which are called relators.

Relators can be classified with respect to their order. A relator is said to be of first order if it connects substances exclusively. Examples of first-order relators are those relational moments, for example flight connections or purchases, whose arguments are substances. A relator universal is a universal whose instances are relators.

A formal relation is a relation which holds between two or more entities directly, without any further intervening individual. A formal relation may be either an extensional relation (i.e., a set) or it may be given by a relation universal (having an intension and an extension). Extensional relations are sets (or set-theoretical classes) of lists. Every extensional relation is formal.

There are many different part-whole relations between individuals, which can be classified by means of the axioms they satisfy. In addition to formal part-whole relations, there are also material part-whole relations.

We can distinguish a number of basic ontological relations which form an important part of the upper level ontology of GOL/GFO. The first and most familiar one is the set-theoretic membership. Further basic relations include the:

- proper part-of relations;
- contextual part-of relation, where a universal denotes the context;
- holding relation;
- inherence relation;
- instantiation relation;
- existential dependency;
- property relations;
- role-of relation.

With regard to the relationship between individuals and time and space, there is the well-known philosophical distinction between endurants and processes. An endurant is an individual that exists in time, but cannot be described as having temporal parts or phases; hence it is entirely present at every time-boundary of its existence and it persists through time. Processes, on the other hand, are extended in time; they unfold in time.

5.3 Relations in BWW

The development of the BWW (Bunge-Wand-Weber) ontology has its roots in fundamental problems of conceptual modeling. Wand and Weber recognized that the quality of conceptual models is always dependent on the correspondence between the model and what the model is about. They assumed that this correspondence is greatly supported by using a conceptual modeling language that provides the constructs that are nearly the same as the concepts people use to structure their conceptions of the world (Weber, 1997).

Wand and Weber in (Wand and Weber, 2002), by reasoning that ontology is a theory that articulates the constructs needed to describe the structure and behavior of the world in general, suggested that the ontological expressiveness of a conceptual modeling grammar could be evaluated by comparing its constructs against the constructs in an ontology. They chose the ontology posed by Mario Bunge as their basis. Bunge ontology is concerned with representing the material world: the world of material objects that possess physical properties existing independently from human perception (Allen and March, 2006).

Equipped with a comprehensive work on scientific ontology, Wand and Weber set out to develop a formal foundation for modeling information systems (Wand and Weber, 1990). In doing so, they adapted a number of notions conceived by Mario Bunge, developing a rather formal ontology. Wand and Weber also adopted the formalism used by Bunge for the formalization of ontological notions (Rosemann and Wyssusek, 2005).

Rosemann and Green describe the main BWW relations in (Rosemann and Green, 2002) according to their properties.

Things possess properties. A property is modeled via a function that maps the thing into some value. For example, the attribute weight represents a property that all humans possess. In this regard, weight is an attribute standing for a property in general. If we focus on the weight of a specific individual, however, we would be concerned with a property in particular. Other properties are properties of pairs, or many things. Such properties are called mutual. Nonbinding mutual properties are those properties shared by two or more things that do not “make a difference” to the things involved; for example, order relations or equivalence relations. By contrast, binding mutual properties are those properties shared by two or more things that “make a difference” to the things involved. A property of a composite thing that belongs to a component thing is called a hereditary property. Otherwise it is called an emergent property. Some properties are inherent properties of individual things. Such properties are called intrinsic.

Two things are said to be coupled (or to interact) if one thing acts on the other and vice versa. Furthermore, those two things are said to share a binding mutual property (or relation), that is, they participate in a relation that “makes a difference” to the things.

Things can have interrelationships in that one thing can influence another thing, and vice versa (i.e., they can act on each other). In the ontological BWW model, such a situation is called coupling and it can be modeled as a recursive relationship. A system must be defined by things and their couplings.

Figure 12 shows that properties can be properties in general if they belong to more than one thing. In contrast to this situation, properties in particular belong exactly to one thing. If a corresponding property in general exists, an is-instance-of relationship exists between these two subtypes. This fact causes a question with regard to the nature of the is-instance-of relationship in terms of whether the two involved elements are disjoint. At this time, this generalization/specialization structure is classified as disjoint. It is difficult to envisage a situation where a property in particular is also a property in general. In this way, any property that can be conceived must be either a property in particular or a property in general, i.e., a total specialization. Having determined whether a property is a property in particular or in general, Figure 12 indicates that it can then be classified as intrinsic, mutual, hereditary, and/or emergent. The categories of intrinsic, mutual, hereditary, and emergent are not mutually exclusive and so this specialization is characterized as nondisjoint.

As noted in (Guizzardi and Wagner, 2005), the BWW mutual property corresponds to the category of relational moments in UFO, and to the concept of relator in GOL/GFO.

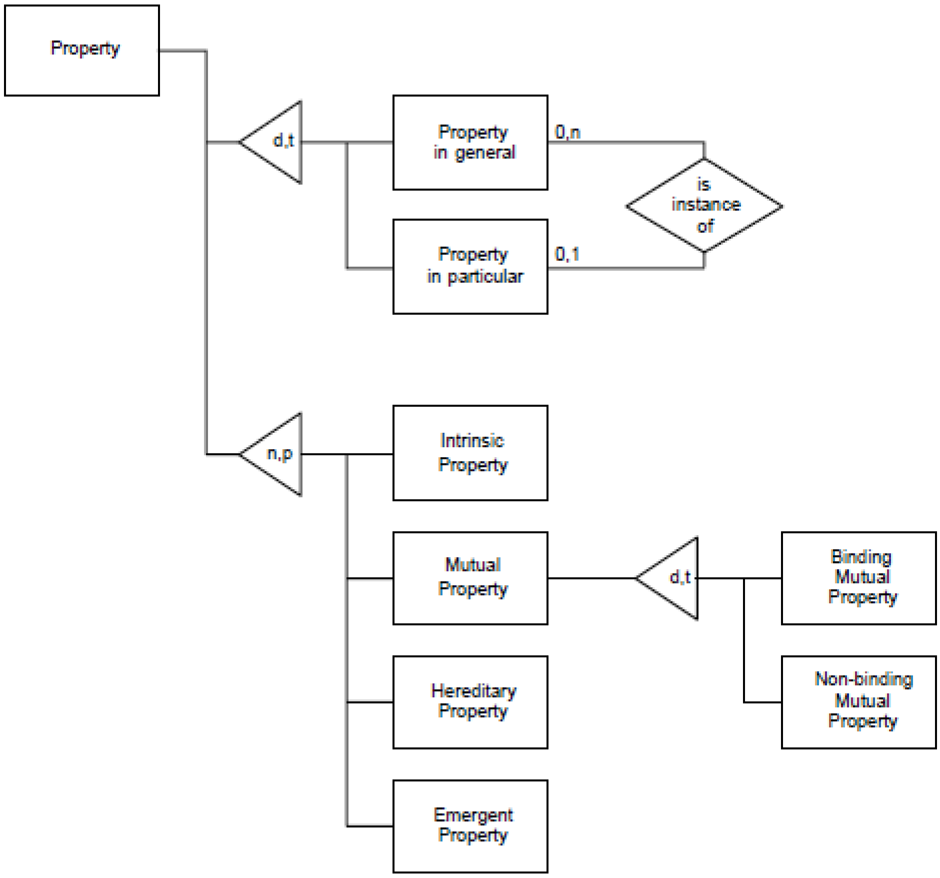


Figure 12 Subtypes of BWW property (Rosemann and Green, 2002).

5.4 Relations in SUMO

The Suggested Upper Merged Ontology (SUMO) is an upper level ontology that has been proposed as a starter document for The Standard Upper Ontology Working Group, an IEEE (Institute of Electrical and Electronics Engineers) sanctioned working group of collaborators from the fields of engineering, philosophy, and information science. SUMO provides definitions for general-purpose terms and acts as a foundation for more specific domain ontologies (Niles and Pease, 2001b).

SUMO is designed to be useful for a large variety of purposes, such as integrating domain ontologies, design of new knowledge bases or enhancing the applications interoperability. The standardization effort is sustained by specialists from various domains like information science, philosophy and engineering, both from academia and from industry. SUMO has not started from scratch, but by merging publicly available (fragments of) upper-level ontologies into a single comprehensive and cohesive structure (Niles and Pease, 2001a).

As stated in (Oberle et al., 2007), as a result of its characteristic of merging different ontology modules and theories, SUMO is actually not influenced by any specific theoretical approach. Rather, it tends to adopt the general categories from various ontology proposals. However, the axiomatization suffers from several shortcomings. A lot of information is represented as instances whereas other modules use concepts on the same level, concepts are instances at the same time, relations are instantiated between concepts, and some relations are even modeled as concepts (e.g., there is a concept Binary Relation).

As pointed out in (Ratiu, 2009), relations are used to represent tuples of elements. Relations are classified according to their arity (e.g., Binary Relation, Ternary Relation). Binary Relations are relations defined between pairs of Entities and are the most common relations encountered in the knowledge representation formalisms (e.g., binary relations are represented as slots in the frame-based knowledge representation paradigm). For temporal relations, the SUMO upper ontology incorporates Allen's influential axiomatization (Pease, Niles and Li, 2002).

SUMO contains a large number of instances of Binary Relations defined between its concepts. A subset of these relations is presented in Figure 13.

Relation	Source (S)	Target (T)	Description
PROPERTY	ENTITY	ATTRIBUTE	S has an attribute T
INSTANCE	ENTITY	SETORCLASS	S is included in T
PART	OBJECT	OBJECT	S is part of T
EXPLOITS	OBJECT	AGENT	S is used by T for performing a PROCESS
MEASURE	OBJECT	PHYS.QUANT.	S is measured by the constant quantity T
AGENT	PROCESS	AGENT	T determines S
MANNER	PROCESS	ATTRIBUTE	S is qualified by T
INSTRUMENT	PROCESS	OBJECT	T is an instrument in performing S
RESOURCE	PROCESS	OBJECT	T is used and changed by S
CAUSES	PROCESS	PROCESS	S causes T
RESULT	PROCESS	ENTITY	T is the output of S
SUBPROCESS	PROCESS	PROCESS	S implies the execution of T
PATIENT	PROCESS	ENTITY	T is a patient of S
SUBCLASS	CLASS	CLASS	S is a subordinate of T
LESSTHAN	QUANTITY	QUANTITY	S is less than T
GREATERTHAN	QUANTITY	QUANTITY	S is greater than T

Figure 13 SUMO relations between the top-level Concepts (Ratiu, 2009).

5.5 Relations in BFO

Basic Formal Ontology (BFO) was developed by Barry Smith and Pierre Grenon, which has been described in (Smith and Grenon, 2004; Grenon, 2003a; Grenon, 2003b).

BFO is a theory developed at the Institute for Formal Ontology and Medical Information Science (IFOMIS) at the University of Leipzig.

The complete framework rests on an ontology of spatio-temporal reality which recognizes both enduring entities, such as people, their smiles, tables and their colors or the regions of space they occupy, and perduring entities, processes and happenings, such as the smiling of a person, the tarnishing of a table or the “reaching the wall” of the table which has been moved from the center of the room next to the wall. Enduring entities are continuants in time, they persist by continuing to exist at different times or during periods of time. They preserve their identity through change. Perduring entities are bound in time, they occur or happen at a time or throughout a period of time. They persist in time by having successively existing (temporal) parts. Entities of each type have a specific relation to time. Endurants exist at a time while occurrents are located in time.

BFO distinguishes between universals and particulars, providing a hierarchy of upper-level abstract classes. It is intended as a complete ontological theory of reality and, therefore, it is divided into two components according to the distinctions between modes of existence of the entities in reality. SNAP is a specific type of ontology of enduring entities (continuants in time) and SPAN is a specific type of ontology of occurring and perduring entities (occurrents throughout time).

Mereology, the theory of the part-whole relationship (Simons, 1987b) is a basic tool in BFO. In most cases, BFO has an extensional mereology in each of its categories. The relation of (proper) part-to-whole is a primitive relation which is used in order to define more mereological terms: relations (e.g., improper parthood, partial overlap), operators (e.g., sum, difference), and kinds or pseudo-categories (e.g., whole, part, aggregate) on the one hand, and terms and relations which are composed of another primitive and a mereological primitive on the other hand.

There are a number of relations and types of relations in the framework that are being putting forward for BFO. In as much as this framework comports two ontology types, it recognizes two kinds of intra-ontological relations: those which obtain between SNAP entities which are constituents of the same SNAP ontology, and those which obtain between two SPAN entities which are constituents of the same SPAN ontology. Besides the intra-ontological relations, BFO also recognizes the trans-ontological relations: those which obtain between SNAP and SPAN entities.

5.5.1 SNAP Relations

Each SNAP ontology is an inventory of the continuants existing at some given time, and is accordingly indexed by the corresponding time instant. Note that to be a SNAP entity it is neither necessary nor sufficient that an entity be instantaneous. Most SNAP entities themselves endure for extended periods of time.

The SNAP portion of the BFO is used to categorize objects, their properties/attributes, the spaces which contain them, and numerous kinds of instantaneous (immediate) relations between the items. Items are spatial items only, thus they contain no temporal parts. Time is represented in SNAP only as instantaneous snapshots of reality taken at some infinitely thin time slice (Little and Rogova, 2005).

Spatial Locational Relations

Exact location in space: it is the primitive locational relation. It holds between an entity and the portion of space that it fully and only occupies, i.e., with which it is coincident, or co-extended in the case of extended regions. The location of an entity is thus a part of space at which any part of the entity is located (possibly an improper part). This is precisely the meaning of the boundedness in space of SNAP entities.

Partial location in space: it is the relation between an entity and a region of space at which a part of the entity is exactly located.

Whole location: it is the relation between an entity and a spatial region which has the entity exact location as a part.

Spatial Relations

Topological relations: relative connectedness.

Distance relations: the most primitive relations are qualitative (being far of, between two entities).

Orientation relations: above, left-of, south-of, and so on.

Spatial part: it is a more specific form of parthood. A spatial part of a SNAP entity is that part which fills a part of the location of the entity. Categories are dissective via the relation of spatial part (a spatial part of a substantial is a substantial, a spatial part of a trope is a trope, and so on).

Inherence

The most salient form of dependence in SNAP is the relation which holds between a trope (a dependent SNAP entity) and an independent entity (typically a substance) in which it inheres, for instance, the relation between the redness of the ball and the ball.

5.5.2 SPAN Relations

In SPAN time exists as part of the domain of the ontology. Instantaneous temporal boundaries of processes fall within the scope of SPAN ontologies.

The SPAN portion of the BFO is used to categorize purely temporal items, independent of their spatial properties. SPAN items amount to processes, events, functions, and the unfoldings of such items over time. In this sense, SPAN items are purely processual items, whose only parts and part-relations are temporal in nature.

While it is apparent that space and time do not exist separately, it is important that they be distinguished from one another within the ontology framework. The partitioning of spatial and temporal items within the ontology provides clear means for analyzing their distinct formal relations, since the item spatial properties do not necessarily stand to one another in the same way that their temporal properties do (Little and Rogova, 2005).

Temporal Relation

The basic primitive relations are between time instants (before, after) in order to account for the temporal order between moments of time.

Complex relations are based on mereological and locational relations: temporal overlap (sharing of a moment of occurrence), a partial version of this relation, temporal subsumption (an entity occurs during a part of the time of occurrence of another), and so on.

Spatio-Temporal Relations

It is possible to introduce a number of spatio-temporal relations holding between processuals in virtue of their respective relation to Spacetime and of its structure. It is also possible to introduce further mereological and mereotopological relations such as spatio-temporal co-location, parthood, overlap, and so on.

Mereology and Mereotopology

Spatio-temporal parthood:

A spatio-temporal part occupies a part of the spatio-temporal region occupied by the entity that it is a part of. In other words, spatio-temporal parthood implies subsumption of spatio-temporal extents.

Temporal Parts:

SPAN entities are bound in time. Those entities which persist through time do so by perduring (having successive temporal parts). Temporally extended SPAN entities are perdurants and have temporal parts. Temporal parthood also implies subsumption of temporal extents.

Temporal Slices:

Typically, if a perduring existent is extended in time, its temporal parts are extended. However, when this does not happen, then we have the instantaneous temporal parts (the temporal slices). This relation is a specific form of temporal part, inheriting most of its structural features. The difference here is that the time at which the slice exists is a moment of time.

Boundaries:

In the case of connected spatio-temporal wholes, there are two temporal boundaries: a beginning and an ending. When the SPAN entity is scattered in spacetime, it has twice as many temporal boundaries as it has maximally connected parts (components). The beginning is its earliest temporal boundary (the beginning of its earliest component) and the ending is its latest temporal boundary (the ending of its latest component).

5.5.3 Trans-Ontological Relations

One way of representing SNAP and SPAN trans-ontological relations in BFO is through spatio-temporal projection. When we talk about John having lived from 1908 to 1988, then we are projecting John onto a certain temporal interval. There is a range of such relations of projecting, including the relations involving regions in space and time, such as temporal projection and spatial projection.

For temporal projection, processes are clearly projectible onto the axis of time, while substances are projectible onto a period of time through the mediation of the processes in which they are involved.

For spatial projection, processes are also projectible onto the (SPAN) spatio-temporal regions in which they occur, as also onto the (SNAP) spatial regions where they start and end. Some processes occur in a given place or area, such as the Revolution took place in Paris; the wind blows across the desert.

The different varieties of projection yield criteria for characterizing processes. Thus a process projects onto:

- its temporal duration;

- the spatio-temporal region it occupies;

- the spatial region it occupies at a given time;

- the sum of its participants at a time;

- the sum of the dependent entities realized through it at a time.

Temporal projection provides the fundamental means for interrelating SNAP and SPAN entities. Each has its own variety of temporal projection: SPAN entities project directly, while SNAP entities project indirectly, via their lives, onto temporal intervals. Although co-temporality (the relation which holds between entities with identical temporal projections) is a prerequisite for obtaining the most of the SNAP-SPAN relations (participation, realization, etc.), there are some exceptions, such as memory and, more generally, all trans-temporal relations between one existing entity and another entity which is either no longer existing or not yet existing.

5.6 Relations in Cyc

Cyc ontology was developed by Cycorp, a private U.S. software company. Lenat and Guha describe the Cyc ontology in (Lenat and Guha, 1990; Lenat et al., 1990).

The Cyc ontology is a high level ontology composed by a representation language (CycL), an inference engine and an ontology of the knowledge base.

CycL is a frame-based language embedded in an expressive predicate calculus framework along with features for representing defaults for reification and for reflection. The inference engine is an optimized reasoning engine about actions, events, and other activities in a dynamic world. The knowledge base has more than one million assertions, many of which are general rules, classifications, constraints, and so on; some of them are specific facts dealing with particular objects and events.

The Cyc ontology is organized around the concept of categories, also referred as classes or collections. The categories are organized in a generalization-specialization hierarchy. The Cyc predicates relating a category to its immediate supersets and subsets are, respectively, “genls” and “specs”. The instances of a category are its elements or members; the inverse of this relation is instanceOf.

The universal set is called Thing. Some of its partitionings are into the sets RepresentedThing, IndividualObject and Collection. In addition to collections of individuals, also there are collections of collections. The hierarchy folds into itself at this level; that is, it does not have collections of collections of collections, and Collection is an instanceOf itself.

Larry Stephens and Yufeng Chen discuss the Cyc relations in (Stephens and Chen, 1994).

The Cyc knowledge base has two fundamental perspectives: the knowledge level and the symbol level. At the knowledge level, knowledge is characterized functionally in terms of how it is used for reasoning. At the symbol level, the organization of a knowledge base focuses on how a user expresses information in a representation language. A knowledge-based system should do, at the symbol level, the same inferences that humans do at the knowledge level.

The knowledge-level view has two separate views: the argument-type and the association-type views. The argument-type view is based on the types of concepts being related, while the association-type view is based on linguistic studies and emphasizes the nature of the semantic relations themselves.

The association-type view can be understood and organized by the nature of their associations, and the specialization of classes can be based on the properties of the associations. The association-type view uses natural groupings, such as classes for temporal, spatial, and part-whole relations. The semantic-relation classes that fall into two higher-order classifications, intensional and pragmatic, were identified in (Bejar, Chaffin and Embretson, 1991). Intensional relations can be understood on the basis of the meaning of the words being related without reference to other concepts. Pragmatic relations require knowledge that goes beyond the meaning of the words being related.

Intensional Relations:

- Class Inclusion (animal : horse, country : Russia);

- Similarity (car : auto);

- Attribute (glass : fragile);

- Contrasts (old : young, alive : dead);

- Nonattribute (reticent : talk, immortal : death).

Pragmatic Relations:

- Case Relations (artist : paint);

- Cause-Purpose (joke : laughter);

- Space-Time (school : learning, summer : harvest);

- Part-Whole (engine : car);

- Reference (red-light : stop).

Relation elements and the categories of reference are the basis for the knowledge level in which the Cyc class structure is reorganized so that the classes are consistently specialized on the basis of the types of underlying semantic relations and their properties.

The argument-type view, at the knowledge level, performs the classifications based on the types of the concepts being related. The argument-type view does not, however, organize classes into a class hierarchy.

Cyc has also a language-feature view at the symbol level. While the knowledge-level classes are based on real-world interpretations for relational concepts, the symbol-level classes are based on the representation-language features implemented within the knowledge-representation system. Thus, the specialization relationship between classes represents a specialization in the inferencing function.

5.7 Relations in Sowa

Sowa ontology is a knowledge representation ontology defined by John F. Sowa, which has been described in (Sowa, 2000).

Summarizing the top levels of the Sowa Knowledge Representation Ontology, Figure 14 shows a lattice of the top-level categories.

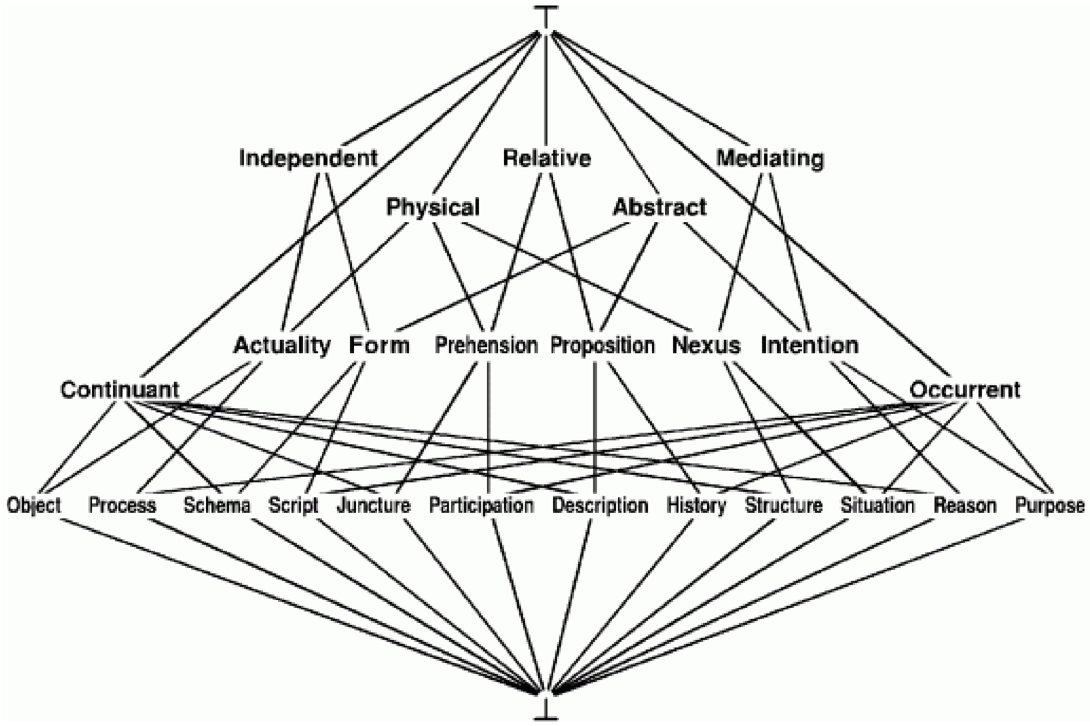


Figure 14 Hierarchy of top-level Categories (Sowa, 2000).

A continuant has stable attributes or characteristics that enable its various appearances at different times to be recognized as the same individual. An occurrent is in a state of flux that prevents it from being recognized by a stable set of attributes. Instead, it can only be identified by its location in some region of space-time. The continuant categories are characterized by a predicate that does not involve time or a time like succession, while occurrents are characterized by a predicate that depends on time or a time like succession.

From the categories in Figure 14, nine primitive categories have associated axioms: T (universal type), ⊥ (absurd type), Independent, Relative, Mediating, Physical, Abstract, Continuant, and Occurrent. Each subtype is defined as the infimum (greatest common subtype) of two supertypes, whose axioms it inherits. For example, the type Form inherits the axioms of Independent and Abstract.

The primitive categories of any theory are indefinable in terms of anything more primitive. The axioms associated with the categories are not closed-form definitions, but constraints on how instances of those categories are related to instances of other categories, many of which are not primitives. The only two categories whose axioms are completely formalized are T and ⊥.

The main basic ontological relations in Sowa ontology are defined according to their categories. Sowa distinguishes between physical and abstract entities. Abstract entities do not have a location in space or in time. In contrast, physical entities are located in space and time. The relation that holds between physical and abstract entities is characterization and representation (instantiation). An abstract entity characterizes, and is represented, in zero or more physical entities. The same physical object may be characterized by more than one abstract entity; thus, the relation of characterization and representation is a many-to-many relation.

In natural languages, roles are usually represented by nouns, such as mother, but in predicate calculus they are often represented by dyadic relations, such as motherOf. This representation makes the mapping from language to logic unsystematic, since the noun woman is mapped to a type or a monadic predicate woman, but the noun mother is mapped to a dyadic predicate motherOf.

In order to make the mapping more systematic, the Sowa Knowledge Representation Ontology uses a primitive dyadic relation Has, which converts roles into relations. The noun mother is represented by the role type Mother. Those types can be used as type labels in a typed logic, such as conceptual graphs or typed predicate calculus, and they can be used as monadic predicates in untyped predicate calculus. The corresponding dyadic relations, in any typed or untyped version of logic, can be defined in terms of the role and the relation Has.

Figure 15 divides the type Actuality into three subtypes: Phenomenon, Role and Sign. A phenomenal entity is an actual entity considered by itself, a role is considered in relation to something else, and a sign is considered as representing something to some agent. The trichotomy in Figure 15 is applied to the way entities are viewed by some observer. The same person, for example, might be classified as a woman by appearance (phenomenon) or as a mother by role.

An intrinsic prehending entity, called Composite, bears a relationship to each component within itself. Its subtypes are distinguished by the kind of prehension: a whole is made up of its parts, and a substrate is the underlying material that supports dependent properties, such as size, weight, shape, color.

An extrinsic prehending or prehended entity, called Correlative, bears a relationship to something outside itself. Examples include mother and child, lawyer and client, employer and employee.

An intrinsic prehended entity, called Component, bears a relationship to the composite in which it inheres. Its subtypes include parts (piece, participant, stage), whose existence is independent of the whole, and properties (attribute, manner), which cannot exist without some substrate.

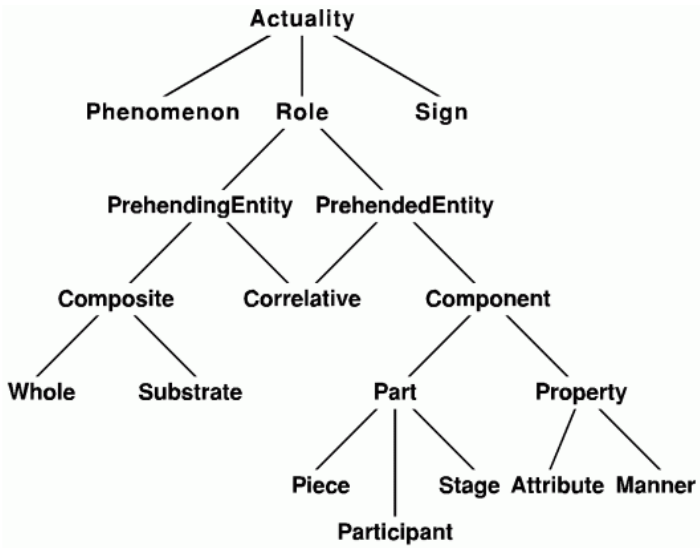


Figure 15 Classification of Roles (Sowa, 2000).

These categories, which are defined by purely semantic distinctions, have a strong correlation with the syntactic categories of natural languages. Continuants are commonly expressed by nouns, and occurrents by verbs. Attributes are expressed by adjectives, and manners by adverbs. Participants are expressed by the case relations or thematic roles associated with verbs. Stages are often expressed by nouns derived from verbs, such as retirement, or by suffixes on role words, such as infancy and motherhood. The roles derived from the participants associated with verbs form a linguistically class that is described as thematic roles.

5.8 A Comparison about the Use of Relations on Ontologies

In order to construct a comparative analysis about the use of relations among the main foundational ontologies, here we define some criteria that we have selected as the most relevant. For this, we take some relation orthogonal classification such as: formal, material, spatial and temporal relations, which may consider continuants and occurrents, and individuals and universals.

As summarized in Table 1, ontologies that meet each specific criterion were classified as "yes", while ontologies that do not suitably meet these specific criteria were classified as "no".

Table 1 Comparison about the use of relations among ontologies.

Ontology/ Criterion	**UFO A**	**UFO B/C**	**OntoClean DOLCE**	**GOL GFO**	**BWW**	**SUMO**	**BFO**	**Cyc**	**Sowa**
Formal	YES	YES	YES	YES	YES	YES	YES	YES	YES
Material	YES	YES	NO	YES	YES	NO	NO	NO	NO
Spatial	YES	YES	YES	YES	YES	YES	YES	YES	YES
Temporal	NO	YES	YES	YES	YES	YES	YES	YES	YES
Continuants	YES	YES	YES	YES	YES	YES	YES	YES	YES
Occurrents	NO	YES	YES	YES	YES	YES	YES	YES	YES
Individuals	YES	YES	YES	YES	YES	YES	YES	YES	YES
Universals	YES	YES	NO	YES	YES	YES	YES	YES	YES

Through this comparison, we note that all the main foundational ontologies meet most, or all, of the selected relevant criteria.

Formal relations, the ones that hold between two or more entities directly without any further intervening individual, are met by all the studied ontologies. Material relations, conversely, have material structure on their own. The relata of a material relation are mediated by relators. The BWW mutual property corresponds to the category of relational moments in UFO, and to the concept of relator in GOL/GFO, therefore, characterizing the material relations for these ontologies.

Spatial relations are met by all these foundational ontologies, while temporal relations are not met by UFO-A. They are both considered to be very relevant because every coherent part of the world has a location in space and in time, and thus they capture a certain spatial region and a certain temporal interval.

While UFO-A defines the core of UFO, as an ontology of endurants (continuants), UFO-B and UFO-C define, as an increment to UFO-A, terms also related to perdurants (occurrents). DOLCE is based on the fundamental distinction between enduring and perduring entities; the main relation between Endurants (objects or substances) and Perdurants (events or processes) is the participation. GOL/GFO distinguishes endurants and processes: an endurant is an individual that exists in time but cannot be described as having temporal parts or phases, and processes, on the other hand, are extended in time. The BWW history of a thing captures the relationship between endurants and perdurants; endurants participate in perdurants, and endurants have histories which consist of perdurants. In SUMO, objects are physicals that exist in full at any instant at which they exist at all and, on the other hand, processes are the complement of physical objects, subsuming all entities that happen in time; processes are only partially present at any time at which they are present. BFO is divided into two components according to the distinctions between modes of existence of the entities in reality: SNAP is a specific type of ontology of enduring entities (continuants in time) and SPAN is a specific type of ontology of occurring and perduring entities (occurrents throughout time). In Cyc there are two types of intrinsicness: a property can be spatially intrinsic or temporally intrinsic; anything that is spatially substance-like is also temporally substance-like, but the converse is not true; the parts of an instance of “something occurring” include all the instances of the involved “something existing”. In Sowa, a continuant has stable attributes or characteristics that enable its various appearances at different times to be recognized as the same individual, while an occurrent is in a state of flux that can only be identified by its location in some region of space-time; the continuant categories are characterized by a predicate that does not involve time, while occurrents are characterized by a predicate that depends on time.

Most of the above foundational ontologies consider individuals and universals. DOLCE is the only of the studied ontologies that does not consider universals. DOLCE is an ontology of particulars (individuals) constructed with a clear cognitive bias.

After researching on ontologies, parts, wholes and relations in the previous sections, here, in this section, we have performed an analysis on the application of relations on the foundational ontologies. Following, we present an analysis about the application of relations considering the perspective of the ontology building tools.

6 RELATIONS IN ONTOLOGY BUILDING TOOLS

Here, in this section, we present an analysis on the application of relations on some of the main ontology building tools, such as Protégé, NeOn Toolkit, WebOnto, WebODE and OntoEdit.

6.1 Protégé

Protégé (Horridge et al., 2007) is one of the main ontology editors, consisting of an open source project. Its knowledge base framework was developed by Stanford Medical Informatics. This framework allows the knowledge representation in several formalisms like the traditional frames and languages like RDF (Resource Description Framework) and OWL (Web Ontology Language), offering a collaborative environment.

Protégé can compute subsumption relationships between classes, and detect inconsistent classes. It can be computed automatically by a reasoner. Binary relations, linking two individuals together, are represented by slots. There are three slot widgets for loading and displaying images, which work both with Protégé-OWL and Protégé frames.

Properties describe binary relationships. There are two main types of properties: datatype properties and object properties. Datatype properties describe relationships between individuals and data values, and object properties describe relationships between individuals.

Object properties can be described according to some characteristics, such as functional, inverse functional, transitive, symmetric, asymmetric, reflexive, irreflexive.

If a property is functional, for a given individual, there can be at most one individual that is related to the individual via the property. If a property is inverse functional, then it means that the inverse property is functional. For a given individual, there can be at most one individual related to that individual via the property.

If a property *P* is transitive, and the property relates individual *a* to individual *b*, and also individual *b* to individual *c*, then we can infer that individual *a* is related to individual *c* via property *P*.

If a property *P* is symmetric, and the property relates individual *a* to individual *b* then individual *b* is also related to individual *a* via property *P*. If a property *P* is asymmetric, and the property relates individual *a* to individual *b* then individual *b* cannot be related to individual *a* via property *P*.

A property *P* is said to be reflexive when the property must relate individual *a* to itself. A property *P* is said to be irreflexive when the property must not relate individual *a* to itself.

Properties may present some restrictions, which describe the constraints on relationships that the individuals participate in for a given property. Restrictions fall into three main categories: quantifier, cardinality and hasValue restrictions.

The quantifier restrictions effectively put constraints on the relationships that the individual participates in. It does this by either specifying that at least one kind of relationship must exist (existential restrictions), or by specifying the only kinds of relationships that can exist (universal restrictions).

Existential restrictions describe classes of individuals that participate in at least one relationship along a specified property to individuals that are members of a specified class.

Universal restrictions describe classes of individuals that for a given property only have relationships along this property to individuals that are members of a specified class.

The cardinality restrictions are used to talk about the number of relationships that an individual may participate in for a given property. Cardinality restrictions may specify the minimum and the maximum cardinality restrictions.

The hasValue restrictions describe the class of individuals that have at least one relationship to another specific individual.

6.2 NeOn Toolkit

The NeOn Toolkit (NTF, 2007) is a multi-platform environment for ontology engineering. Based on methodology for ontology building, the environment intends to provide understanding and support for the whole development cycle of an ontology. The tool is built on the Eclipse platform (Java development platform) and has a modular architecture, providing features such as ontology repository, distributed components, inference and collaboration. The focus of the tool is the lifecycle of the ontology.

The concept graph displays the taxonomic relationship between concepts of the ontology. When selecting a concept, its attributes and relations are shown within the concept detail tree. Relations describe the dependencies between concepts, being inherited to sub-concepts.

There are two main types of properties: datatype properties and object properties. Datatype properties relate individuals to data values. Object property is a binary relation between two individuals that lets you assert general facts about the members of classes and specific facts about individuals. Object properties can be organized into a superproperty-subproperty hierarchy, also known as taxonomy.

A property axiom, besides defining the existence of a property, may define the property characteristics, such as domain, range, cardinality, inverse of, functional, inverse functional, transitive, symmetric.

Properties may have a domain and a range specified, that is, they link individuals from the domain to individuals from the range. It is possible to map an attribute value to a relation by creating an instance of the target relation range with a corresponding attribute value.

Cardinalities are used to define how many values a property can have at least (minimal cardinality) and in maximum (maximum cardinality).

The "Inverse" relations are inverse to the active relation.

If a property is functional, for a given individual, there can be at most one individual that is related to the individual via the property. If a property is inverse functional, then it means that the inverse property is functional. For a given individual, there can be at most one individual related to that individual via the property.

If a property *P* is transitive, and the property relates individual *a* to individual *b*, and also individual *b* to individual *c*, then we can infer that individual *a* is related to individual *c* via property *P*.

If a property *P* is symmetric, and the property relates individual *a* to individual *b*, then individual *b* is also related to individual *a* via property *P*.

6.3 WebOnto

WebOnto (Domingue, Motta and Garcia, 1999) was designed to support the collaborative browsing, creation and editing of ontologies. It is implemented as a Java Applet, and includes both a graphical user interface, for coarse-grained browsing, and fine grained inspector windows. WebOnto also provides a set of options to customize the presentation of information to navigate large ontologies. OCML (Operational Conceptual Modelling Language) provides the underlining representation for WebOnto models.

OCML defines the various notions associated with relations. These include the universe and the extension of a relation, the definition of reflexive and transitive relations, partial and total orders, etc. Relations allow users to define labeled n-ary relationships between entities. The relation options play both a specification and an operational role.

The relation specification options have the purpose of helping to characterize the extension of a relation, specifying:

- both “sufficient” and “necessary” conditions for the relation to hold for a given set of arguments;

- a “sufficient” condition for the relation to hold for a given set of arguments;

- an expression which follows from the definition of the relation and must be true for each instance of the relation;

- a constraint which is also meant to provide a partial definition of a relation;

- a statement which mentions the relation to which it is associated, providing a mechanism to associate theory axioms with specific relations.

Relation options also play an operational role. Specifically, some relation options support constraint checking over relation instances while others provide proof mechanisms which can be used to find out whether or not a relation holds for some arguments. The various types of relation options can be used concurrently to specify a relation and to support constraint checking and efficient proofs.

The set of relation options aims to provide a flexible and versatile range of modeling constructs supporting various styles of modeling. While the emphasis is on operational modeling, WebOnto OCML also supports formal specification. Moreover, it provides facilities for integrating a specification with efficient proof mechanisms.

A relation mapping provides a mechanism to associate rules and procedures to a relation. Its main purpose is to ensure that the consistency between domain and task/method levels is maintained.

6.4 WebODE

The WebODE environment (Arpírez et al., 2001) focuses on the whole ontology life cycle, providing a scalable infrastructure for the development of other ontology development tools, or applications based on ontologies.

WebODE is not just a development environment, but a complete structure with various services related to ontology. It allows the post-processing of the ontology, using the OntoClean methodology for identifying incorrect taxonomic (is-a) relations.

WebODE works with both built-in relations and ad-hoc relations.

Built-in relations are predefined relations in the WebODE knowledge model, related to the representation of taxonomies of concepts and mereology relationships between concepts. They are divided into three groups: taxonomical relations between concepts, taxonomical relations between groups and concepts, and mereological relations between concepts.

The taxonomical relations between concepts have two predefined relations: subclass-of and not-subclass-of. Single and multiple inheritance are allowed.

The taxonomical relations between groups (a group is a set of disjoint concepts) and concepts have two predefined relations: disjoint-subclass-partition and exhaustive-subclass-partition.

A disjoint subclass partition *Y* of class *X* defines the set *Y* of disjoint classes as subclasses of class *X*. This classification is not necessarily complete; there may be instances of *X* that are not included in any subclass of the partition.

An exhaustive subclass partition *Y* of class *X* defines the set *Y* of disjoint subclasses as subclasses of the class *X*, where *X* can be defined as the union of all the classes of the partition.

The mereological relations between concepts have two predefined relations: transitive-part-of and intransitive-part-of.

Ad-hoc relations are characterized by their name, the name of the origin (source) and destination (target) concepts, and its cardinality, which establishes the number of facts (instances of the relation) that can hold between the origin and the destination term. Their cardinality can be restricted to one (only one fact) or N (any number of facts).

WebODE allows just binary ad-hoc relations to be created between concepts. The creation of relations of higher arity must be made by reification (creating a concept for the relation itself and n binary relations between the concepts that appear in the relation and the concept that is used for representing the relation).

Additionally, there is some optional information that can be provided for an ad-hoc relation, such as its NL (natural language) description and its properties (they are used to describe algebraic properties of the relation). References and formulae can be also attached to the ad-hoc relations.

6.5 OntoEdit

OntoEdit (Ontoprise, 2003) is an ontology engineering environment supporting the development and maintenance of ontologies by using graphical means. OntoEdit is built on top of a powerful internal ontology model. This paradigm supports representation-language neutral modeling as much as possible for concepts, relations and axioms.

Several graphical views onto the structures contained in the ontology support modeling the different phases of the ontology engineering cycle. OntoEdit focuses on combining the ontology development based on methodologies in three main steps: requirement specification, refinement and evaluation. OntoEdit provides the ontology post-processing functionality, using the OntoClean methodology for identifying incorrect taxonomic (is-a) relations.

Concepts are abstract terms that are organized in taxonomies (hierarchical concepts are linked with an “is-a” relation), relations link nonhierarchical concepts to each other, and attributes are relations of predefined data types.

In order to define a relation of a concept, first we have to select the desired concept and then insert the new relation for the selected concept.

When inserting a relation, the relation identification can be given, the relation range can be specified and the relation cardinalities can be informed. The range of a relation can be either a built-in concept (string, boolean or integer) or a set of new datatypes (concepts, relations or file) or another concept of the ontology. The cardinalities of a relation specify the minimum and the maximum number of individuals that may participate in.

The relation axioms have some predefined axioms, such as inverse, symmetric and transitive axioms. A new relation axiom may also be added.

An inverse relation is a relation inverse to the active relation.

If a property *P* is symmetric, and the property relates individual *a* to individual *b*, then individual *b* is also related to individual *a* via property *P*.

If a property *P* is transitive, and the property relates individual *a* to individual *b*, and also individual *b* to individual *c*, then we can infer that individual *a* is related to individual *c* via property *P*.

6.6 Remarks about the tools

Analyzing the application of relations on some of the main available ontology building tools, we noticed that most of them have both implementation and user interface oriented to formal languages of representation, such as OWL, making it harder for users who do not have this expertise to use them properly, besides being against the principle of the minimal encoding bias proposed by Gruber in (Gruber, 1993b). We also noticed that most of these tools do not include ontological foundations, and just Protégé supports visual knowledge domains.

Most of the analyzed tools do not provide adequate support to the ontological choice problem, that is, how to choose the best primitives to represent the needed relations in order to create models better anchored in reality. These issues may produce many different specifications for the same conceptual model, or result in many different interpretations of the same model by different users.

The use of metadata based on foundational ontologies guides the choice of the representations, consequently reducing the number of open possibilities in the model specification. More uniform models result in more uniform interpretations.

Furthermore, the lack of system assistance may cause misunderstanding about the meaning of the concepts and their relationships, resulting in ambiguous and redundant modeling.

Likewise, the vocabulary sharing is presently associated with the use of images and visual constructs as a result of the increasing need of visual support by the visual domains. The construction of the spatial relations in the user mind is strongly based on visual knowledge, but this topic is still incipient for most of the main ontology building tools.

In this work, besides the interest in the ontological foundation of relations, there is also a strong interest in supporting visual domains. In the next section we present a review on visual knowledge.

7 VISUAL KNOWLEDGE

The formally defined and partially implemented set of primitives of representation in ontological languages has proved to be insufficient for representing many of the concepts and relationships necessary for expressing knowledge in natural domains. Spatial relationships and visual objects are essential components for geological knowledge. Parthood relationships are especially important for modeling visual knowledge, since the object recognition by cognitive systems that support vision is strongly based on composition and decomposition operations.

Lorenzatti describes visual knowledge in (Lorenzatti, 2010; Lorenzatti et al., 2010) as the set of mental models of real or imaginary scenes manipulated by the brain in order to deal with image-based tasks, such as image interpretation or recognition of patterns or shapes in the reality.

There are domains in which visual knowledge plays a crucial role in the process of problem solving. These visual domains, such as Geology, make constant use of visual representation to facilitate the acquisition and dissemination of knowledge. In the case of Geology, for example, visual representation captures knowledge and information that geologists could not express explicitly through words. Without the proper visual support, it would be difficult for geologists to represent the necessary information and to communicate this information to each other. Thus, considering only textual representation in these domains can cause loss of crucial information for the problem-solving process.

Through the construction of alternative ontological models, it is possible to represent visual knowledge in imagistic domains. Several previous approaches seek to capture the visual knowledge like neural networks, case-based reasoning and image processing. It is important to underline that the focus of the visual knowledge acquisition and dissemination is not in the images themselves, but in the mental model created by the expert to express his/her theoretical and practical experience.

In order to understand these distinctions, Stephen Ullmann presents the Ullmann's triangle in (Ullmann, 1972), as seen in Figure 16, describing the relation among an Object in the reality, a Concept in some conceptualization and a Symbol in some language. An Object is supposed to be a real object in the world, although its existence only can be referred through the process of perception and abstraction by someone. Concepts, by their side, are abstract mental (internal) representation of portions of the external world, which are created in order to reason about and to act upon the environment. Symbols are one of the many possibilities in which concepts can be externalized in a process of communication in order to share the conceptualization among the community.

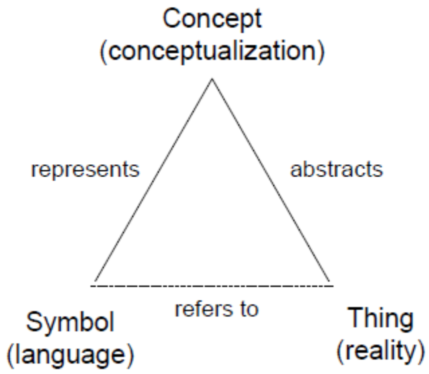


Figure 16 The Ullmann's triangle (Ullmann, 1972).

Consequently, when we mention visual knowledge, we are referring to the conceptualization vertex of the Ullmann's triangle in the human mind scope. A pictorial representation of a scene, like a picture, a map or a draw, is related to the language vertex, i.e., it refers to some external representation of the internal conceptualization. Propositional and visual concepts are both part of the conceptualization and appear to be manipulated in mind in some indistinct way. The choice of one instead of the other is defined by their use, for example, spatial problems that demand visual representation or communication problems that require shared concepts. Pictorial representations of visual knowledge are, then, produced by people in order to express the visual knowledge. They are symbols that cannot be translated to propositional representations. Thus, Lorenzatti has added a new dimension into the Ullmann's triangle (the new vertex: "Pictorial representation in a Visualization", in the base of the triangle in Figure 17) in order to separate the symbolic representations of propositional and visual concepts and their visualizations. Therefore, the representation of a concept is its label in some language, while the same concept can be depicted as an image, a draw, a graphic or an icon. The correspondence between the pictorial representation and the symbol in a language, when both refer to the same concept is called anchoring.

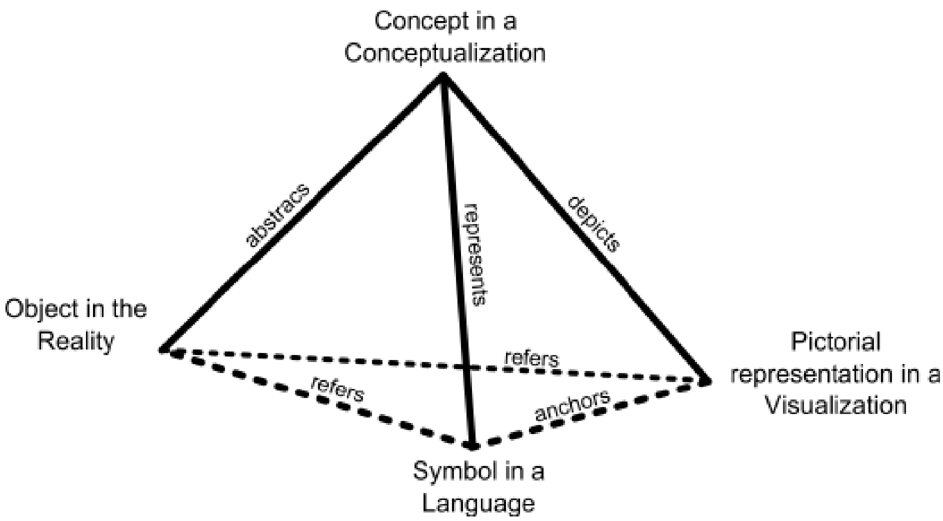


Figure 17 The extended Ullmann's triangle (Lorenzatti et al., 2010).

A representation of an idea is a sign that connects another idea. When someone intends to communicate an idea to another person, the idea is embodied through an image which directly connects the idea; then the other person, perceiving that image, gets the idea. Two persons may agree upon a conventional sign which results to them an idea that would not result to anybody else. But in framing the convention they must have resorted to the primitive diagrammatic method of embodying the idea in an outward form, a picture (Peirce, 1967).

In order to embody a visual representation, a symbolic and graphical language was created by Charles K. Bliss in 1949. As illustrated in (O'Donnell et al., 2010), like words and unlike ordinary pictures, the Bliss symbols are abstract and schematic, depicting only some characteristics of the concepts they represent. In particular, it has a vocabulary for abstract concepts and the potential to combine symbols to express new and complex meanings. There are also symbols for relations between individuals or things, that is, symbols for events of different types and static relationships; for example, a symbol for an individual may be combined with a symbol for an action. Thus, events involving the same individuals in different thematic roles can be distinguished explicitly by using symbols and visual properties. Locative relations, as exemplified in Figure 18, are expressed by combining the symbol for what is located (e.g., box) with a symbol combination expressing a specific spatial relation (e.g., on) and the reference object for that relation (e.g., chair).

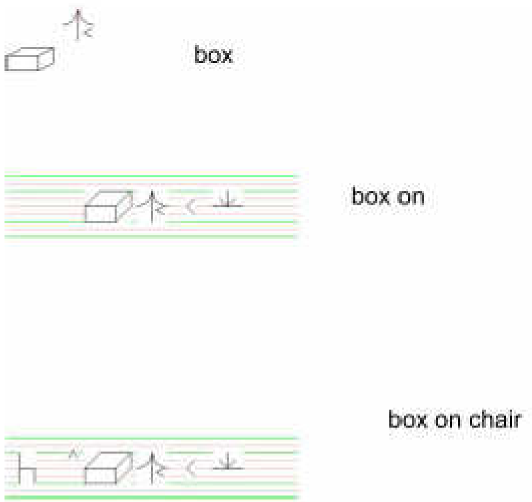


Figure 18 Example of symbol combinations expressing locative relations (O'Donnell et al., 2010).

A core vocabulary of spatial relations also is presented visually in (Bennett, Chaudhri and Dinesh, 2013) as a set of topological relations. The significance of holes and cavities in spatial information is widely recognized and has received considerable attention from the ontological point of view. They also consider a number of formal definitions of precise spatial relationships that capture spatial conditions relevant to notions of surrounding, enclosure and containment. In Figure 19 are represented some examples of images involving open and closed cavity relations; the images (a) thru (e) are all special cases of the relation is-in-closed-cavity-of, whereas the image (f) is a case of is-in-open-cavity-of. Each of these relations, and many others, can easily be distinguished simply by looking at the images.

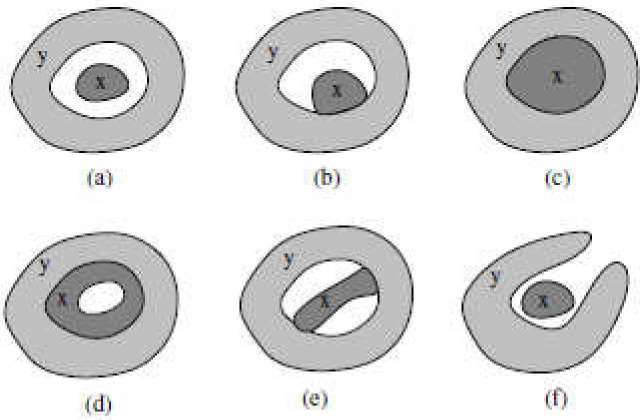


Figure 19 Some images of relations (Bennett, Chaudhri and Dinesh, 2013).

As presented by Shimon Ullman in (Ullman, 1984), for the human visual system, the perception of spatial properties and relations that are complex from a computational standpoint, nevertheless often appears immediate and effortless as, for example, the ones seen in Figure 20. The proficiency of the human system in analyzing spatial information far surpasses the capacities of current artificial systems.

Visual perception requires the capacity to extract shape properties and spatial relations among objects and their parts. This capacity is fundamental to visual recognition, since objects are often defined visually by abstract shape properties and spatial relations among their components.

The role of establishing properties and relations visually is not confined to the task of visual recognition; they require the visual analysis of shape and spatial relations among parts. Spatial relations in three-dimensional space play an important role in visual perception. The perception of inside and outside relationships, as shown in Figure 20, is performed by the human perceptual system with efficiency. In (a) and (b) the perception is immediate and effortless, but in (c) it demands some effort.

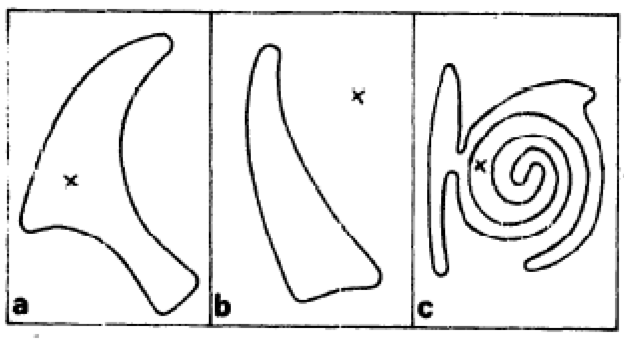


Figure 20 Perceiving inside and outside (Ullman, 1984).

Concerning the visual and spatial relations, Knauff and Johnson-Laird (2002) formalize three sorts of relations: the visual-spatial relations, which are the relations such as above and below that are easy to envisage visually and spatially; the visual relations, which are the relations such as cleaner and dirtier that are easy to envisage visually but hard to envisage spatially; and the control relations, which are the relations such as better and worse that are hard to envisage both visually and spatially.

Winn and Holliday (1982) stated that the proper use of spatial displays is to present concepts in a way that enables people to use the least amount of mental effort to understand the relations among those concepts. An effective denoting relation should be a structure preserving correspondence between a data structure and a visual structure where the visual structure is required to be perceptually motivated (Dastani, 1997). Visual characteristics can also be formed by the integration of image elements according to both position and relative spatial relationships (Silva et al., 2005). The importance of images for relations is illustrated in (Guizzardi, Pires and Sinderen, 2002), as seen in Figure 21. The relation among three objects, *A*, *B* and *C*, is represented using propositional language in (a), while (b) represents the same relation using visual language. However, the same conclusion as (iii) in (a) is achieved in a more straightforward way when exploring the visual representation in (b). Therefore, semantic information can be captured directly from a pictorial representation.

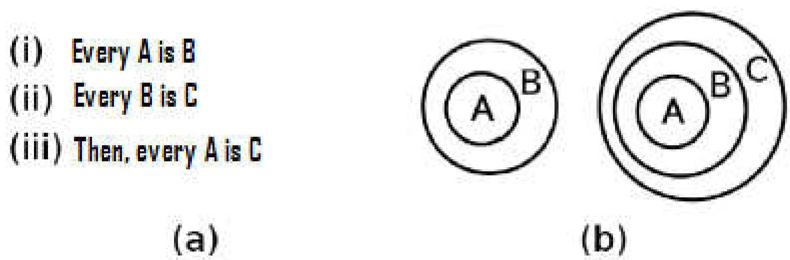


Figure 21 Propositional language (a) and visual language (b) (Guizzardi, Pires and Sinderen, 2002).

In some domains, the recognition of key features of elements and the identification of the visual-spatial relations among them is an important research issue (Ericsson and Smith, 1991). As a general example of visual patterns, someone could be interested in describing relationships among objects on a human face, searching to annotate and interpret a set of visual patterns to describe emotions, or semantically describe visual objects being captured from different frames of video, allowing the annotation and interpretation of temporal facts and events (Silva et al., 2004). Cibelli, Nappi and Tucci (2001) address visual domains where the physical attributes are insufficient to recognize, classify and describe objects and their complex relations. As an example of a complex relation, Figure 22 shows a functional relationship between the locker and the key.

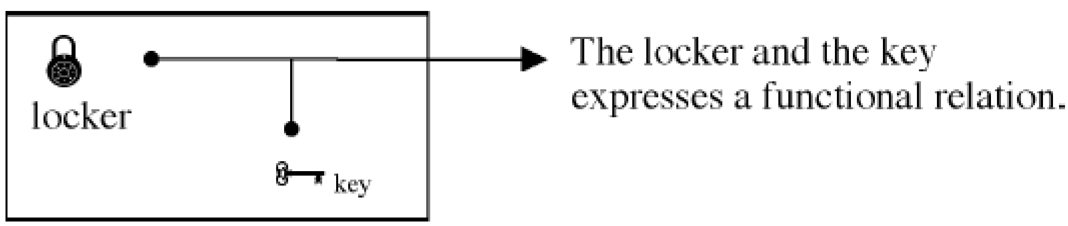


Figure 22 An example of a complex relation (Cibelli, Nappi and Tucci, 2001).

As discussed in (Santin, 2007), in imagistic domains only textual and numerical data may not result in useful information, therefore the use of images is essential; the visualization and interpretation of an image can bring important information for supporting the decision making processes. In Medicine, diagnostics are heavily based on image analysis, where medical images are analyzed in order to identify pathologies. Figure 23 displays an image of a human knee radiograph. From this image we can identify three objects. The two main objects in the image are those identified by the letters *A* and *B*. The third object is the background of the image, identified by the letter *C*. From these objects we may extract some attributes (e.g., color, texture, shape, size) that, in a particular domain, assist in identifying the object. In addition to the attributes, we can establish relationships between objects and between their edges.

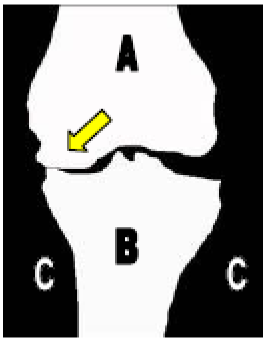


Figure 23 Artificial image of a human knee (Santin, 2007).

As underlined in (Mastella et al., 2005), in the field of Geology, geologists examine images of rocks in order to identify the quality of a petroleum reservoir rock based on the identification of the constituents that form the rock and their relationships. For instance, a geologist identifies visual-spatial relations among rock constituents (called paragenetic relations), as does a physician when analyzing medical images to identify a pathology.

Paragenetic relations are visual-spatial relations arranged among rock minerals at the time of its formation, presenting the physicochemical processes that formed the rock. These processes affect the rock porosity and permeability with great impact on the predictability in oil well production. Many of the paragenetic relations, like growth or dissolution of grains, among others, can be determined by the topological relationships among the grains (Santin, 2007).

The visual-spatial relations among rock constituents reflect the changes undergone by the rock as a result of diagenetic events. In Figure 24 an example of rock sample and the visual-spatial relations between minerals, which are the paragenetic relations that were identified, such as (1) hematite covering quartz grains (Qz), (2) quartz covering the hematite, and (3) quartz being covered by illite, which is covering the hematite.

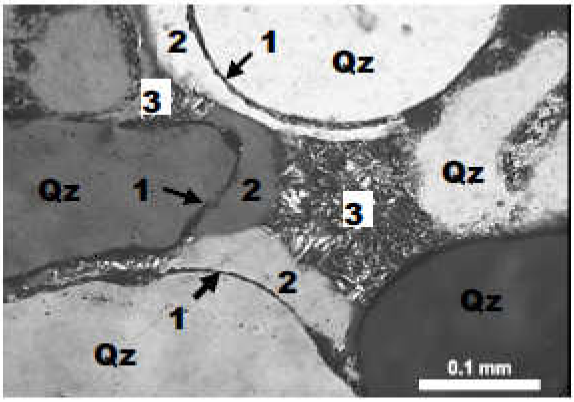


Figure 24 An example of rock sample and the visual-spatial relations between minerals (Mastella et al., 2005).

In this work, we have investigated the ontological foundations of relations and the visual knowledge in order to enforce ontological consistency and provide visual component support into the ontology relations of the Obaitá ontology building tool. In the next section we present the architecture of the Obaitá Portal, which is the ontology building tool where the outcomes of this research project have been made available.

8 OBAITÁ PORTAL

Obaitá Portal is an ontology building tool which is under development by the Intelligent Databases Research Group (BDI) from UFRGS. It has been developed through previous continuous work (Lorenzatti, 2010; Carbonera, 2012; Torres, 2012), as described in this section; now it is being evolved by this research project, as described in Sections 9 and 10. Its long-term goal is to offer an environment for ontological specification of concepts, allowing the definition of terms, qualities, quality domains and relationships that define a particular concept in Geology, particularly in the Stratigraphy domain. The complexity of this domain requires the development of modeling tools that extend the knowledge engineering state of the art.

Our intention in developing the ontology for stratigraphy is to provide a defined vocabulary to be shared and used by geologists in the description of well cores and outcrops. In order to achieve an acceptable ontology, we provide a tool that allows geologists to consult, be aware of, and negotiate meanings of the vocabulary of sedimentary concepts, sharing drawings and pictures. Achieving a shared accepted vocabulary formally defined provides the adequate basis for developing knowledge systems for stratigraphic documentation and interpretation.

One of the most difficult tasks in the development of ontologies is to balance properly the lack of knowledge of the human expert on the ontology semantic constraints with the lack of knowledge of the knowledge engineer about the domain. In other words, it is desirable that domain specialists directly evolve the ontology, keeping the semantic consistency, without the need of a knowledge engineer help in all phases of the updating process.

There are some knowledge domains where it is fundamental to have the expert knowledge for problem solving. Considering this factor, and taking the characteristic of conceptualization sharing present on ontologies, the BDI Research Group is developing, on the Obaitá Project, a tool for collaborative construction of visual domain ontologies based on a foundational ontology (UFO-A). This tool provides an interface where the domain expert may collaboratively build an ontology along other experts within the same area.

The project falls in the area of knowledge management and engineering, researching on ontologies applied to stratigraphic interpretation based on facies analysis for the petroleum exploration. It aims at studying the knowledge engineering techniques for capturing and modeling knowledge based on new models that share their meaning through web environments.

We address the issue of the convergence of vocabulary within a community of geologists, supporting collaboration in ontology construction. The tool allows geologists to negotiate the meaning of a particular geological term with the support of foundational ontology meta-types. Users can modify the terms and show their interpretation on the geological term. It is intended to have as a product a domain ontology of sedimentological description able to support the tasks of facies analysis for geological interpretation along advances in the state of the art in the acquisition and modeling of the domain knowledge.

The Obaitá Portal presents a knowledge model based on meta-ontology in order to allow both domain ontology and collaboration representations. It includes a web system for collaborative ontology building, which is based on a set of metadata that provides specialized constructs for creating the domain ontology elements. This model specifies meta-constructs for enabling the system to understand the domain ontology components, manipulating and storing the corresponding changes and discussions that may occur during the collaboration process.

The knowledge model uses the concepts of two ontologies that were developed for allowing the manipulation of ontological objects in a collaborative environment:

- Representation meta-ontology: specifies the structure of the domain ontology components;

- Collaboration meta-ontology: specifies the structure of the collaboration ontology components in order to obtain a consensual and shared conceptualization by a community.

The meta-ontologies structure the manipulation of the ontological objects of the domain ontology that is being constructed collaboratively by users. The domain ontology specifies the domain structure, that is, it is the artifact which is manipulated by users. Every change on the domain ontology is done through the structure defined by the meta-ontologies, which provide constructs for supporting the ontological foundation.

The representation ontology defines how the application interprets the ontological components, helping the collaborative system to detect whether they were correctly defined by users. Therefore, the domain ontology created by users is formalized in terms of the representation ontology by instantiating its concepts.

The collaboration ontology defines which collaborative activities can be done on the domain ontology. The collaboration process focuses on managing and storing the changes made on the domain ontology components. Through the web application, users may create changes and annotations directly on the domain model by including, updating or removing the ontology components. Collaboratively, they have access to the history of changes that were done by other users, discussing about them through annotations, and making new changes whenever necessary, until achieving collaboratively a steady domain model. The set of changes is stored in a structured way in order to allow the mapping of the ontology evolution, which happened during the interactions done in the collaborative process.

This tool consists of an online system, allowing users to interact with the system through the internet. The application has been developed in a structured way, using a layer based model (MVC - Model View Controller). The application contains an additional data access layer, which has the responsibility of abstracting and handling the triple structure, besides other low-level functions for helping manipulating the ontology.

The system architecture, as proposed by Torres (2012), is composed by layers as seen in Figure 25:

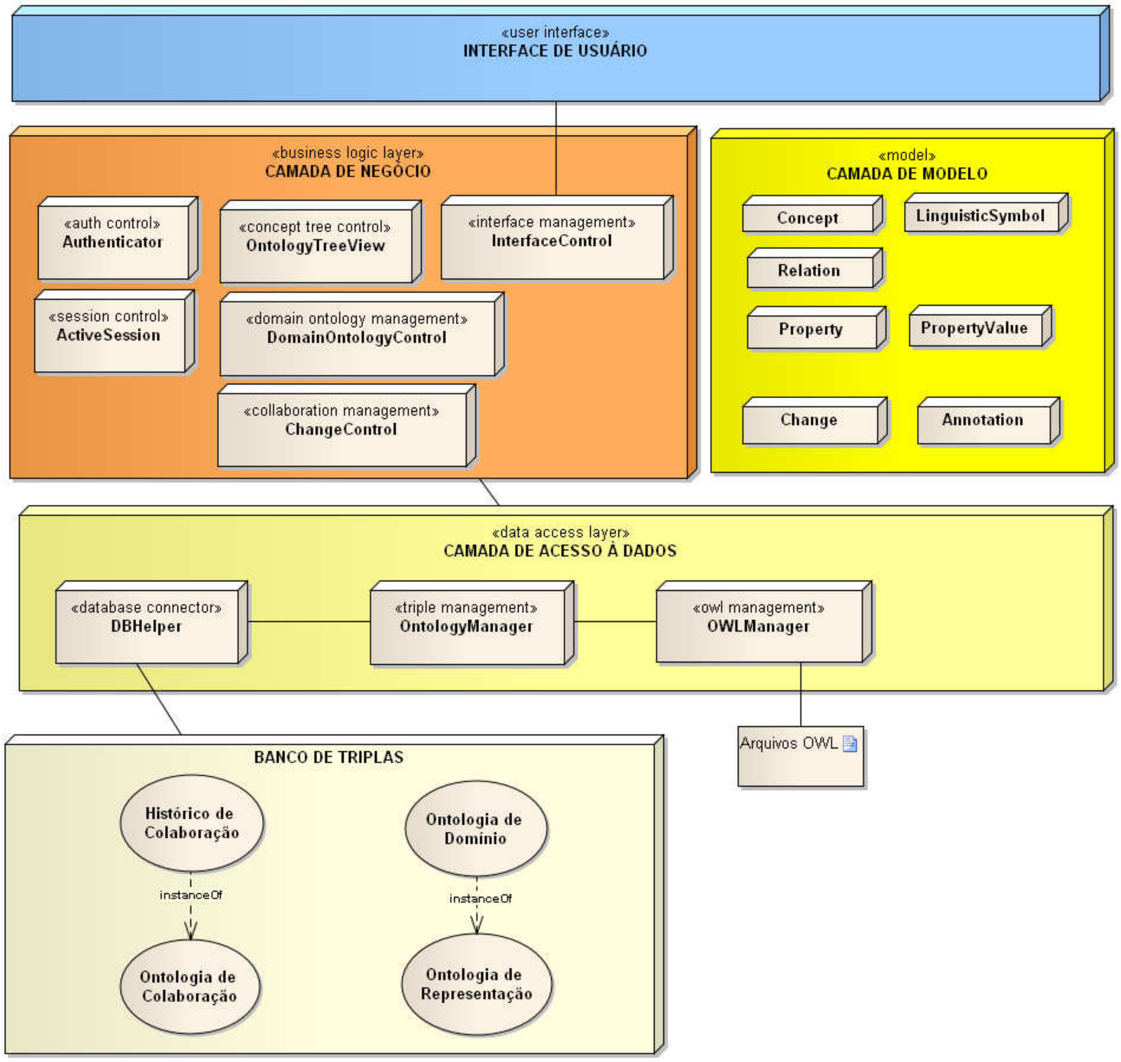


Figure 25 The system architecture layers (Torres, 2012).

- The User Interface Layer is responsible for the visual components, the ones that users interact, such as buttons, lists and forms. Most of these components are provided by the JBoss Seam framework, which is integrated with the business layer components;

- The Model Layer includes the classes that define the basic components of the system. In this layer, the components of the domain ontology are defined based on the structure that has been specified in the representation meta-ontology;

- The Business Layer includes the classes that satisfy the business rules responsible for the functionalities of the system. The intelligence of the system belongs to this layer. This layer uses the models that are defined in the Model Layer;

- The Data Access Layer is responsible for abstracting and performing the database access;

- The Database Layer consists of a Postgres database, where the ontologies persistent data is stored in the form of triplets.

The application stores the persistent information from the system ontologies on the database by structuring it in the form of Triple Store. This form of storage enables a more general and flexible manipulation of data, thereby allowing the expansion of the knowledge model without requiring changes in the structure of the database.

The stratigraphy domain ontology is under continuing development, where there are some details in the domain that require refinement of the constructed model. Continuing the development of the Obaitá ontology building tool, along with the domain ontology, we describe in the next section the solution that has been modeled in order to achieve the goals of this research project.

9 ONTOLOGY RELATION MODELING

We have noticed in the area of knowledge engineering a lack of an ontology building tool based on well-founded ontology dedicated to support modeling about visual domains. This tool should allow experts and knowledge engineers constructing more expressive and precise domain ontologies with proper representations, especially in visual domain areas such as Geology.

Continuing the development of the Obaitá ontology building tool, this research project provides support to the ontological foundations of the *relations* among the ontology concepts in order to obtain better accuracy in their formalization, expressing richer semantic models. This work proposes an alternative for the conceptual modeling of these relations, enforcing ontological consistency, providing inference and visual component support into the ontology relations.

9.1 Ontological Relations

Relations are used to structure the concepts in the ontology, being divided into two broad categories, called formal and material relations. While formal relations hold directly between the related entities, material relations, conversely, need another individual, that is called relator, in order to mediate the related entities. The main formal relations include the taxonomic relations (also called subclass-of, is-a, or subsumption relations), part-whole relations (also called part-of, parthood, or partonomic relations), existential relations, spatial relations, among others.

Here, in this modeling, we focus on the endurants (continuants) objects, the ones that persist through time. This research project uses the foundation ontological constructs for supporting the ontological choices of the binary relations through the semantic expressiveness of a foundational ontology, especially the formal and material relations, where a relation is defined as a universal that has existential dependence of two entities to which it establishes some association in some conceptualization. Besides the material relations, this work focuses on the formal existential, part-whole and spatial relations.

The material relations are formalized such that, let “R” be a Material Relation on universe “U”, and “x”, “y” and “z” be elements that belong to universe “U”, and“z” representing a relacional moment, then for every “x” that is related to “y” via relation “R” having “z” as a relator, the relation is represented as “xR(z)y”.

On the other hand, the formal relations are formalized such that, let “R” be a Formal Relation on universe “U”, and “x” and “y” be elements that belong to universe “U”, then for every “x” that is related to “y” via relation “R”, the relation is represented as “xRy”.

The existential relations, as proposed in this project, are classified based on the nature that the concept is conceived with respect to another concept, as coexist-with, constituted-by, correlated-with or polymorphic-with relations.

The part-whole relations, which in this project are specialized according to UFO-A, are classified based on the type of entities that they relate, as component-of, a part-whole relation which relates individuals that are functional complexes; member-of, a part-whole relation which relates individuals that are functional complexes or collectives (as part) and a collective (as a whole); subcollection-of, a part-whole relation which relates individuals that are collectives; or subquantity-of, a part-whole relation which relates individuals that are quantities.

The spatial relations, as proposed in this project, are classified based on the concept physical location with respect to another concept, as cross-cut, inside-of, overlay or surrounded-by relations.

Following this approach, the Portal Obaitá implements the meta-concept OntologyRelation and its specializations as presented in Figure 26.

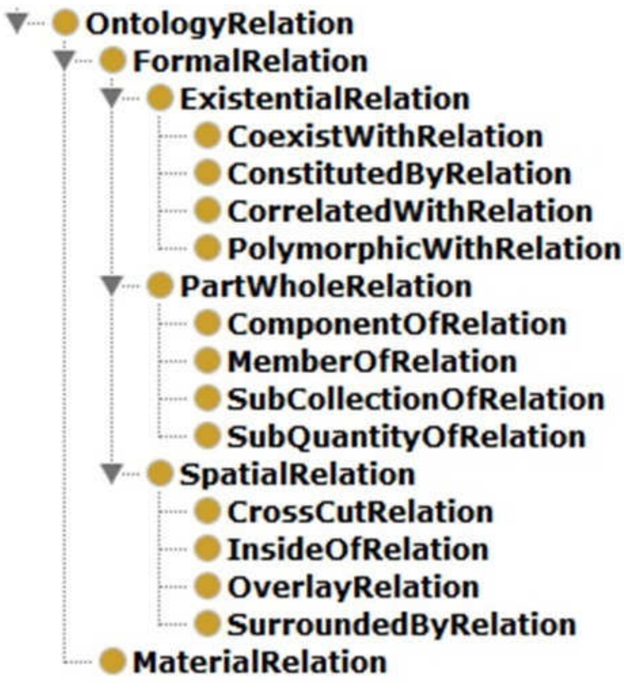


Figure 26 The meta-ontology relation structure.

These specializations increase the expressiveness of the resulting models, generating more accurate constructs to describe the objects of the domain ontology. The well-founded relation classification facilitates the ontological choices and avoids ambiguities and modeling errors, achieving as a result a well-founded domain ontology.

The domain ontology relations are instances of the meta-concept OntologyRelation from the representation meta-ontology.

The relations are specialized as formal or material relations. The material relations associate two connected entities (association ends) and they are materialized by a relator universal. The formal relations contain two connected entities. The connected entities are existing concepts (Substantial and Moment Universals) from the domain ontology. The relator is a Relational Moment in the domain ontology. The formal relations are further specialized as existential, part-whole or spatial relations.

The existential relations are further specialized as coexist-with, constituted-by, correlated-with or polymorphic-with relations.

Coexist-with relations:

The classes connected to both association ends must represent universals whose instances are evaluated in respect to each other by means of their coexistence. They have to be irreflexive, symmetric and transitive.

Constituted-by relations:

The class connected to the association end relative to the constituted object must represent a universal whose instances are constituted by an instance of the universal connected to the association end relative to the constituting object. They have to be irreflexive, asymmetric and transitive.

Correlated-with relations:

The classes connected to both association ends must represent universals whose instances are stratigraphic units which are located at different places, but demonstrate equivalence. They have to be irreflexive, symmetric and transitive.

Polymorphic-with relations:

The classes connected to both association ends must represent universals whose instances are minerals that have the same chemical composition, but different crystal structures. They have to be irreflexive, symmetric and transitive.

The part-whole relations are further specialized as component-of, member-of, subcollection-of or subquantity-of relations.

Component-of relations:

The classes connected to both association ends must represent universals whose instances are functional complexes. They have to be irreflexive, asymmetric and nontransitive; and they have weak supplementation.

Member-of relations:

The class connected to the association end relative to the whole individual must be a universal whose instances are collectives, while the class connected to the association end relative to the part can be either a universal whose instances are collectives, or a universal whose instances are functional complexes. They have to be irreflexive, asymmetric and intransitive; and they have weak supplementation.

Subcollection-of relations:

The classes connected to both association ends must represent universals whose instances are collectives. They have to be irreflexive, asymmetric and transitive; and they have weak supplementation.

Subquantity-of relations:

The classes connected to both association ends must represent universals whose instances are quantities. They have to be irreflexive, asymmetric and transitive; they have strong supplementation; and they have to be nonshareable.

The spatial relations are further specialized as cross-cut, inside-of, overlay or surrounded-by relations.

Cross-cut relations:

The class connected to the association end relative to the crossing object must represent a universal whose instances are geological features that cut through an instance of the universal connected to the association end relative to the crossed object. They have to be irreflexive, asymmetric and intransitive.

Inside-of relations:

The class connected to the association end relative to the inner object must represent a universal whose instances are stratigraphic units that can be found inside of an instance of the universal connected to the association end relative to the outer object. They have to be irreflexive, asymmetric and transitive.

Overlay relations:

The class connected to the association end relative to the superposing object must represent a universal whose instances are geological sediments deposited over an instance of the universal connected to the association end relative to the superposed object. They have to be irreflexive, asymmetric and transitive.

Surrounded-by relations:

The class connected to the association end relative to the inner object must represent a universal whose instances are geological formations surrounded by an instance of the universal connected to the association end relative to the outer object. They have to be irreflexive, asymmetric and transitive.

9.2 Visual Representation

In some domains, such as the field of Geology, only textual and numerical data may not result in useful information, where geologists may examine images of rocks in order to identify the quality of a petroleum reservoir rock based on the identification of the constituents that form the rock and their relationships.

Visual perception requires the capacity to extract shape properties and spatial relations among objects and their parts. This capacity is fundamental to visual recognition, since objects are often defined visually by abstract shape properties and spatial relations among their components.

Visual characteristics can also be formed by the integration of image elements according to both position and relative spatial relationships. The visualization and interpretation of an image can bring important information; the use of images is essential for the recognition of key features of elements and the identification of the visual spatial relations.

Besides the traditional symbolic representation of a linguistic term, we enable the use of pictorial representation by using visual constructs along the relations in the environment, allowing the representation of visual domains, associating images to the spatial relations in the domain ontology.

In this work, we have modeled visual representation in the sense that, unlike concrete sortals, we do not have photographs of relationships, since relations are abstract concepts. Nevertheless, due to their physical characteristics, the spatial relations may be associated to icons, as presented in Section 7. A visual representation of a binary spatial relation should present both concrete objects, expressing the relationship between them, as shown in Figure 27, where the inner object is presented in red and the outer object is presented in white.

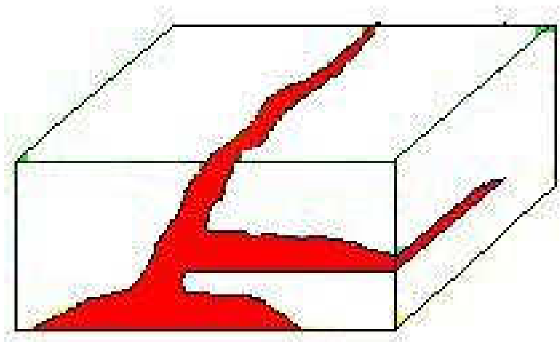


Figure 27 Visual representation of a binary spatial relation.

9.3 Inference Features

This research project provides inference and visual component support into the ontology concept relations based on the conceptual modeling and the definitions proposed in Sections 9.1 and 9.2.

The support to the inference of the relation ontological meta-type is provided based on the meta-types of the respective related concepts, according to UFO-A. We use pictorial representations, allowing the representation of visual domains, associating images to the ontology concept relations. We also use an interface which provides assistance, not requiring users to have any prior knowledge of ontological representation formal languages.

When editing a universal, in order to help users to define the universal meta-type, the system guides them by asking questions. If the user answers the question telling the system that an individual from this universal is existentially dependent and acts as a mediating entity in the relationship among other entities (e.g., an enrollment is existentially dependent and acts as a mediating entity in the relation between a student and an educational institution), then the system infers that the universal meta-type is "relator".

On the other hand, in order to help users to define the relation type, the system guides them by asking questions. If the user answers the question telling the system that the relation needs the existence of a mediating entity in order to connect the related entities (e.g., the relation between a student and an educational institution needs the existence of an enrollment), then the system infers that the relation type is "material".

The system also has the ability to infer the relation type based on the meta-types of the respective related entities. For a part-whole relation, if the meta-type of both related entities, the part and the whole, is "quantity" (e.g., alcohol is part of wine), then the system infers that the relation type is "subquantity-of".

In the case of inferring that the relation type is “material”, the system requires the existence of a “relator” to be connected to the relation; then, the user has to inform the mediating entity, selecting it from a list, composed by entities with meta-type “relator”, provided by the system.

In the case of inferring that the relation type is “formal”, the system suggests some possible relation types in order to help users to better specialize it as an existential relation, such as coexist-with, constituted-by, correlated-with or polymorphic-with; a part-whole relation, such as component-of, member-of, subcollection-of or subquantity-of; or a spatial relations, such as cross-cut, inside-of, overlay or surrounded-by.

For the part-whole relations, the source concept represents the “part”, while the target concept represents the “whole”; the system infers the suggested possible part-whole relation types based on the meta-types of the part and the whole, as defined in Section 4.1, which are summarized in Table 2.

Table 2 Possible types of part-whole relations.

Source/ Target	**Kind**	**Collective**	**Quantity**	**other**
Kind	component-of	---	---	---
Collective	member-of	member-of subcollection-of	---	---
Quantity	---	---	subquantity-of	---
other	---	---	---	---

As a result, for the formal relations, the system infers the suggested possible relation types as follows:

When the meta-type of the source concept is “collective”, and:

- the meta-type of the target concept is “collective”, then the inferred possible relation types are “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “member-of”, “subcollection-of”, “cross-cut”, “inside-of”, “overlay”, “surrounded-by” and “formal” (users may choose not to specialize the relation);

- the meta-type of the target concept is not “collective”, then the inferred possible relation types are “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “cross-cut”, “inside-of”, “overlay”, “surrounded-by” and “formal” (users may choose not to specialize the relation).

When the meta-type of the source concept is “kind”, and:

- the meta-type of the target concept is “kind”, then the inferred possible relation types are “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “component-of”, “cross-cut”, “inside-of”, “overlay”, “surrounded-by” and “formal” (users may choose not to specialize the relation);

- the meta-type of the target concept is “collective”, then the inferred possible relation types are “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “member-of”, “cross-cut”, “inside-of”, “overlay”, “surrounded-by” and “formal” (users may choose not to specialize the relation);

- the meta-type of the target concept is neither “kind” nor “collective”, then the inferred possible relation types are “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “cross-cut”, “inside-of”, “overlay”, “surrounded-by” and “formal” (users may choose not to specialize the relation).

When the meta-type of the source concept is “quantity”, and:

- the meta-type of the target concept is “quantity”, then the inferred possible relation types are “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “subquantity-of”, “cross-cut”, “inside-of”, “overlay”, “surrounded-by” and “formal” (users may choose not to specialize the relation);

- the meta-type of the target concept is not “quantity”, then the inferred possible relation types are “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “cross-cut”, “inside-of”, “overlay”, “surrounded-by” and “formal” (users may choose not to specialize the relation).

When the meta-type of the source concept is not “collective”, “kind” and “quantity”, then the inferred possible relation types are “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “cross-cut”, “inside-of”, “overlay”, “surrounded-by” and “formal” (users may choose not to specialize the relation).

In the next section, as part of the development of this research project, we describe how the solution proposed here in this section has been implemented accordingly in the Obaitá ontology building tool.

10 IMPLEMENTED SOLUTION

This section presents the required implementation in order to add our proposed alternative for the ontology relation conceptual modeling into the Obaitá ontology building tool, enforcing ontological consistency, providing inference and visual component support for the Sedimentary Stratigraphy domain ontology relations.

The user access to the tool is based on authentication via username and password. After logging in, the user is taken to the area of collaboration, where he/she can choose the domain ontology (the system is able to support more than one domain ontology). The user selects the domain ontology he/she wants to edit, and then the system displays the tree of universals from the selected domain ontology, as partially seen in Figure 28, where the branches of the tree represent the subsumption relationship. From the universal tree view, the user selects the domain ontology universal he/she wants to visualize or edit.

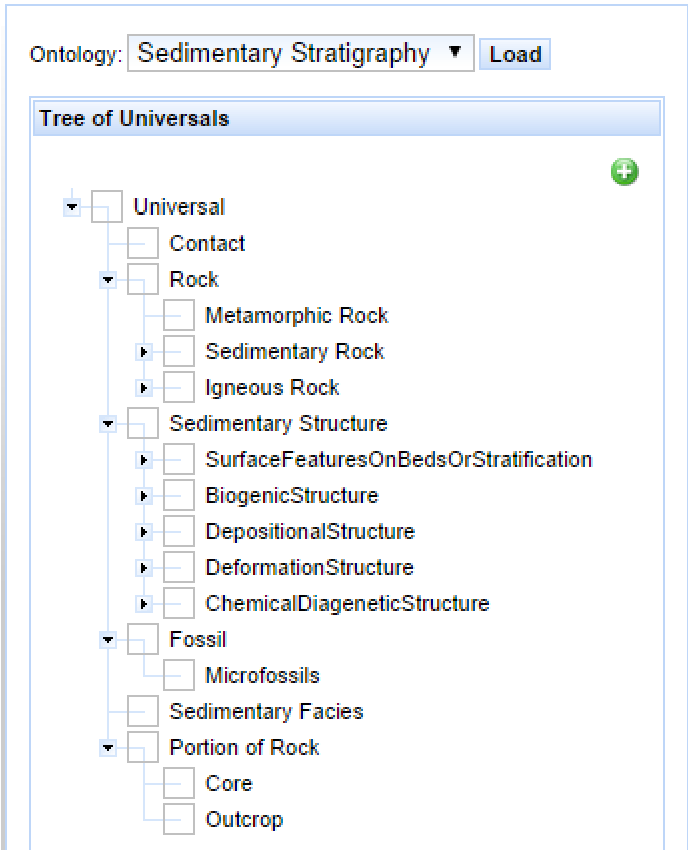


Figure 28 The domain ontology universal tree view.

When editing the universal details, the user is guided by the system such that the universal meta-type is defined in an ontologically consistent way. If the user answers the question telling the system that an individual extension from this universal is existentially dependent and acts as a mediating entity in the relationship among other entities, then the system infers that the universal meta-type is “relator”, as shown in Figure 29.

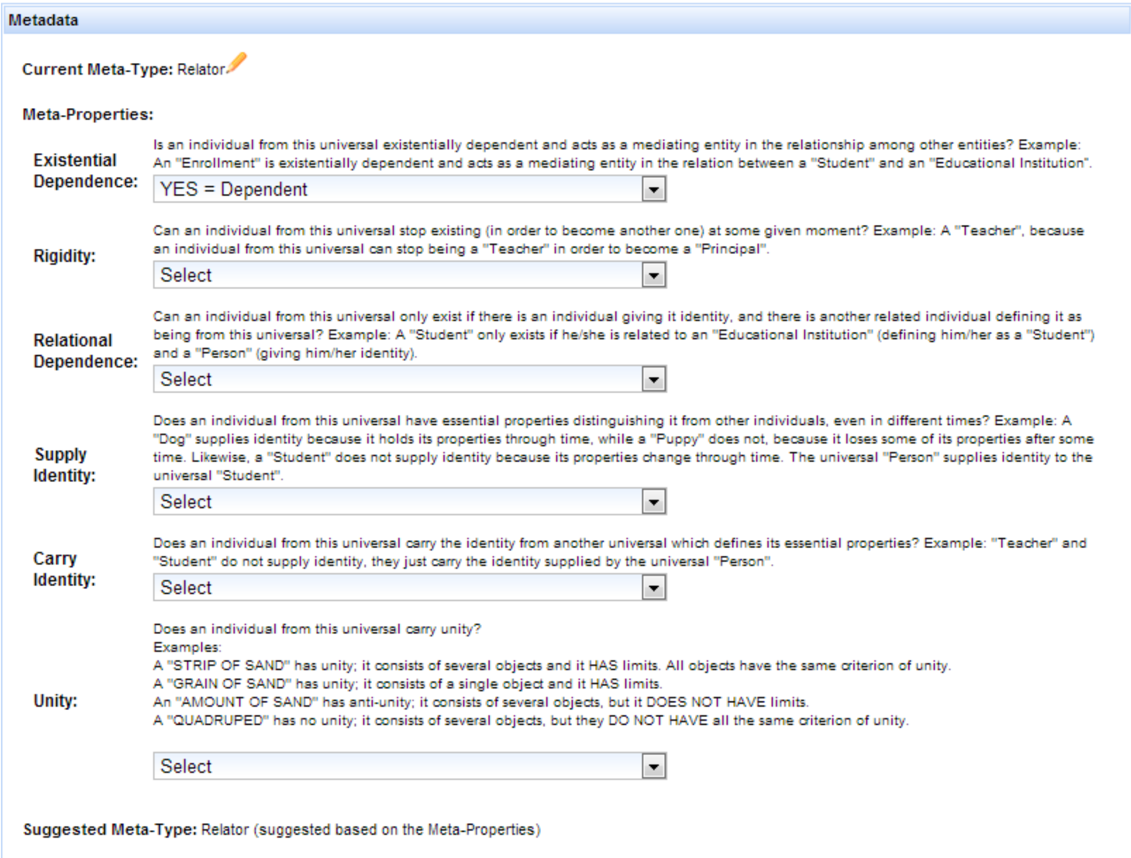
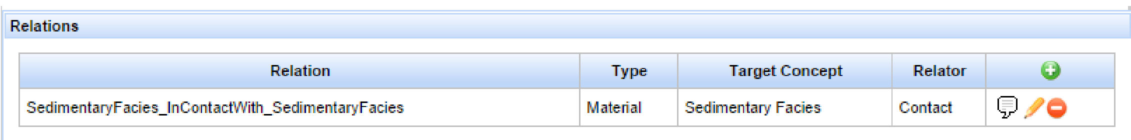


Figure 29 The universal meta-type definition.

Along the universal details, the system displays the binary relations in which the universal is participant (Figure 30), from where the user may edit the universal relations, create new relations (or attach already existing relations) to the universal, or remove relations from the universal.


Relations

Relation	Type	Target Concept	Relator	
SedimentaryFacies_InContactWith_SedimentaryFacies	Material	Sedimentary Facies	Contact	

Figure 30 The universal relations.

When editing a relation, it is possible to choose its name, the relation visual representation, the source concept, the source cardinality, the target concept, the target cardinality, the relation type, the relator, and to inform a change description, as seen in Figure 31.

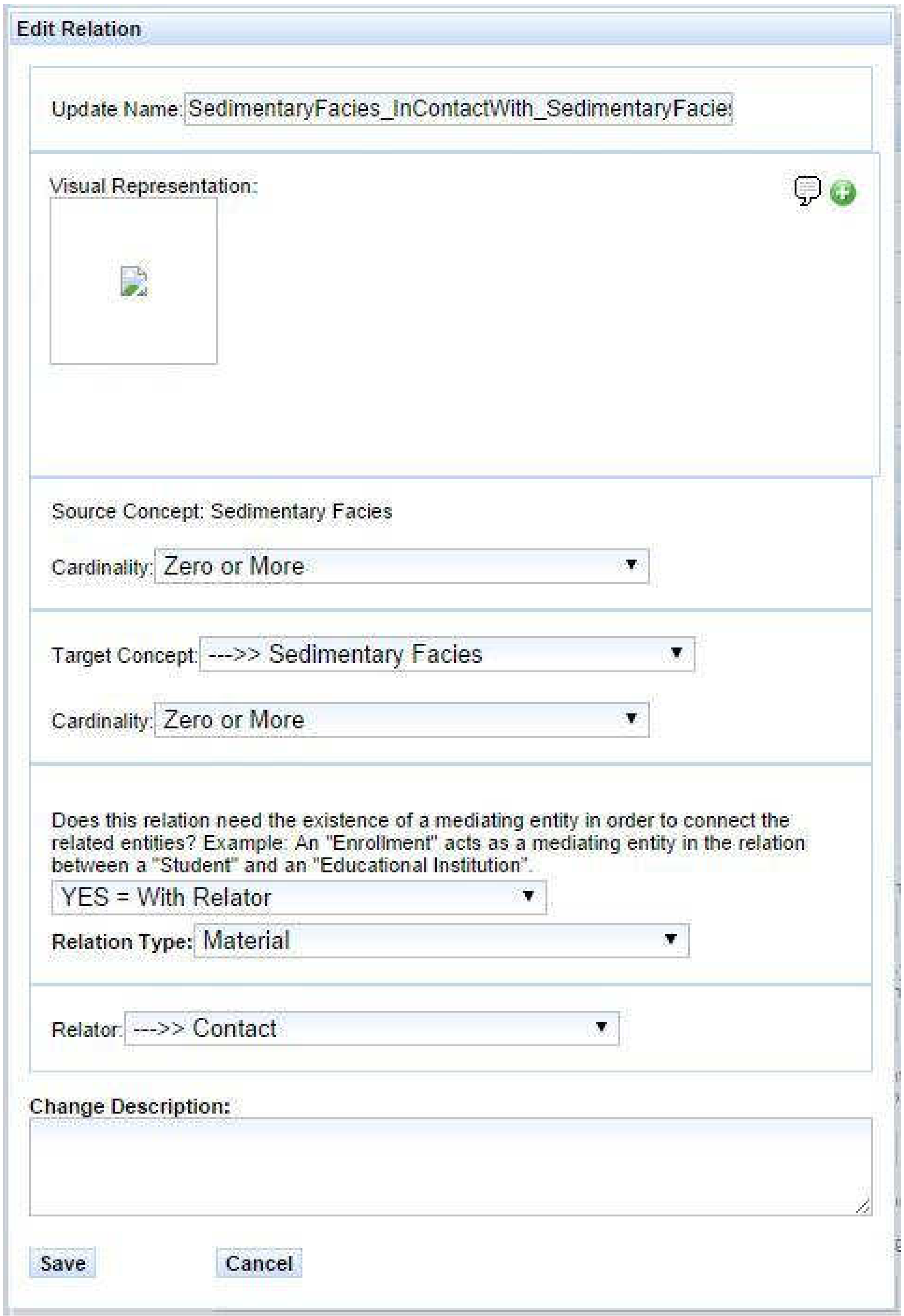


Figure 31 Editing a universal relation.

The relation name is composed by a textual term.

An image may be associated to the spatial relations in order to connect their visual representation, increasing the communication and understanding by experts. The relation image is selected from a list of image files.

The source concept is automatically selected as the universal that is being viewed in detail in the system.

The source cardinality is selected from a list, such as “zero or more”, “zero or one”, “one” or “one or more”.

The target concept is selected from a list containing the existing Substantial and Moment Universals from the domain ontology.

The target cardinality is selected from a list, such as “zero or more”, “zero or one”, “one” or “one or more”.

In order to define the relation type, besides guiding users by asking questions, the system also evaluates the meta-types of the respective related concepts.

If the user answers the question telling the system that the relation needs the existence of a mediating entity in order to connect the related entities, then the system infers that the relation type is “material”, otherwise the system infers that the relation type is “formal”. In other words, as seen in Algorithm 1, if the user selects the item "YES = With Relator" from the select menu, then the relation is assumed to be “material”, otherwise, if the user selects the item "NO = Without Relator" from the select menu, then the relation is assumed to be “formal”.

Algorithm 1 - With or Without Relator

```
Does this relation need the existence of a mediating entity in order to connect
the related entities?
Example: An "Enrollment" acts as a mediating entity in the relation between
            a "Student" and an "Educational Institution”.
<h:selectOneMenu
   value="#{relationWithRelator}">
   <f:selectItem itemLabel="YES = With Relator" itemValue="yes" />
   <f:selectItem itemLabel="NO = Without Relator" itemValue="no" />
</h:selectOneMenu>
```

After the selection showed in Algorithm 1, if the user informed that the relation needs the existence of a mediating entity (with relator), the system directly applies Algorithm 2, infering that the only possible relation type to be selected is “material”.

Algorithm 2 - Material Relation

```
<h:selectOneMenu
   rendered="#{if relationWithRelator == 'yes'}"
   value="#{relationType}">
```

```
    <f:selectItem itemLabel="Material" itemValue="Material" />
</h:selectOneMenu>
```

On the other hand, after the selection showed in Algorithm 1, if the user informed that the relation does not need the existence of a mediating entity (without relator), the system infers that the relation type is “formal”.

Consequently, by infering that the relation type is “formal”, the system suggests the corresponding possible relation types, further applying Algorithms 3 to 10, where the possible specializations for the part-whole relations are based on the meta-types of the respective related entities. Therefore, while the system enforces ontological consistency, the user may select the desired relation type from the suggested menu.

If both the source concept meta-type and the target concept meta-type are defined as collective, then the system presents the suggested possible relation types such as “formal” “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “member-of”, “subcollection-of”, “cross-cut”, “inside-of”, “overlay” and “surrounded-by”, as seen in Algorithm 3.

Algorithm 3 - Formal Relation

```
<h:selectOneMenu
    rendered="#{if relationWithRelator == 'no' and
                      relationSourceConceptType == 'Collective' and
                      relationTargetConceptType == 'Collective'}"
    value="#{relationType}">
    <f:selectItem itemLabel="Formal" itemValue="Formal" />
    <f:selectItem itemLabel="CoexistWith" itemValue="CoexistWith" />
    <f:selectItem itemLabel="ConstitutedBy" itemValue="ConstitutedBy" />
  <f:selectItem itemLabel="CorrelatedWith" itemValue="CorrelatedWith" />
    <f:selectItem itemLabel="PolymorphicWith" itemValue="PolymorphicWith" />
    <f:selectItem itemLabel="MemberOf" itemValue="MemberOf" />
    <f:selectItem itemLabel="SubCollectionOf" itemValue="SubCollectionOf" />
    <f:selectItem itemLabel="CrossCut" itemValue="CrossCut" />
    <f:selectItem itemLabel="InsideOf" itemValue="InsideOf" />
    <f:selectItem itemLabel="Overlay" itemValue="Overlay" />
    <f:selectItem itemLabel="SurroundedBy" itemValue="SurroundedBy" />
</h:selectOneMenu>
```

If the source concept meta-type is defined as collective and the target concept meta-type is not defined as collective, then the system presents the suggested possible relation types such as “formal” “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “cross-cut”, “inside-of”, “overlay” and “surrounded-by”, as seen in Algorithm 4.

Algorithm 4 - Formal Relation

```
<h:selectOneMenu
   rendered="#{if relationWithRelator == 'no' and
                  relationSourceConceptType == 'Collective' and
                  relationTargetConceptType != 'Collective'}"
   value="#{relationType}">
   <f:selectItem itemLabel="Formal" itemValue="Formal" />
   <f:selectItem itemLabel="CoexistWith" itemValue="CoexistWith" />
   <f:selectItem itemLabel="ConstitutedBy" itemValue="ConstitutedBy" />
   <f:selectItem itemLabel="CorrelatedWith" itemValue="CorrelatedWith" />
   <f:selectItem itemLabel="PolymorphicWith" itemValue="PolymorphicWith" />
   <f:selectItem itemLabel="CrossCut" itemValue="CrossCut" />
   <f:selectItem itemLabel="InsideOf" itemValue="InsideOf" />
   <f:selectItem itemLabel="Overlay" itemValue="Overlay" />
   <f:selectItem itemLabel="SurroundedBy" itemValue="SurroundedBy" />
</h:selectOneMenu>
```

If both the source concept meta-type and the target concept meta-type are defined as kind, then the system presents the suggested possible relation types such as “formal” “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “component-of”, “cross-cut”, “inside-of”, “overlay” and “surrounded-by”, as seen in Algorithm 5.

Algorithm 5 - Formal Relation

```
<h:selectOneMenu
   rendered="#{if relationWithRelator == 'no' and
                  relationSourceConceptType == 'Kind' and
                  relationTargetConceptType == 'Kind'}"
   value="#{relationType}">
   <f:selectItem itemLabel="Formal" itemValue="Formal" />
```

```
    <f:selectItem itemLabel="CoexistWith" itemValue="CoexistWith" />
    <f:selectItem itemLabel="ConstitutedBy" itemValue="ConstitutedBy" />
  <f:selectItem itemLabel="CorrelatedWith" itemValue="CorrelatedWith" />
    <f:selectItem itemLabel="PolymorphicWith" itemValue="PolymorphicWith" />
    <f:selectItem itemLabel="ComponentOf" itemValue="ComponentOf" />
    <f:selectItem itemLabel="CrossCut" itemValue="CrossCut" />
    <f:selectItem itemLabel="InsideOf" itemValue="InsideOf" />
    <f:selectItem itemLabel="Overlay" itemValue="Overlay" />
    <f:selectItem itemLabel="SurroundedBy" itemValue="SurroundedBy" />
</h:selectOneMenu>
```

If the source concept meta-type is defined as kind and the target concept meta-type is defined as collective, then the system presents the suggested possible relation types such as “formal” “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “member-of”, “cross-cut”, “inside-of”, “overlay” and “surrounded-by”, as seen in Algorithm 6.

Algorithm 6 - Formal Relation

```
<h:selectOneMenu
    rendered="#{if relationWithRelator == 'no' and
                        relationSourceConceptType == 'Kind' and
                        relationTargetConceptType == 'Collective'}"
    value="#{relationType}">
    <f:selectItem itemLabel="Formal" itemValue="Formal" />
    <f:selectItem itemLabel="CoexistWith" itemValue="CoexistWith" />
    <f:selectItem itemLabel="ConstitutedBy" itemValue="ConstitutedBy" />
  <f:selectItem itemLabel="CorrelatedWith" itemValue="CorrelatedWith" />
    <f:selectItem itemLabel="PolymorphicWith" itemValue="PolymorphicWith" />
    <f:selectItem itemLabel="MemberOf" itemValue="MemberOf" />
    <f:selectItem itemLabel="CrossCut" itemValue="CrossCut" />
    <f:selectItem itemLabel="InsideOf" itemValue="InsideOf" />
    <f:selectItem itemLabel="Overlay" itemValue="Overlay" />
    <f:selectItem itemLabel="SurroundedBy" itemValue="SurroundedBy" />
</h:selectOneMenu>
```

If the source concept meta-type is defined as kind and the target concept meta-type is neither defined as kind nor defined as collective, then the system presents the suggested possible relation types such as “formal” “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “cross-cut”, “inside-of”, “overlay” and “surrounded-by”, as seen in Algorithm 7.

Algorithm 7 - Formal Relation

```
<h:selectOneMenu
    rendered="#{if relationWithRelator == 'no' and
                      relationSourceConceptType == 'Kind' and
                      relationTargetConceptType != 'Kind' and
                      relationTargetConceptType != 'Collective'}"
    value="#{relationType}">
    <f:selectItem itemLabel="Formal" itemValue="Formal" />
    <f:selectItem itemLabel="CoexistWith" itemValue="CoexistWith" />
   <f:selectItem itemLabel="ConstitutedBy" itemValue="ConstitutedBy" />
    <f:selectItem itemLabel="CorrelatedWith" itemValue="CorrelatedWith" />
    <f:selectItem itemLabel="PolymorphicWith" itemValue="PolymorphicWith" />
    <f:selectItem itemLabel="CrossCut" itemValue="CrossCut" />
    <f:selectItem itemLabel="InsideOf" itemValue="InsideOf" />
    <f:selectItem itemLabel="Overlay" itemValue="Overlay" />
    <f:selectItem itemLabel="SurroundedBy" itemValue="SurroundedBy" />
</h:selectOneMenu>
```

If both the source concept meta-type and the target concept meta-type are defined as quantity, then the system presents the suggested possible relation types such as “formal” “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “subquantity-of”, “cross-cut”, “inside-of”, “overlay” and “surrounded-by”, as seen in Algorithm 8.

Algorithm 8 - Formal Relation

```
<h:selectOneMenu
    rendered="#{if relationWithRelator == 'no' and
                      relationSourceConceptType == 'Quantity' and
                      relationTargetConceptType == 'Quantity'}"
    value="#{relationType}">
```

```
    <f:selectItem itemLabel="Formal" itemValue="Formal" />
    <f:selectItem itemLabel="CoexistWith" itemValue="CoexistWith" />
    <f:selectItem itemLabel="ConstitutedBy" itemValue="ConstitutedBy" />
  <f:selectItem itemLabel="CorrelatedWith" itemValue="CorrelatedWith" />
    <f:selectItem itemLabel="PolymorphicWith" itemValue="PolymorphicWith" />
    <f:selectItem itemLabel="SubQuantityOf" itemValue="SubQuantityOf" />
    <f:selectItem itemLabel="CrossCut" itemValue="CrossCut" />
    <f:selectItem itemLabel="InsideOf" itemValue="InsideOf" />
    <f:selectItem itemLabel="Overlay" itemValue="Overlay" />
    <f:selectItem itemLabel="SurroundedBy" itemValue="SurroundedBy" />
</h:selectOneMenu>
```

If the source concept meta-type is defined as quantity and the target concept meta-type is not defined as quantity, then the system presents the suggested possible relation types such as “formal” “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “cross-cut”, “inside-of”, “overlay” and “surrounded-by”, as seen in Algorithm 9.

Algorithm 9 - Formal Relation

```
<h:selectOneMenu
    rendered="#{if relationWithRelator == 'no' and
                    relationSourceConceptType == 'Quantity' and
                    relationTargetConceptType != 'Quantity'}"
    value="#{relationType}">
    <f:selectItem itemLabel="Formal" itemValue="Formal" />
    <f:selectItem itemLabel="CoexistWith" itemValue="CoexistWith" />
    <f:selectItem itemLabel="ConstitutedBy" itemValue="ConstitutedBy" />
  <f:selectItem itemLabel="CorrelatedWith" itemValue="CorrelatedWith" />
    <f:selectItem itemLabel="PolymorphicWith" itemValue="PolymorphicWith" />
    <f:selectItem itemLabel="CrossCut" itemValue="CrossCut" />
    <f:selectItem itemLabel="InsideOf" itemValue="InsideOf" />
    <f:selectItem itemLabel="Overlay" itemValue="Overlay" />
    <f:selectItem itemLabel="SurroundedBy" itemValue="SurroundedBy" />
</h:selectOneMenu>
```

If the source concept meta-type is not defined as collective, kind and quantity, then the system presents the suggested possible relation types such as “formal” “coexist-with”, “constituted-by”, “correlated-with”, “polymorphic-with”, “cross-cut”, “inside-of”, “overlay” and “surrounded-by”, as seen in Algorithm 10.

Algorithm 10 - Formal Relation

```
<h:selectOneMenu
   rendered="#{if relationWithRelator == 'no' and
                  relationSourceConceptType != 'Collective' and
                  relationSourceConceptType != 'Kind' and
                  relationSourceConceptType != 'Quantity'}"
   value="#{relationType}">
   <f:selectItem itemLabel="Formal" itemValue="Formal" />
   <f:selectItem itemLabel="CoexistWith" itemValue="CoexistWith" />
   <f:selectItem itemLabel="ConstitutedBy" itemValue="ConstitutedBy" />
   <f:selectItem itemLabel="CorrelatedWith" itemValue="CorrelatedWith" />
   <f:selectItem itemLabel="PolymorphicWith" itemValue="PolymorphicWith" />
   <f:selectItem itemLabel="CrossCut" itemValue="CrossCut" />
   <f:selectItem itemLabel="InsideOf" itemValue="InsideOf" />
   <f:selectItem itemLabel="Overlay" itemValue="Overlay" />
   <f:selectItem itemLabel="SurroundedBy" itemValue="SurroundedBy" />
</h:selectOneMenu>
```

When the relation type is “material”, the system requires the existence of a relator to be connected to the relation in order to mediate the related entities. The relator is selected from a list containing the existing Relational Moments from the domain ontology.

The change description is composed by a free text comment inserted by the user.

Next, we present our proposed validation case study, using a real domain ontology from the Sedimentary Stratigraphy area, in order to evaluate our research project proposed approach.

11CASE STUDY

This section describes the case study used as the validation approach for the proposals of this work, where the tool has been used for the improvement of the Sedimentary Stratigraphy domain ontology, aiming to achieve as a result an ontologically consistent structure for the relations among the concepts of the original ontology.

In order to validate the system in a real environment, we brought a case study in the Sedimentary Stratigraphy domain, an area from Geology responsible for studying the formation processes of sedimentary rocks. The case study has been validated along with a geologist, a user from the Sedimentary Stratigraphy participating in the project.

Sedimentary Stratigraphy is the study of sedimentary terrains in surface or subsurface in order to define the geological history of their formation based on the visual description of well cores and outcrops. The description of cores and analog coexisting outcrops provides essential information for the understanding of depositional environments and systems, as well as of their stratigraphic evolution, basis for the construction of realistic reservoir models.

The main concepts for rock description implemented in this study were previously formalized in (Lorenzzatti, 2010) and further improved in (Carbonera, 2012). They are Sedimentary Facies, Sedimentary Structures and Depositional Processes, which will be described in this section. The ontological relations among these concepts have been studied in this work, where the proposed modeling is a contribution of this thesis.

A Sedimentary Facies is a particular organization of a rock in a spatial arrangement that, along with the preserved fossil content, identifies the depositional environment in which the existing sediment has been deposited and consolidated in that rock. It is a region in a well core or outcrop, visually distinguishable of adjacent regions. Each Sedimentary Facies is assumed as a direct result of the occurrence of a Depositional Process; they group together a set of diagnostic visual aspects of sedimentary rocks strongly connected with the depositional conditions in which this rock has been created.

Sedimentary Structure is the external visual aspect of some internal spatial arrangement of the rock grains that, along with the preserved fossil content and the rock type, identifies the depositional environment in which the existing sediment has been deposited and consolidated in that rock. They can be found inside of sedimentary rocks. They were formed at the moment of deposition that represent multiple manifestations of the biological as well as the physical processes that operate within any type of depositional environment. It is the main visual object recognized in the domain, and the first one used for interpretation hypotheses.

Depositional Processes are events that involve the complex interaction of natural forces and sediments; they are responsible for the formation of sedimentary rocks through transportation and deposition of sediments in a sedimentation place.

This domain has been chosen because it presents some important aspects for our focus; its structure is complex, therefore our system intends to help experts in solving many domain natural structural problems through the correct use of the ontological foundation of the relations; on the other hand, this domain is strongly based on visual knowledge, therefore our system also intends to help experts in interpreting and describing the domain knowledge; another important aspect is that this domain has scientific and economic relevance, it studies the generation and depositional conditions of important mineral deposits, such as coal and oil. Also, the domain is representative for many other visual domains and we suppose that our approach, once validated for modeling sedimentary facies, can be applied for visual interpretation tasks in Medicine, Biology and several other scientific problems.

This work has taken as a starting point the ontology taxonomy of the sedimentary structures along with their set of descriptive attributes. While evaluating the case study over the original domain ontology, we have identified some problems which we have worked on accordingly along with the development of this research project. We have noticed that there were no foundation ontological constructs for supporting the ontological choices of the relations through the semantic expressiveness of a foundational ontology; the ontological meta-types of the relations were not based on the meta-types of the related concepts; it was not possible to use pictorial representations in order to associate images to the ontology relations; the interface did not release users from having some knowledge of ontological representation formal languages when interacting with the ontology.

Following, as the result of the proposed contributions from this research project, some important improvements into our domain ontology are presented.

The main concepts and relations which are fundamental to our domain ontology activities include Rock, Portion of Rock, Sedimentary Facies, Sedimentary Structure, Fossil, Contact and their subtypes, which are partly seen in Figure 32 (the complete domain ontology may be seen in Appendix A). Events are not in the scope of this research project, therefore Depositional Processes will be covered by a future Obaitá Project. We also emphasize that the hierarchy relations were not considered in our analysis because these relations are inherent to the taxonomy instead of to the semantics of the domain.

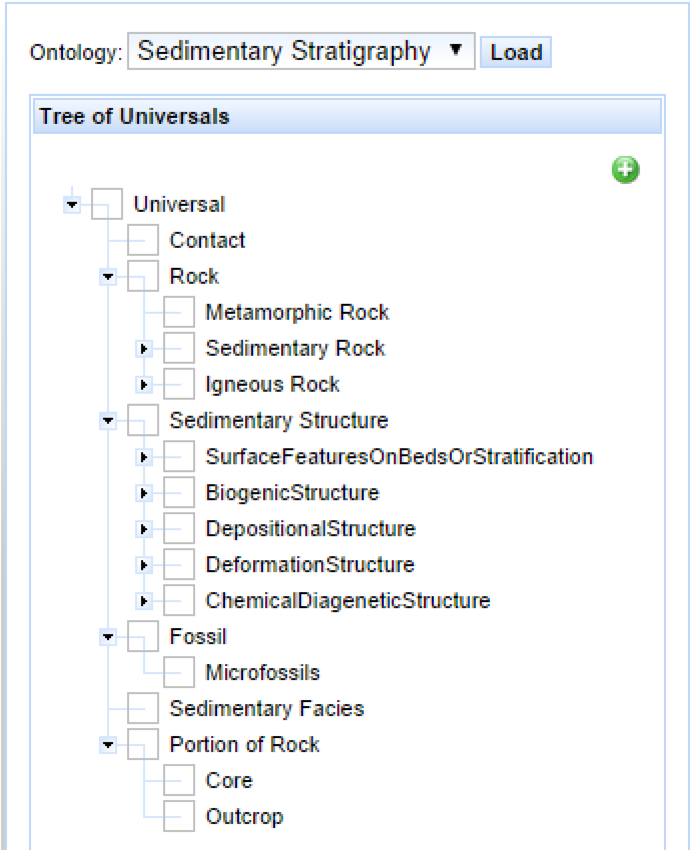


Figure 32 Partial view of the domain ontology.

Rock is considered as an amount of matter because it represents individuals that lack individuation and counting principles. In our domain ontology, it is represented by Quantity, even if UFO considers that Quantities represent "portions" of matter and, therefore, are countable objetcs. Since, in this particular implementation, the countable principle has no effect of inference and UFO does not offer a meta-type for uncountable objects, we have decided to use this approximation in our model. The Rock concept subsumes three direct specific subtypes, such as Metamorphic Rock, Sedimentary Rock and Igneous Rock. Additionally, Sedimentary Rock and Igneous Rock are further specialized in more specific subtypes.

Portion of Rock is considered as a Kind because it represents a rigid sortal that supplies principles of identity and individualization to its instances; in our domain ontology, it presents two specific subtypes, such as Core and Outcrop.

Sedimentary Facies is a functional complex (Kind) that is composed by other functional complexes (Kind). Therefore, the relations between Sedimentary Facies and its parts are defined as ComponentOf. The Sedimentary Facies parts comprise each of the specific subtypes of Sedimentary Structure, plus Fossil.

Sedimentary Structure is considered as a Category because it represents a dispersive universal that aggregates essential properties which are common to different Substance Sortals; in our domain ontology, it presents five direct specific subtypes, such as Surface Features on Beds or Stratification, Biogenic Structure, Depositional Structure, Deformation Structure and Chemical Diagenetic Structure, which are all defined as Kind. Additionally, each of them is further specialized in more specific subtypes.

Fossil is considered as a Kind; in our domain ontology, it may be specialized as Microfossils.

Contact is considered as a Relator because it is existentially dependent and acts as a mediating entity in the relationship among other entities.

Aiming to achieve an ontologically consistent structure for the relations among the concepts of the domain ontology, our tool enforces the ontology relations to be ontologically well founded; consequently, we have performed the identification of the set of the existing relations among the concepts of the Sedimentary Stratigraphy domain ontology accordingly using the support of the foundational ontology meta-types in order to ensure semantic consistency in the domain ontology.

Portion of Rock is constituted by Rock, as seen in Figure 33. Metamorphic Rock, Sedimentary Rock and Igneous Rock are Subkinds of Rock; consequently, Portion of Rock is constituted by Metamorphic Rock, Sedimentary Rock or Igneous Rock. In cascade effect, this is also true for the relations between Portion of Rock and every Subkind of Metamorphic Rock, Sedimentary Rock and Igneous Rock, their Subkinds, and so on, resulting in a total of 20 (twenty) ConstitutedBy Relations.

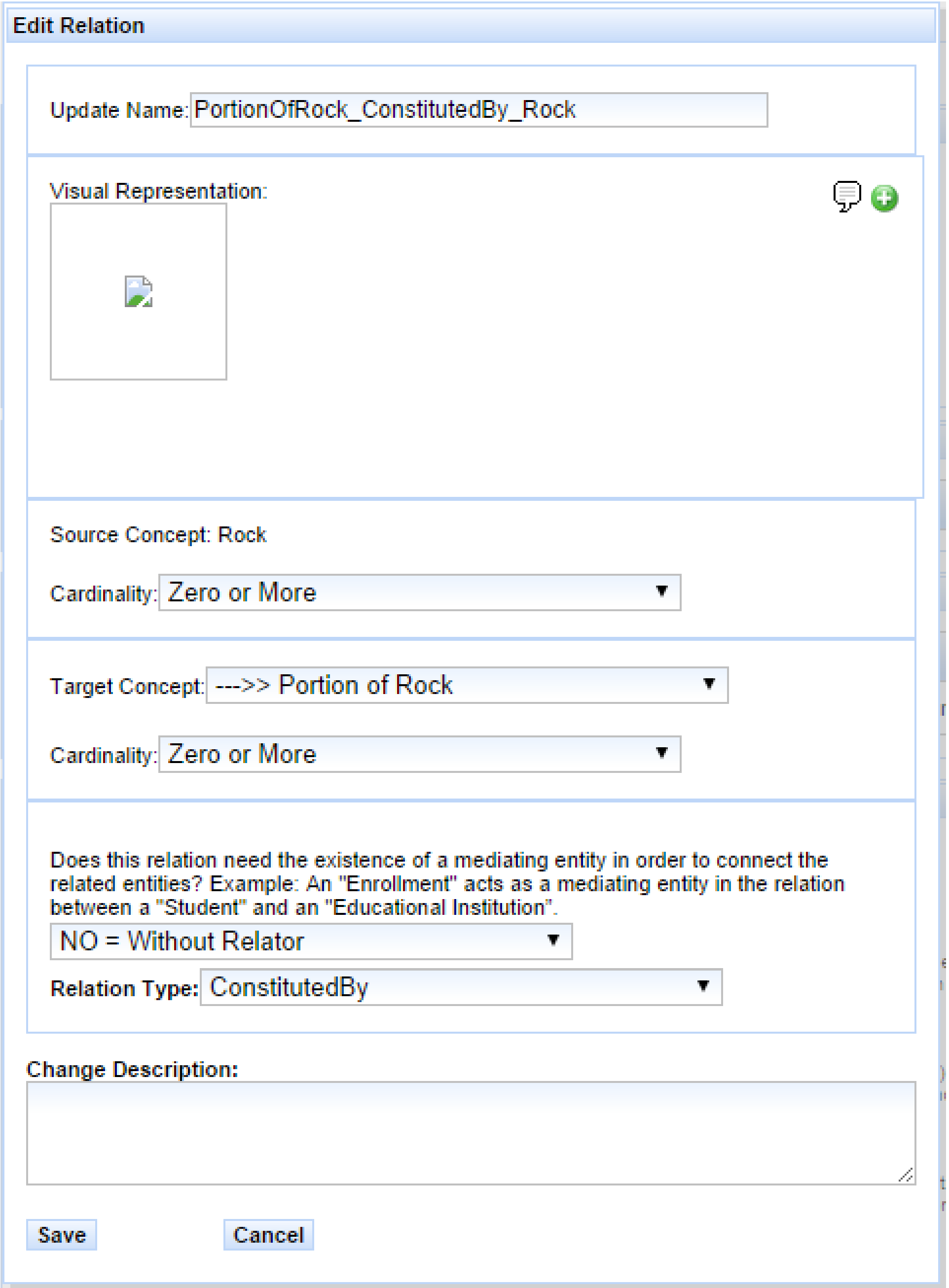


Figure 33 Portion of Rock is constituted by Rock.

Igneous Rock, which is a Subkind of Rock, cross cuts Sedimentary Rock, which is also a Subkind of Rock, as seen in Figure 34. In cascade effect, this is also true for the relations between Igneous Rock and every Subkind of Sedimentary Rock, their Subkinds, and so on, resulting in a total of 14 (fourteen) CrossCut Relations.

CrossCut is a specialization of the spatial relations, therefore we may associate a visual representation to this relation.

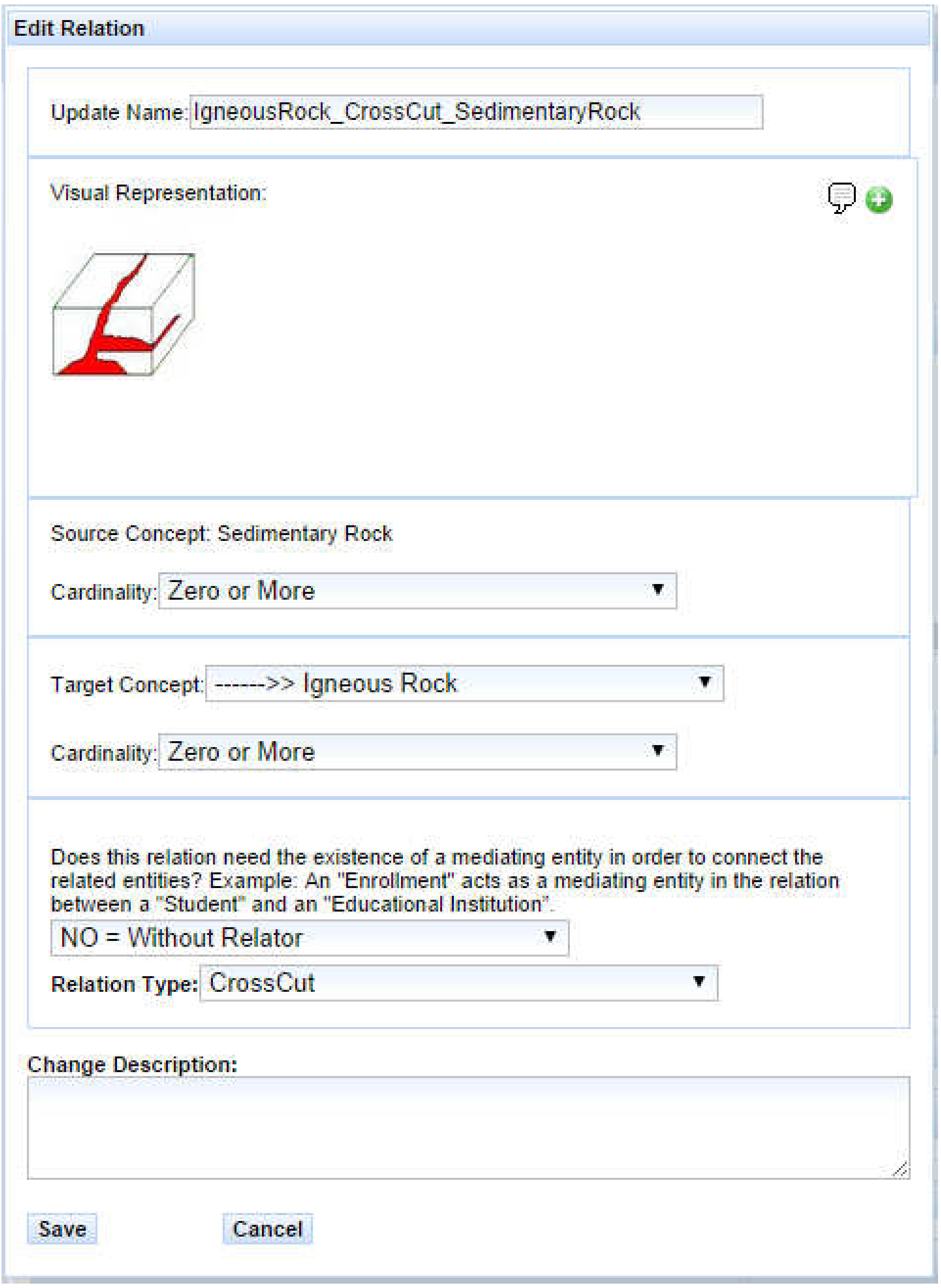


Figure 34 Igneous Rock cross cuts Sedimentary Rock.

Core, which is a Subkind of Portion of Rock, coexists with Outcrop, which is also a Subkind of Portion of Rock, as seen in Figure 35.

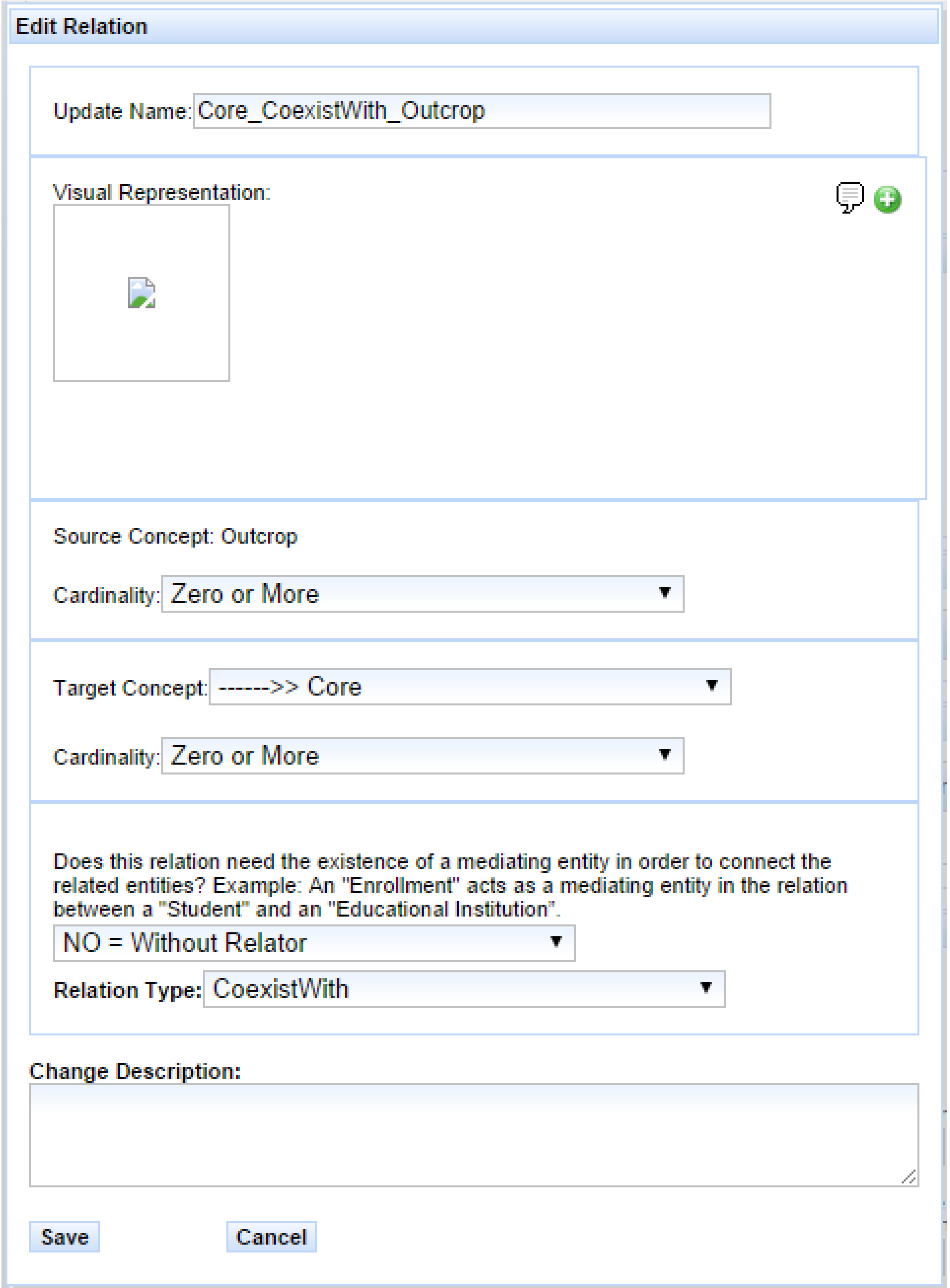


Figure 35 Core coexists with Outcrop.

Sedimentary Facies is constituted by Sedimentary Rock, as seen in Figure 36. In cascade effect, this is also true for the relations between Sedimentary Facies and every Subkind of Sedimentary Rock, their Subkinds, and so on, resulting in a total of 14 (fourteen) ConstitutedBy Relations.

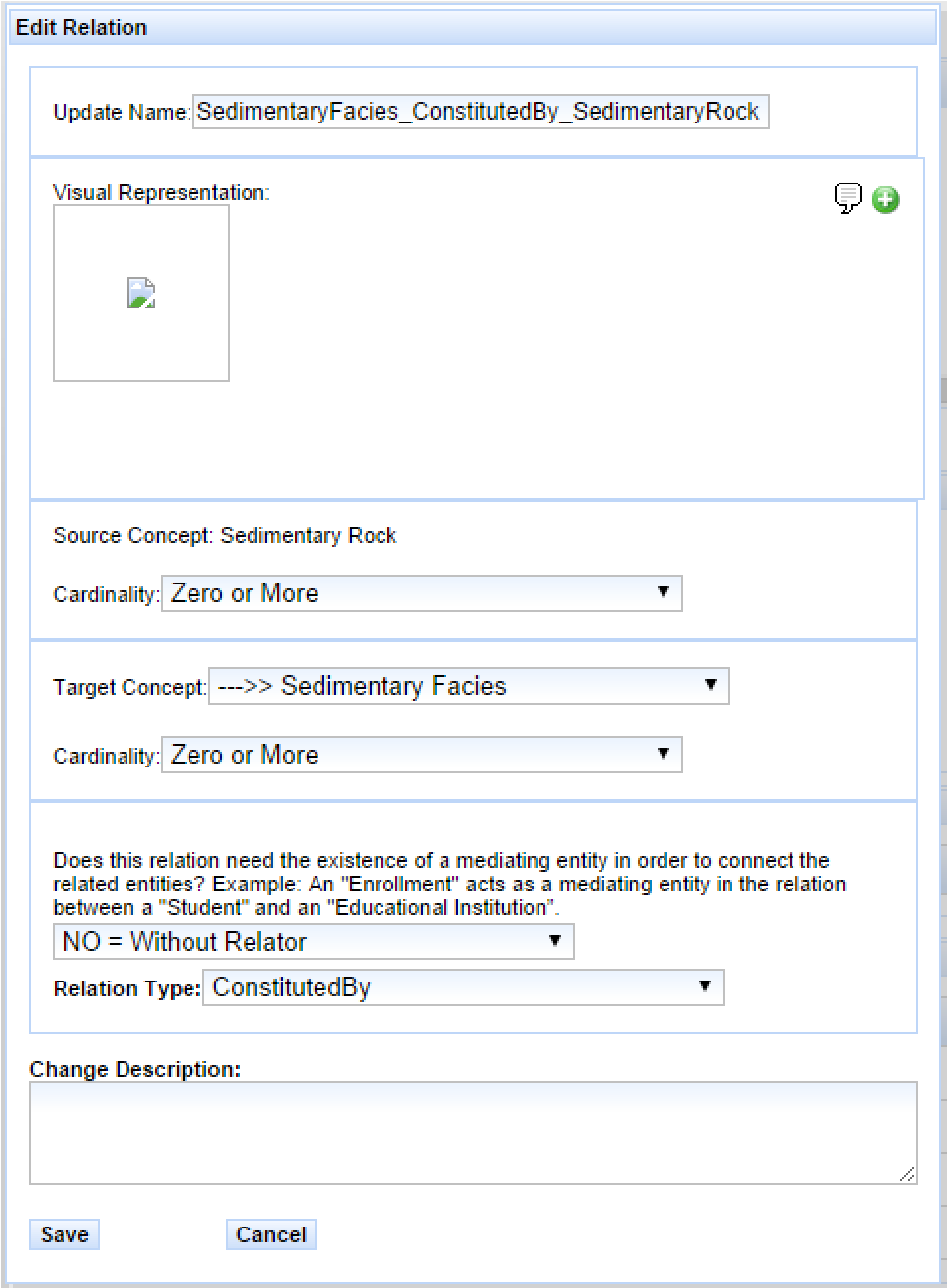


Figure 36 Sedimentary Facies is constituted by Sedimentary Rock.

Sedimentary Facies, which is a Kind, has Fossil, which is also a Kind; therefore, the relation between Sedimentary Facies and Fossil is defined as a ComponentOf Relation, as seen in Figure 37. Microfossils is Subkind of Fossil; consequently, Sedimentary Facies has Microfossils, which is also defined as a ComponentOf Relation.

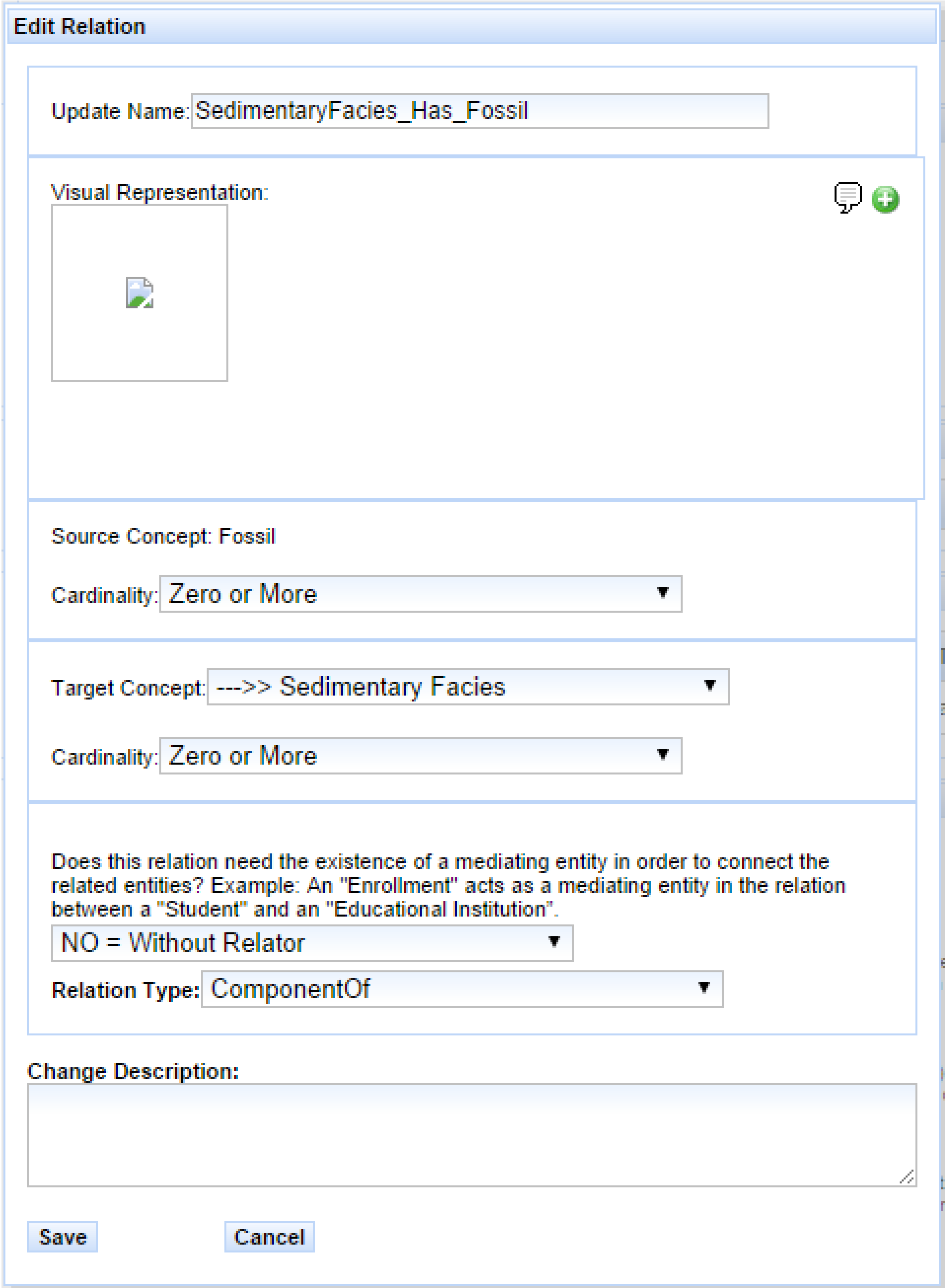


Figure 37 Sedimentary Facies has Fossil.

Sedimentary Facies, which is a Kind, has Sedimentary Structure, which is a Category; therefore, the relation between Sedimentary Facies and Sedimentary Structure is defined as a Formal Relation, as seen in Figure 38.

Surface Features on Beds or Stratification, Biogenic Structure, Depositional Structure, Deformation Structure and Chemical Diagenetic Structure, which are subtypes of Sedimentary Structure, are considered as Kind; consequently, the relations between Sedimentary Facies and its component parts, such as Sedimentary Facies has Surface Features on Beds or Stratification, Sedimentary Facies has Biogenic Structure, Sedimentary Facies has Depositional Structure, Sedimentary Facies has Deformation Structure and Sedimentary Facies has Chemical Diagenetic Structure, are all defined as ComponentOf Relations. In cascade effect, this is also true for the relations between

Sedimentary Facies and every Subkind of Surface Features on Beds or Stratification, Biogenic Structure, Depositional Structure, Deformation Structure and Chemical Diagenetic Structure, their Subkinds, and so on, resulting in a total of 190 (one hundred and ninety) ComponentOf Relations.

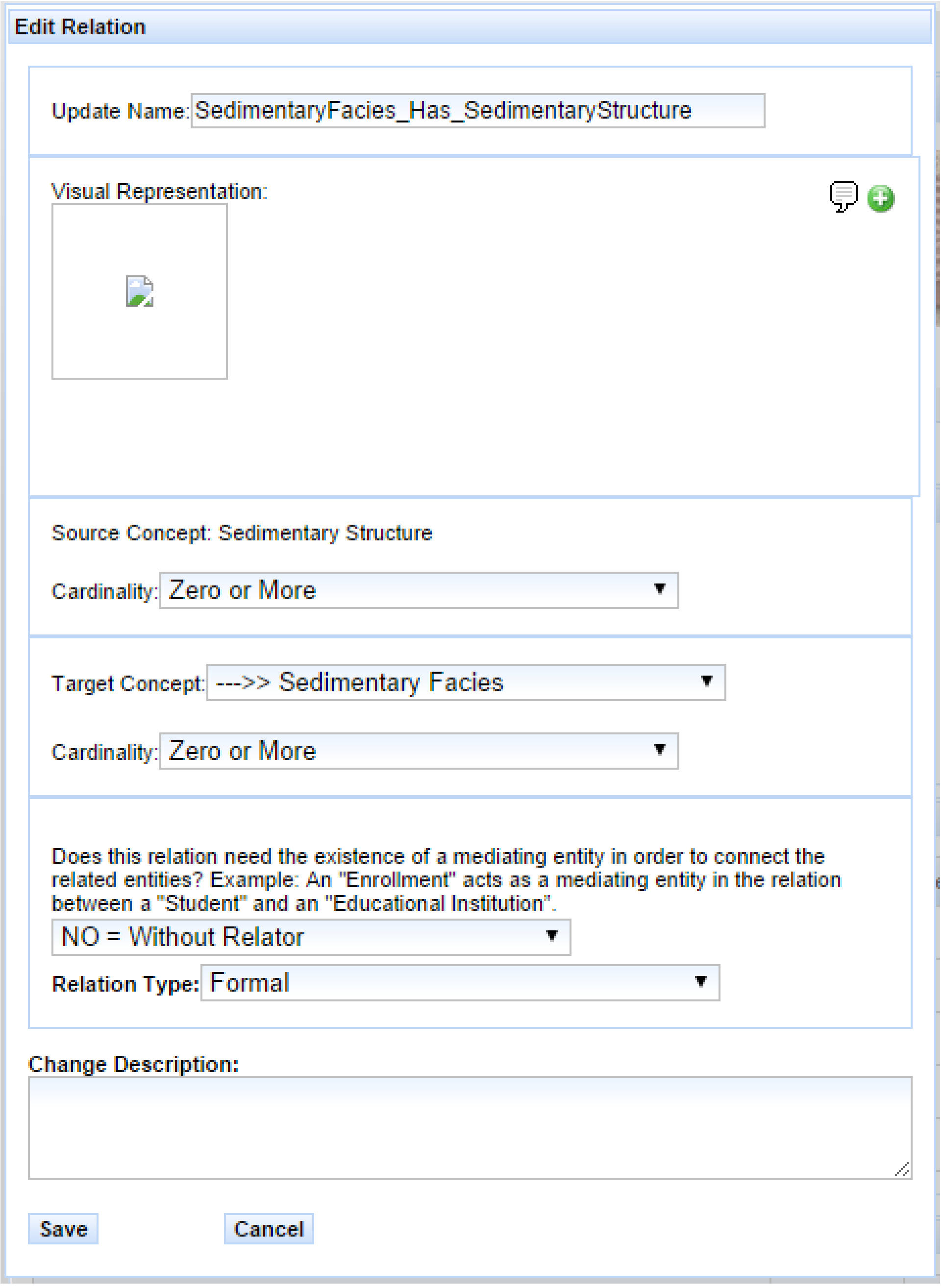


Figure 38 Sedimentary Facies has Sedimentary Structure.

Sedimentary Structure is inside of Sedimentary Rock, as seen in Figure 39. In cascade effect, this is also true for the relations between Sedimentary Structure and every Subkind of Sedimentary Rock, their Subkinds, and so on, resulting in a total of 14 (fourteen) InsideOf Relations.

InsideOf is a specialization of the spatial relations, therefore we may associate a visual representation to this relation.

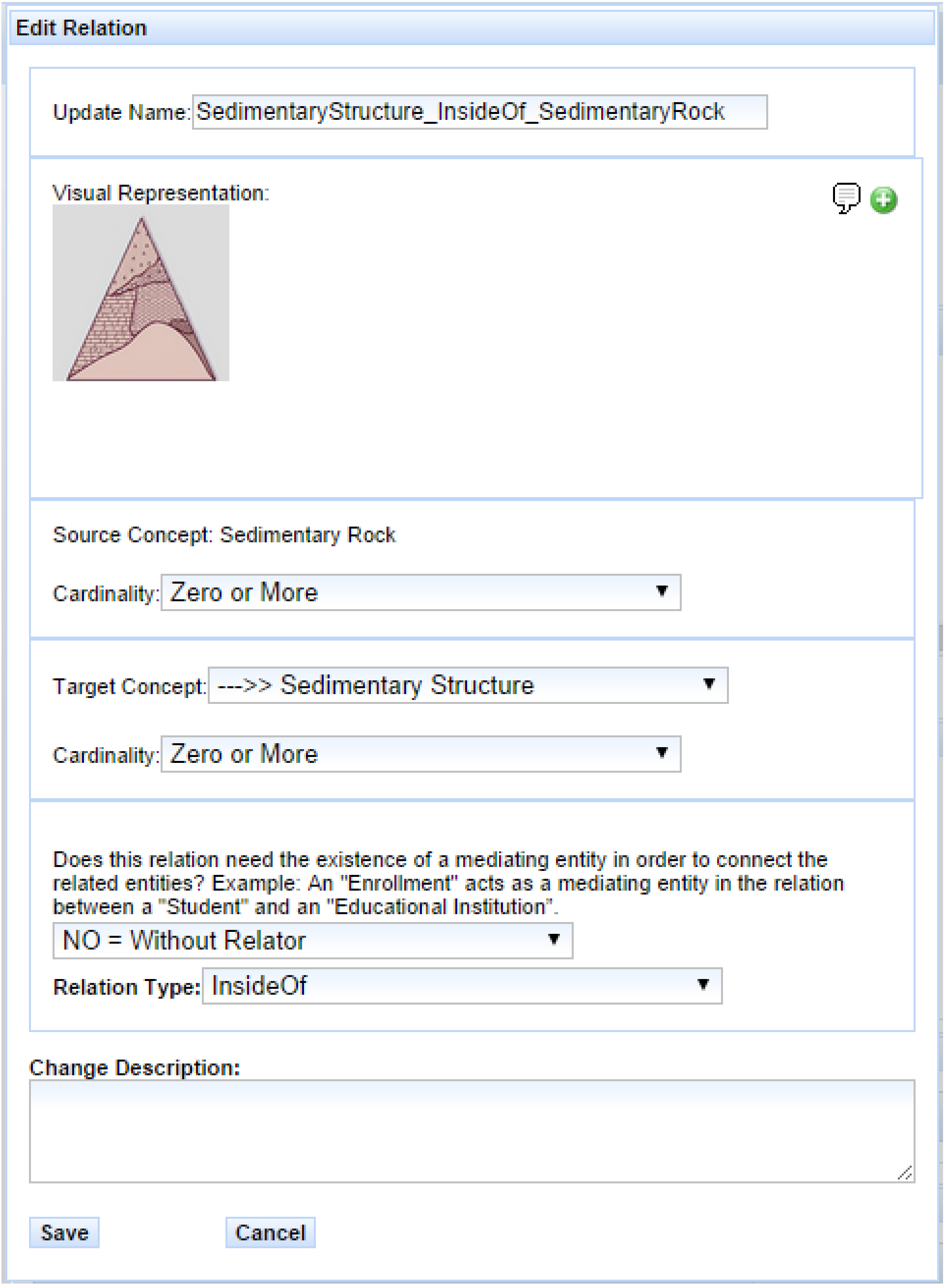


Figure 39 Sedimentary Structure is inside of Sedimentary Rock.

Sedimentary Facies is in contact with Sedimentary Facies; this relation needs the existence of a mediating entity, a Contact as a Relator, in order to connect the related entities. Therefore, the relation Sedimentary Facies is in contact with Sedimentary Facies is defined as a Material Relation, as seen in Figure 40.

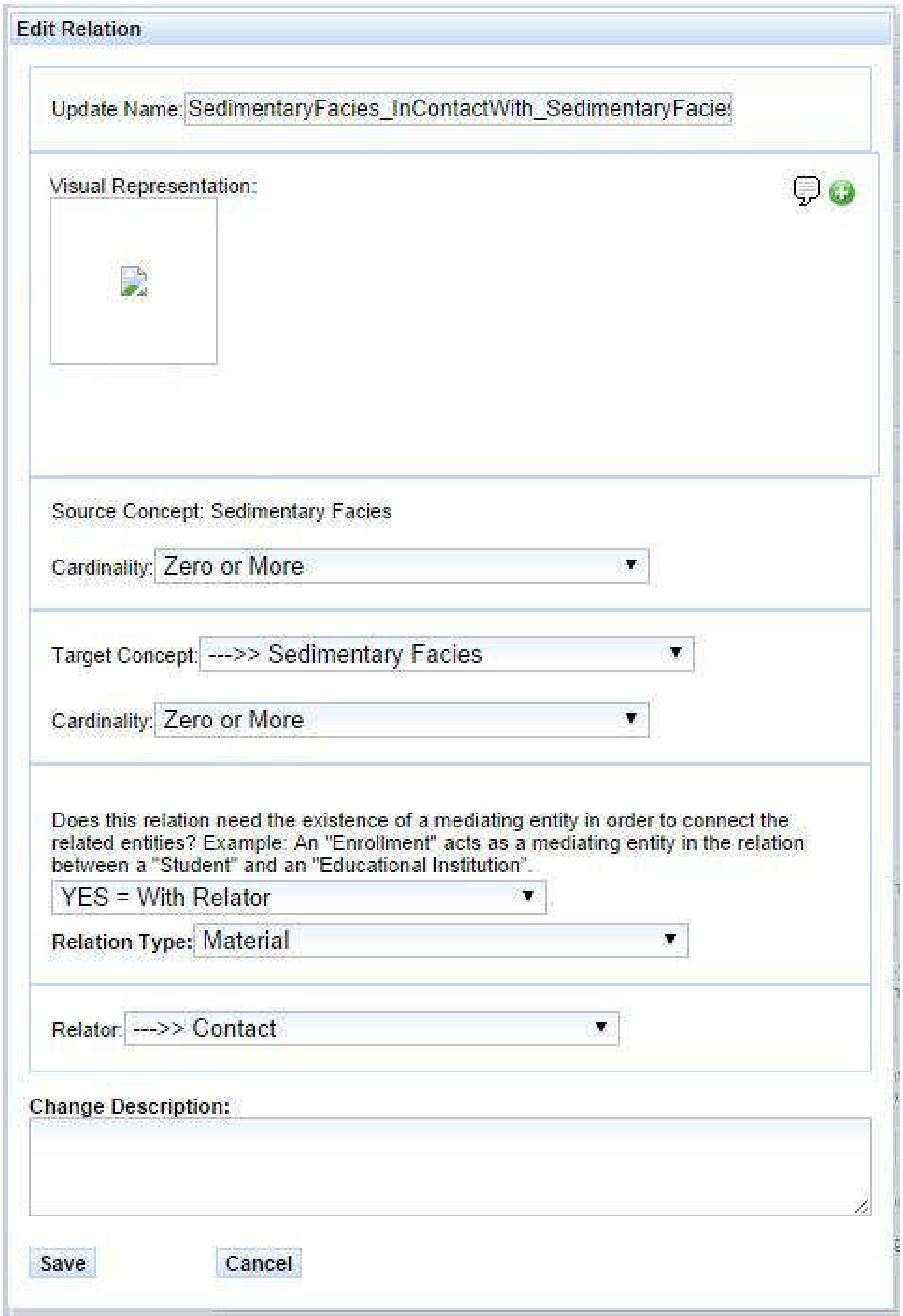


Figure 40 Sedimentary Facies is in Contact with Sedimentary Facies.

As a result from our case study, a total of 257 (two hundred fifty-seven) binary relations have been identified in the domain ontology, as seen in Table 3. From these relations, 256 (two hundred fifty-six) have been defined as Formal Relations, while one has been defined as Material Relation.

Table 3 Domain ontology relations.

	Formal	Material	Total
Relations	256	1	257

Among the Formal Relations, 35 (thirty-five) have been defined as Existential Relations, 192 (one hundred ninety-two) have been defined as Part-Whole Relations, 28 (twenty-eight) have been defined as Spatial Relations, while one relation has not been specialized, as seen in Table 4.

Table 4 Domain ontology Formal relations.

	Existential	Part-Whole	Spatial	Formal (not specialized)	Total
Relations	35	192	28	1	256

From the Existential Relations, one has been specialized as CoexistWith Relation, while 34 (thirty-four) have been specialized as ConstitutedBy Relations, as seen in Table 5. The specialized CoexistWith Relation has been created by relating two entities defined as Subkind of a Kind. Among the specialized ConstitutedBy Relations, one has been created by relating an entity defined as Kind and an entity defined as Quantity, while 33 (thirty-three) have been created by relating an entity defined as Kind and an entity defined as Subkind of a Quantity.

Table 5 Domain ontology Existential relations.

Relata/Relation	CoexistWith	ConstitutedBy	Total
Kind x Quantity	---	1	1
Kind x Subkind of Quantity	---	33	33
Subkind of Kind x Subkind of Kind	1	---	1
Total	1	34	35

From the Part-Whole Relations, 192 (one hundred ninety-two) have been specialized as ComponentOf Relations, as seen in Table 6. Among the specialized ComponentOf Relations, 6 (six) have been created by relating two entities defined as Kind, while 186 (one hundred eighty-six) have been created by relating an entity defined as Kind and an entity defined as Subkind of a Kind.

Table 6 Domain ontology Part-Whole relations.

Relata/Relation	ComponentOf	Total
Kind x Kind	6	6
Kind x Subkind of Kind	186	186
Total	192	192

From the Spatial Relations, 14 (fourteen) have been specialized as CrossCut Relations, while 14 (fourteen) have been specialized as InsideOf Relations, as seen in Table 7. Among the specialized CrossCut Relations, 14 (fourteen) have been created by relating two entities defined as Subkind of a Quantity. Among the specialized InsideOf Relations, 14 (fourteen) have been created by relating an entity defined as Category and an entity defined as Subkind of a Quantity.

Table 7 Domain ontology Spatial relations.

Relata/Relation	CrossCut	InsideOf	Total
Subkind of Quantity x Subkind of Quantity	14	---	14
Category x Subkind of Quantity	---	14	14
Total	14	14	28

In order to evaluate the improvements resulting from this research project, we defined some metrics for analyzing the results achieved by the application of the relations according to our proposals, comparing the case study original Sedimentary Stratigraphy domain ontology against the resulting domain ontology. Therefore, we defined metrics for scope, quantitative, visual knowledge, inference, assistance to the user, and ontological consistency analysis.

Considering the scope analysis metric, we observed that the original domain ontology presented 7 (seven) different types of relations, while the resulting domain ontology presents 17 (seventeen) different types of relations, as seen in Table 8.

Table 8 Metric: Scope.

	Relation types
Original ontology	7
Resulting ontology	17

Considering the quantitative analysis metric, we observed that the original domain ontology presented 15 (fifteen) relations, while the resulting domain ontology presents 257 (two hundred fifty-seven) relations, as seen in Table 9.

Table 9 Metric: Quantitative.

	Relations
Original ontology	15
Resulting ontology	257

Considering the visual knowledge analysis metric, we observed that the original domain ontology presented no relation with visual representation, while the resulting domain ontology presents 28 (twenty-eight) relations with visual representation, as seen in Table 10.

Table 10 Metric: Visual knowledge.

	Relations with visual representation
Original ontology	---
Resulting ontology	28

Considering both the inference and the assistance to the user analysis metrics, we observed that the original domain ontology presented no relation defined based on question provided by the system, while the resulting domain ontology presents all the 257 (two hundred fifty-seven) relations defined based on question provided by the system, as seen in Table 11.

Table 11 Metric: Inference / Assistance to the user.

	Relations defined based on question provided by the system
Original ontology	---
Resulting ontology	257

Also considering both the inference and the assistance to the user analysis metrics, we observed that the original domain ontology presented no relation defined based on the meta-types of the related entities, while the resulting domain ontology presents 192 (one hundred ninety-two) relations defined based on the meta-types of the related entities, as seen in Table 12.

Table 12 Metric: Inference / Assistance to the user.

	Relations defined based on the meta-types of the related entities
Original ontology	---
Resulting ontology	192

Considering the ontological consistency analysis metric, we observed that the original domain ontology presented 9 (nine) ontologically consistent relations, representing 60% (sixty percent) of the relations, while the resulting domain ontology presents 257 (two hundred fifty-seven) ontologically consistent relations, representing 100% (one hundred percent) of the relations, as seen in Table 13.

Table 13 Metric: Ontological consistency.

	Ontologically consistent relations
Original ontology	9 (60%)
Resulting ontology	257 (100%)

The system has been validated by a geologist, a user from the Sedimentary Stratigraphy, featuring the importance of the applicability of the ontology built in the real world due to the generation of a modeling with higher consistency; this benefit has been achieved as a result of the assistance provided by the system for helping users to select the precise relation type while creating the relationships between the domain concepts. Furthermore, the geologist emphasized that the system presents an interactive and clear language such that the user interaction with the system flows easily and smoothly. The user also underlined the gains obtained due to the relevance of the information added through the use of visual representation in the domain of geology.

The current state of the ontology can be understood as a refinement of the original ontology developed in previous stages of the Obaitá Project. After these evaluations, we have identified more clearly the benefits from this research project regarding the ontological consistency of the domain ontology relations. As a result, it was possible to extract by inference the meta-type of the relations, support the representation of visual objects and provide an environment for knowledge modeling for users that have only initial training in ontology representation formal languages. In the next section, we present our conclusions and some open possibilities for future improvement of this work.

12CONCLUSIONS

Ontology is a formal and explicit specification of a shared conceptualization. An important distinction that we have to emphasize is between foundational ontology and domain ontology. Foundational ontologies define the top-level domain-independent ontological categories, creating the general foundations for the domain-specific ontologies. Foundational ontologies provide the basic concepts allowing the construction of consistent domain-specific ontologies. Domain ontologies acquire the consensual knowledge, allowing it to be formalized and shared among a community of interest, minimizing the domain ambiguities.

Relationships are used to describe how the concepts are structured in the world. In ontologies all concepts are hierarchically defined, but there are other relationships that are definitional, giving identity to the concepts and meaning to the world.

Mereology provides the foundational basis for the analysis and representation of the relations between parts and wholes, and among parts that compose a whole. The conceptual theory of parthood must also consider the theory of wholes in order to take into account the relations that bind the parts of a whole together. The composite objects are not just an aggregation of entities, but complex entities suitably unified by proper binding relations.

The subsumption relationship allows structuring the taxonomy of concepts; besides the main hierarchical organization, other formal and material relations assist in structuring the domain and the conceptual definition. Formal relations hold between two or more entities directly without any further intervening individual. Material relations need another mediating entity; the relata of a material relation are mediated by individuals that are called relators.

In our study, we noticed that the analyzed ontology building applications do not provide both relationship ontological foundations and visual knowledge, and most of them require users to understand the main concepts about formal modeling in order to build applicable models.

Aiming the creation of more cohesive diagrams, the use of a foundational ontology plays an important role in achieving the common consensus, reducing the possibilities of interpretation on the domain through the semantic categorization of the concepts, properties and relations of the ontology. A foundational ontology aims to establish a basis in order to obtain consistency in the meaning negotiation on a conceptual model.

There are information domains where visual knowledge is crucial for its completeness. On these imagistic domains, visual pattern recognition is the initial process for capturing information and supporting problem solving. The use of visual communication, as images, allows a better understanding of the domain where the linguistic symbolic representation is not enough for explaining certain kind of knowledge. One of the goals of our research project is to provide components for representing visual knowledge and support imagistic domains in the definition of the relations among the ontology concepts. Thus, this tool aims to provide support to specialists that need to build a conceptual model of visual knowledge, taking advantage of the visual representation in order to help them to express the complete meaning of the concept relations.

As a result of our researches, our ontology building tool is constantly under improvement; we keep adding important features on its implementation, which many of them we do not find on most of the other tools. Thus, this specific research project has fundamental importance, continuing the evolution of an innovative tool focusing on enabling the ontology construction richer and more applicable for both academic and commercial purposes.

The benefits of the modeling of the relationships of the domain ontology have become explicit through the conceptual and intuitive approach added to the tool. The capabilities of the proposed metadata model have been assessed through a practical application case study by the construction of an ontology for describing sedimentary facies in the Sedimentary Stratigraphy domain. As a result from this research project, we have obtained a robust domain ontology, presenting precision in the specification of the meaning of the ontology concept relations.

The main contributions of this work include the definition of the ontological relations based on a set of metadata that provides specialized ontological constructs for creating the domain ontology relations, supporting an ontology building environment which is independent of the representation formal languages, providing assistance so that users do not need any previous knowledge in ontology representation in order to interact with the ontology. Some constructs are applied to support the ontological choices supported by the semantic expressivity of the foundational ontology primitives. Other constructs allow the association of visual representation in order to obtain a higher domain understanding. This work takes in consideration the importance of the ontological foundation and the visual knowledge as supporting instruments.

This project can be considered as a basis for future work in order to complement the ontological foundation of relations into the Obaitá ontology building tool, such as: creating a catalog of images for structuring the visual representation of the domain ontology relations; considering the possible specialization of the taxonomic relations; and considering the occurrence of temporal relations along with the existence of perdurants.

The definition of a catalog of images in order to better structure the visual representation for the ontology relations has to be worked accordingly along with geologists familiar with the domain.

Taxonomic relationship is based on highly general ontological notions drawn from philosophy, which are used to elicit and characterize the intended meaning of properties, classes, and relations making up an ontology. These aspects impose several constraints on the taxonomic relationships between concepts. The analysis of these constraints helps in evaluating and validating the choices made. Under this topic, we may deal with important issues such as inheritance.

In the literature, depending on the point of view, relations may be structured according to different kinds of classification; besides formal and material relations, there is another orthogonal category addressing the spatio-temporal relations. The foundational ontology has to be extended in order to consider the occurrence of temporal relations. Under this topic, we may deal with important issues such as the existence of perdurants.

REFERENCES

ABEL, M. et al. Projeto Petrographer - Construção de Ontologias de Domínio para Geologia de Petróleo. IN: SEMINÁRIO DE PESQUISA EM ONTOLOGIA NO BRASIL, 2008. **Proceedings...** [S.l.: s.n.], 2008.

ALLEN, G. A.; MARCH, S. T. A Critical Assessment of the Bunge-Wand-Weber Ontology for Conceptual Modeling. IN: WORKSHOP ON INFORMATION TECHNOLOGIES AND SYSTEMS, 2006, Milwaukee, WI, U.S.A. **Proceedings...** [S.l.: s.n.], 2006.

ARPÍREZ, J. C. et al. WebODE: A Scalable Workbench for Ontological Engineering. IN: THE FIRST INTERNATIONAL CONFERENCE ON KNOWLEDGE CAPTURE (K-CAP), 2001. **Proceedings...** [S.l.: s.n.], 2001.

ARTALE, A. et al. Part-Whole Relations in Object-Centered Systems: An Overview. **Data and Knowledge Engineering**, [S.l.: s.n.], v.20, n.3, p.347-383, 1996.

ARTALE, A.; KEET, C. M. Essential and Mandatory Part-Whole Relations in Conceptual Data Models. IN: THE 21ST INTERNATIONAL WORKSHOP ON DESCRIPTION LOGICS, 2008, Dresden. **Proceedings...** [S.l.: s.n.], 2008.

ARTALE, A.; KEET, C. M. Essential, Mandatory, and Shared Parts in Conceptual Data Models. In: Halpin, T. A., Proper, H. A., Krogstie, J. **Innovations in Information Systems modeling: Methods and Best Practices**, [S.l.], IGI Global, p.17-52, 2009.

BAIÔCO, G. et al. IT Service Management and Governance Modeling an ITSM Configuration Process: a Foundational Ontology Approach. IN: IFIP/IEEE INTERNATIONAL SYMPOSIUM ON INTEGRATED NETWORK MANAGEMENT-WORKSHOPS, 2009. **Proceedings...** [S.l.: s.n.], 2009.

BALA, P. S.; AGHILA, G. Relationship Based Reasoning. **International Journal of Computer Applications**, [S.l.: s.n.], v.36, n.9, 2011.

BEJAR, I. I.; CHAFFIN, R.; EMBRETSON, S. **Cognitive and Psychometric Analysis of Analogical Problem Solving**, New York: Springer-Verlag, 1991.

BENNETT, B.; CHAUDHRI, V. K.; DINESH, N. A Vocabulary of Topological and Containment Relations for a Practical Biological Ontology. IN: THE 11TH INTERNATIONAL CONFERENCE, COSIT, 2013. **Proceedings...** Scarborough, UK: Springer, v.8116, p.418-437, 2013.

BITTNER, T. Judgments about Spatio-Temporal Relations. IN: PRINCIPLES OF KNOWLEDGE REPRESENTATION AND REASONING-INTERNATIONAL

CONFERENCE, 2002. **Proceedings...** [S.l.], Morgan Kaufmann Publishers, p.521-532, 2002.

BITTNER, T.; DONNELLY, M. Logical Properties of Foundational Relations in Bio-Ontologies. **Artificial Intelligence in Medicine**, [S.l.: s.n.], v.39, p.197-216, 2007.

BITTNER, T.; DONNELLY, M.; SMITH, B. Individuals, Universals, Collections: On the Foundational Relations of Ontology. IN: THE 3RD INTERNATIONAL CONFERENCE ON FORMAL ONTOLOGY IN INFORMATION SYSTEMS. **Proceedings...** Torino, Italy: A. C. Varzi and L. Vieu (Eds.), 2004.

BORST, W. N. **Construction of Engineering Ontologies for Knowledge Sharing and Reuse**. Thesis (PhD), University of Tweenty, Centre for Telematica and Information Technology, The Netherlands, 1997.

CARBONERA, J. L. **Raciocínio sobre Conhecimento Visual: Um Estudo em Estratigrafia Sedimentar**. Dissertação (Mestrado em Ciência da Computação), Universidade Federal do Rio Grande do Sul, 2012.

CARDEÑOSA, J. et al. A New Knowledge Representation Model to Support Multilingual Ontologies. A Case Study. IN: IKE 2008 - THE INTERNATIONAL CONFERENCE ON INFORMATION AND KNOWLEDGE ENGINEERING, 2008, Nevada, U.S.A. **Proceedings...** [S.l.: s.n.], 2008.

CIBELLI, M.; NAPPI, M.; TUCCI, M. Content Image Retrieval: A New Query Paradigm Toward Analogy Based Indexing. **Lecture Notes in Computer Science 2184**, Berlin: Springer-Verlag, p.117-129, 2001.

COHN, A. G.; HAZARIKA, S. M. Spatio-Temporal Continuity in Geographic Space. IN: MEETING ON FUNDAMENTAL QUESTIONS IN GEOGRAPHICAL INFORMATION SCIENCE, 2001. **Proceedings...** [S.l.: s.n.], 2001.

DASTANI, M. A Formal Framework for Visual Representations. IN: THE 2ND INTERNATIONAL WORKSHOP ON THEORY OF VISUAL LANGUAGES, 1997, Capri, Italy. **Proceedings...** [S.l.: s.n.], 1997.

DOMINGUE, J.; MOTTA, E.; GARCIA, O. C. **Knowledge Modelling in WebOnto and OCML - A User Guide. Version 2.4**, [S.l.: s.n.], 1999.

DU, R. et al. Study on Ontology-Based Knowledge Construction of Petroleum Exploitation Domain. IN: INTERNATIONAL CONFERENCE ON ARTIFICIAL INTELLIGENCE AND COMPUTATIONAL INTELLIGENCE (AICI), 2010. **Proceedings...** [S.l.: s.n.], 2010.

ERICSSON, K.; SMITH, J. **Toward a General Theory of Expertise: Prospects and Limits**, Cambridge, UK: Cambridge University Press, 1991.

FERRARIO, R.; OLTRAMARI, A. Towards a Computational Ontology of the Mind. IN: THE 3RD INTERNATIONAL CONFERENCE ON FORMAL ONTOLOGY IN INFORMATION SYSTEMS (FOIS), 2004, Torino, Italy. **Proceedings...** [S.l.: s.n.], 2004.

FIORINI, S. R. **Similarity, Structure and Spaces: Representation of Part-Whole Relations in Conceptual Spaces.** Tese (Doutorado em Ciência da Computação), Universidade Federal do Rio Grande do Sul, 2014.

GANGEMI, A. et al. Understanding Top-Level Ontological Distinction. IN: IJCAI-2001, WORKSHOP ON ONTOLOGIES AND INFORMATION SHARING, 2001. **Proceedings...** [S.l.: s.n.], 2001.

GANGEMI, A. et al. Sweetening Ontologies with DOLCE. IN: KNOWLEDGE ENGINEERING AND KNOWLEDGE MANAGEMENT: ONTOLOGIES AND THE SEMANTIC WEB, 2002. **Proceedings...** [S.l.: s.n.], 2002.

GERSTL, P.; PRIBBENOW, S. Midwinters, End Games, and Body Parts: A Classification of Part-Whole Relations. **International Journal of Human-Computer Studies**, [S.l.: s.n.], 43, 865-889, 1995.

GÓMEZ-PÉREZ, A.; FERNÁNDEZ-LÓPEZ, M.; CORCHO, O. **Ontological Engineering: With Examples from the Areas of Knowledge Management, e-Commerce and the Semantic Web**, London, UK: Springer-Verlag, 2004.

GRENON, P. Spatio-Temporality in Basic Formal Ontology: SNAP and SPAN, Upper-Level Ontology, and Framework for Formalization. Part I. **IFOMIS Reports (ISSN 1611-4019)**, Germany: University of Leipzig, 2003a.

GRENON, P. The Formal Ontology of Spatio-Temporal Reality and its Formalization. IN: AAAI SPRING SYMPOSIUM ON THE FOUNDATIONS AND APPLICATIONS OF SPATIO-TEMPORAL REASONING, 2003, Stanford University, Palo Alto, California, U.S.A. **Proceedings...** [S.l.: s.n.], 2003b.

GRENON, P. **On Relations**. Thesis (PhD), University of Geneva, Dept. of Philosophy, Switzerland, 2007.

GRENON, P.; SMITH, B. SNAP and SPAN: Towards Dynamic Spatial Ontology. In: **Event-Oriented Approaches in Geographic Information Science: A Special Issue of Spatial Cognition and Computation**, [S.l.: s.n.], 4:1, 69-103, 2004.

GRUBER, T. R. A Translation Approach to Portable Ontology Specifications. **Knowledge Acquisition**, [S.l.: s.n.], 5(2), 199-220, 1993a.

GRUBER, T. R. Toward Principles for the Design of Ontologies Used for Knowledge Sharing. **International Journal of Human Computer Studies**, [S.l.: s.n.], 43(5/6), 907-928, 1993b.

GUARINO, N. Formal Ontology and Information Systems. IN: FORMAL ONTOLOGY IN INFORMATION SYSTEMS (FOIS), 1998. **Proceedings...** The Netherlands: IOS Press, 1998.

GUARINO, N. The Ontological Level: Revisiting 30 Years of Knowledge Representation. **Conceptual Modeling: Foundations and Applications**, [S.l.], Springer-Verlag, LNCS 5600, p.52-67, 2009.

GUARINO, N.; WELTY, C. A. Evaluating Ontological Decisions with OntoClean. **Communications of the ACM**, [S.l.: s.n.], v.45, n.2, 2002.

GUARINO, N.; WELTY, C. A. An Overview of OntoClean. In: **Handbook on Ontologies, International Handbooks on Information Systems**, [S.l.: s.n.], 2009.

GUIZZARDI, G. **Ontological Foundations for Structural Conceptual Models**, Enschede, The Netherlands: Universal Press, CTIT PhD Thesis Series, ISBN 90-75176-81-3, 2005.

GUIZZARDI, G. The Role of Foundational Ontologies for Conceptual Modeling and Domain Ontology Representation. IN: CONFERENCE ON DATABASES AND INFORMATION SYSTEMS, THE 7TH INTERNATIONAL BALTIC, 2006. **Proceedings...** [S.l.: s.n.], 2006.

GUIZZARDI, G. Ontological Foundations for Conceptual Part-Whole Relations: The Case of Collectives and Their Parts. **Advanced Information Systems Engineering**, Berlin/Heidelberg: H. Mouratidis and C. Rolland, Eds., Springer, v.6741, p.138-153, 2011.

GUIZZARDI, G.; FALBO, R. A.; GUIZZARDI, R. S. S. The Importance of Foundational Ontologies for Domain Engineering: The case of the Software Process Domain. **IEEE Latin America Transactions**, [S.l.: s.n.], v.6, n.3, 2008.

GUIZZARDI, G.; HERRE, H.; WAGNER, G. On the General Ontological Foundations of Conceptual Modeling. **Conceptual Modeling, ER, Lecture Notes in Computer Science**, [S.l.: s.n.], v.2503, p.65-78, 2002.

GUIZZARDI, G.; PIRES, L. F.; SINDEREN, M. J. V. On the Role of Domain Ontologies in the Design of Domain-Specific Visual Modeling Languages. IN: THE SECOND WORKSHOP ON DOMAIN SPECIFIC VISUAL LANGUAGES, THE 17TH ANNUAL ACM CONFERENCE ON OBJECT ORIENTED PROGRAMMING, SYSTEMS, LANGUAGES AND APPLICATIONS, 2002, Seattle, WA, U.S.A. **Proceedings...** [S.l.: s.n.], 2002.

GUIZZARDI, G.; WAGNER, G. On a Unified Foundational Ontology and some Applications of it in Business Modeling. IN: OPEN INTEROP WORKSHOP ON ENTERPRISE MODELLING AND ONTOLOGIES FOR INTEROPERABILITY, IN THE 16TH INTERNATIONAL CONFERENCE ON ADVANCES IN INFORMATION SYSTEMS ENGINEERING (CAiSE), 2004, Latvia. **Proceedings...** [S.l.: s.n.], 2004.

GUIZZARDI, G.; WAGNER, G. Towards Ontological Foundations for Agent Modelling Concepts Using the Unified Fundational Ontology (UFO). **Agent-Oriented Information Systems II**, [S.l.], Springer, 2005.

GUIZZARDI, G.; WAGNER, G. What's in a Relationship: An Ontological Analysis. IN: THE 27TH INTERNATIONAL CONFERENCE ON CONCEPTUAL MODELING, 2008, Barcelona. **Proceedings...** [S.l.], Springer Verlag, LNCS 5231, 2008.

GUIZZARDI, G.; WAGNER, G. Using the Unified Foundational Ontology (UFO) as a Foundation for General Conceptual Modeling Languages. **Theory and Applications of Ontology: Computer Applications**, [S.l.], Springer, p.175-196, 2010.

GUIZZARDI, R. S. S. et al. Towards an Ontological Account of Agent-Oriented Goals. **Software Engineering for Multi-Agent Systems V**, [S.l.], Springer, 2007.

HELLER, B.; HERRE, H. Ontological Categories in GOL. **Axiomathes**, [S.l.], Springer, v.14, i.1, p.57-76, 2004.

HERRE, H. et al. General Formal Ontology (GFO) - Part I: Basic Principles. Version 1.0, **Onto-Med Report No. 8**, Germany: Institute of Medical Informatics, Statistics and Epidemiology, University of Leipzig, 2006.

HORRIDGE, M. et al. **A Practical Guide to Building OWL Ontologies Using Protégé 4 and CO-ODE Tools**, UK: University of Manchester, Edition 1.1, 2007.

KEET, C. M.; ARTALE, A. Representing and Reasoning Over a Taxonomy of Part-Whole Relations. **Applied Ontology**, [S.l.: s.n.], 3(1-2), 91-110, 2008.

KNAUFF, M.; JOHNSON-LAIRD, P. N. Visual Imagery Can Impede Reasoning. **Psychonomic Society, Memory and Cognition**, [S.l.: s.n.], v.30, n.3, p.363-371, 2002.

LENAT, D. et al. Cyc: Toward Programs with Common Sense. **Communications of the ACM**, [S.l.: s.n.], v.33, i.8, p.30-49, 1990.

LENAT, D.; GUHA, R. V. CYC: A Midterm Report. **AI Magazine**, [S.l.: s.n.], v.11, n.3, 1990.

LITTLE, E. G.; ROGOVA, G. L. Ontology Meta-Model for Building a Situational Picture of Catastrophic Events. IN: 7TH INTERNATIONAL CONFERENCE ON INFORMATION FUSION (FUSION), 2005. **Proceedings...** [S.l.: s.n.], 2005.

LORENZATTI, A. **Ontologia para Domínios Imagísticos: Combinando Primitivas Textuais e Pictóricas**. Dissertação (Mestrado em Ciência da Computação), Universidade Federal do Rio Grande do Sul, 2010.

LORENZATTI, A. et al. Ontological Primitives for Visual Knowledge. **SBIA 2010, LNAI 6404**, Berlin Heidelberg: Springer-Verlag, p.1-10, 2010.

MASOLO, C. et al. WonderWeb Deliverable D18. **Technical Report, CNR**, [S.l.: s.n.], 2003.

MASOLO, C. et al. Relational Roles and Qua-Individuals. IN: AAAI FALL SYMPOSIUM ON ROLES, AN INTERDISCIPLINARY PERSPECTIVE, 2005, Virginia, U.S.A. **Proceedings...** [S.l.: s.n.], 2005.

MASTELLA, L. S. et al. Cognitive Modelling of Event Ordering Reasoning in Imagistic Domains. IN: INTERNATIONAL JOINT CONFERENCE ON ARTIFICIAL INTELLIGENCE, 2005, Edinburgh, UK. **Proceedings...** [S.l.: s.n.], 2005.

MIZOGUCHI, R.; SANO, T.; KITAMURA, Y. An Ontology-Based Human Friendly Message Generation in a Multiagent Human Media System for Oil Refinery Plant Operation. IN: IEEE INTERNATIONAL CONFERENCE ON SYSTEMS, MAN, AND CYBERNETICS (SMC), 1999. **Proceedings...** [S.l.: s.n.], 1999.

MULLIGAN, K.; SMITH, B. A Relational Theory of the Act. **Topoi**, [S.l.: s.n.], v.5, i.2, p.115-130, 1986.

NECHES, R. et al. Enabling Technology for Knowledge Sharing. **AI Magazine**, [S.l.: s.n.], 12(3):36-56, 1991.

NILES, I.; PEASE, A. Origins of the IEEE Standard Upper Ontology. IN: THE IJCAI WORKSHOP ON THE IEEE STANDARD UPPER ONTOLOGY, 2001, Seattle, U.S.A. **Proceedings...** [S.l.: s.n.], 2001a.

NILES, I.; PEASE, A. Towards a Standard Upper Ontology. IN: THE INTERNATIONAL CONFERENCE ON FORMAL ONTOLOGY IN INFORMATION SYSTEMS, 2001. **Proceedings...** [S.l.: s.n.], 2001b.

NTF, THE NEON TECHNOLOGIES FOUNDATION. **NeOn Toolkit 1.2 Manual**. [S.l.: s.n.], 2007.

O'DONNELL, T. et al. Knowledge is Bliss: An Investigation into the Transparency of Bliss Symbol Strings Directed by a Person with Aphasia. **International Journal of Language and Communication Disorders**, [S.l.: s.n.], v.45, n.4, p.461-479, 2010.

OBERLE, D. et al. DOLCE ergo SUMO: On Foundational and Domain Models in the SmartWeb Integrated Ontology (SWIntO). **Web Semantics: Science, Services and Agents on the World Wide Web**, [S.l.: s.n.], v.5, i.3, p.156-174, 2007.

OBRST, L. Ontological Architectures. In: R. Poli, M. Healy, A. Kameas. **Theory and Applications of Ontology: Computer Applications**, The Netherlands: Springer, chapter 2, p.27-66, 2010.

ODELL, J. J. Six Different Kinds of Composition. In: **Advanced Object-Oriented Analysis and Design Using UML**, New York: Cambridge University Press, 1998.

ONTOPRISE. **How to Work with OntoEdit - User's Guide for OntoEdit Version 2.6,** Germany: Ontoprise GmbH, 2003.

PARTRIDGE, C. A Study in Ontology. **Technical Report 04/02, LADSEB-CNR**, Padova, Italy: June 2002a.

PARTRIDGE, C. The CEO Project: An Introduction. **Technical Report 07/02, LADSEB-CNR,** Padova, Italy: December 2002b.

PEASE, A.; NILES, I.; LI, J. Origins of the IEEE Standard Upper Ontology. IN: THE AAAI-2002 WORKSHOP ON ONTOLOGIES AND THE SEMANTIC WEB, July 28-August 1, 2002, Edmonton, Canada. **Proceedings...** [S.l.: s.n.], 2002.

PEIRCE, C. S. **The Charles S. Peirce Papers: Manuscript Collection in the Houghton Library**. Worcester, MA, U.S.A.: The University of Massachusetts Press, 1967.

RAJAGOPAL, P.; MASON, J. A. **Discrete Mathematics for Computer Science**. Canada: Saunders College, 1992.

RATIU, D. **Intentional Meaning of Programs**. Thesis (PhD), University of Munich, Germany, 2009.

RESCHER, N.; OPPENHEIM, P. Logical Analysis of Gestalt Concepts. **British Journal for the Philosophy of Science**, [S.l.: s.n.], n.6, p.89-106, 1955.

ROSEMANN, M.; GREEN, P. Developing a Meta Model for the Bunge-Wand-Weber Ontological Constructs. **Information Systems**, [S.l.], Elsevier, v.27, i.2, p.75-91, 2002.

ROSEMANN, M.; WYSSUSEK, B. Enhancing the Expressiveness of the Bunge-Wand-Weber Ontology. IN ELEVENTH AMERICAS CONFERENCE ON INFORMATION SYSTEMS, 2005, Omaha, Nebraska, U.S.A. **Proceedings...** [S.l.: s.n.], 2005.

SALAMAT, N.; ZAHZAH, E. H. Spatiotemporal Relations and Modeling Motion Classes by Combined Topological and Directional Relations Method, **ISRN Machine Vision**, [S.l.: s.n.], 2012.

SANTIN, C. E. **Construtos Ontológicos para Representação Simbólica de Conhecimento Visual**. Dissertação (Mestrado em Ciência da Computação), Universidade Federal do Rio Grande do Sul, 2007.

SIDER, T. Parthood. **The Philosophical Review**, [S.l.], Duke University Press, v.116, n.1, p.51-91, January 2007.

SILVA, L. A. L. et al. An Ontology-Based Approach for Visual Knowledge: Image Annotation and Interpretation. IN: THE 17TH BRAZILIAN SYMPOSIUM ON ARTIFICIAL INTELLIGENCE, 2004. **Proceedings...** [S.l.: s.n.], 2004.

SILVA, L. A. L. et al. Ontology-Based Annotation of Atomic and Abstract Petrographic Image Features. **Journal of the Brazilian Computer Society**, [S.l.: s.n.], 2005.

SIMONS, P. **Parts: A Study in Ontology**. Oxford: Clarendon Press, 1987a.

SIMONS, P. M. **Parts. An Essay in Ontology**. Oxford: Clarendon Press, 1987b.

SMITH, B.; GRENON, P. The Cornucopia of Formal-Ontological Relations. **Dialectica**, [S.l.], Wiley Online Library, v.58, n.3, p.279-296, 2004.

SMITH, D. Mereology without Weak Supplementation. **Australasian Journal of Philosophy**, [S.l.: s.n.], v.87, i.3, 2009.

SOTIRIOS, B. **SOWL: A Framework for Handling Spatio-Temporal Information in OWL**. Thesis (PhD), Technical University of Crete (TUC), Department of Electronic and Computer Engineering, Greece, 2011.

SOWA, J. F. **Knowledge Representation: Logical, Philosophical, and Computational Foundations**. Pacific Grove, CA: Brooks Cole Publishing Co., 2000.

STEPHENS, L. M.; CHEN, Y. F. Principles for Organizing Semantic Relations in Large Knowledge Bases. **IEEE Transactions on Knowledge and Data Engineering**, [S.l.: s.n.], v.8, n.3, 1994.

STUDER, R.; BENJAMINS, V. R.; FENSEL, D. Knowledge Engineering: Principles and Methods. **IEEE Transactions on Knowledge and Data Engineering**, [S.l.: s.n.], 1998.

TORRES, G. M. **Construção Colaborativa de Ontologias para Domínios Visuais Utilizando Fundamentação Ontológica**. Dissertação (Mestrado em Ciência da Computação), Universidade Federal do Rio Grande do Sul, 2012.

TUDORACHE, T. Representation and Management of Reified Relationships in Protégé. IN: PROTÉGÉ CONFERENCE, 2004, Bethesda, Maryland, **Proceedings...** [S.l.: s.n.], 2004.

ULLMAN, S. **Visual Routines**. Cambridge, MA, U.S.A., Massachusetts Institute of Technology, Artificial Intelligence Laboratory, 1984.

ULLMANN, S. **Semantics: An Introduction to the Science of Meaning**. Oxford, UK, Basil Blackwell, 1972.

VARZI, A. C. Parts, Wholes, and Part-Whole Relations: The Prospects of Mereotopology. **Data and Knowledge Engineering**, [S.l.: s.n.], v.20, n.3, p.259-286, 1996.

VARZI, A. C. Spatial Reasoning and Ontology: Parts, Wholes, and Locations. In: Aiello, M., Pratt-Hartmann, I. E., van Benthem, J. **Handbook of Spatial Logics**. Heidelberg: Springer, p.945-1038, 2007.

WAND, Y.; WEBER, R. Mario Bunge's Ontology as a Formal Foundation for Information Systems Concepts. In: P. Weingartner and G. J. W. Dorn. **Studies on Mario Bunge's Treatise.** Amsterdam, The Netherlands: Rodopi, 123-149, 1990.

WAND, Y.; WEBER, R. Research Commentary: Information Systems and Conceptual Modeling - A Research Agenda. **Information Systems Research**, [S.l.: s.n.], (13:4), p.363-376, 2002.

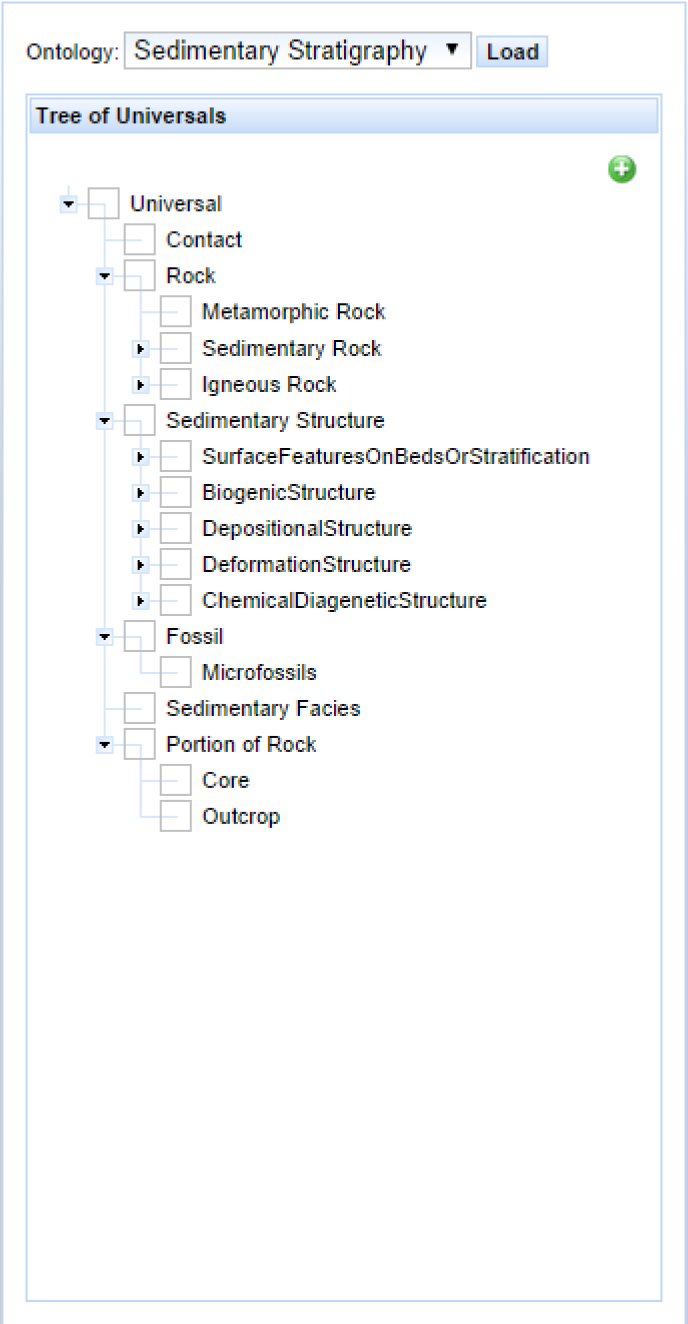
WEBER, R. **Ontological Foundations of Information Systems**. Melbourne: Coopers and Lybrand Research Methodology, 1997.

WINN, W. D.; HOLLIDAY, W. G. Design Principles for Diagrams and Charts. In: D. Jonassen. **The Technology of Text.** Englewood Cliffs, NJ, U.S.A.: Educational Technology Publications, v.1, p.277-299, 1982.

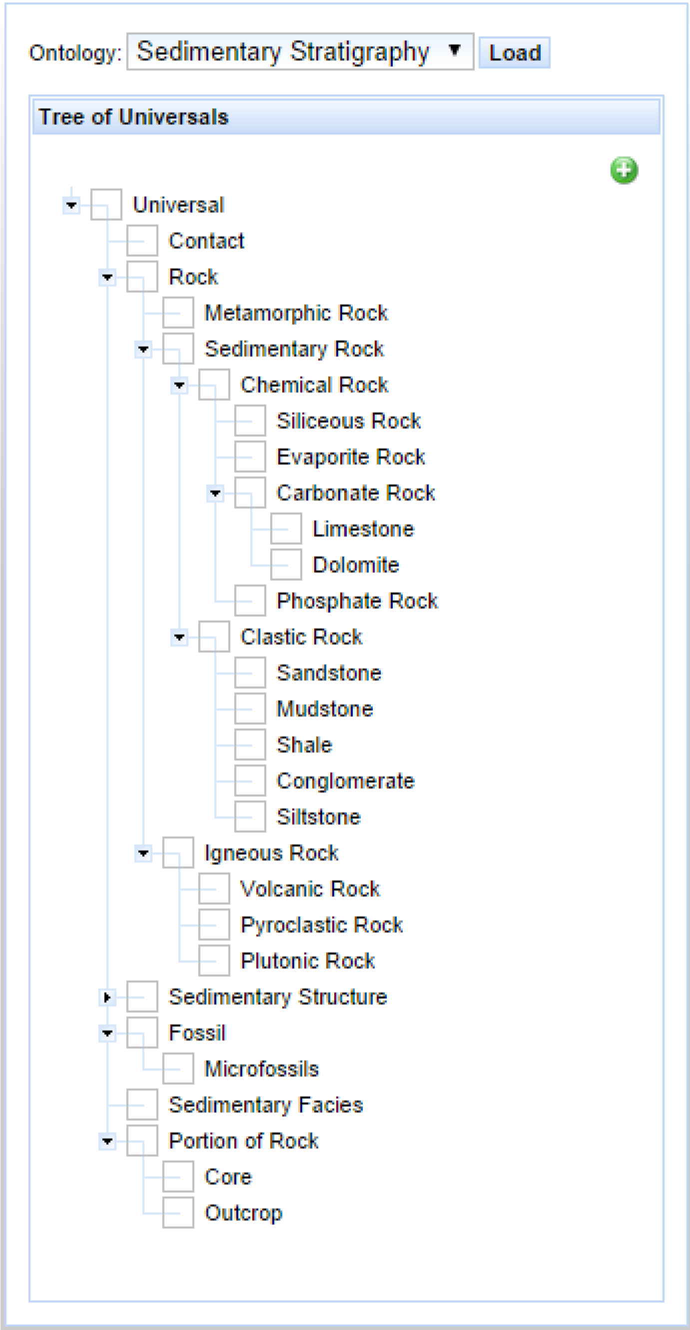
WINSTON, M. E.; CHAFFIN, R.; HERRMANN, D. A Taxonomy of Part-Whole Relations. **Cognitive Science**, [S.l.: s.n.], v.11, p.417-444, 1987.

APPENDIX A - SEDIMENTARY STRATIGRAPHY DOMAIN ONTOLOGY

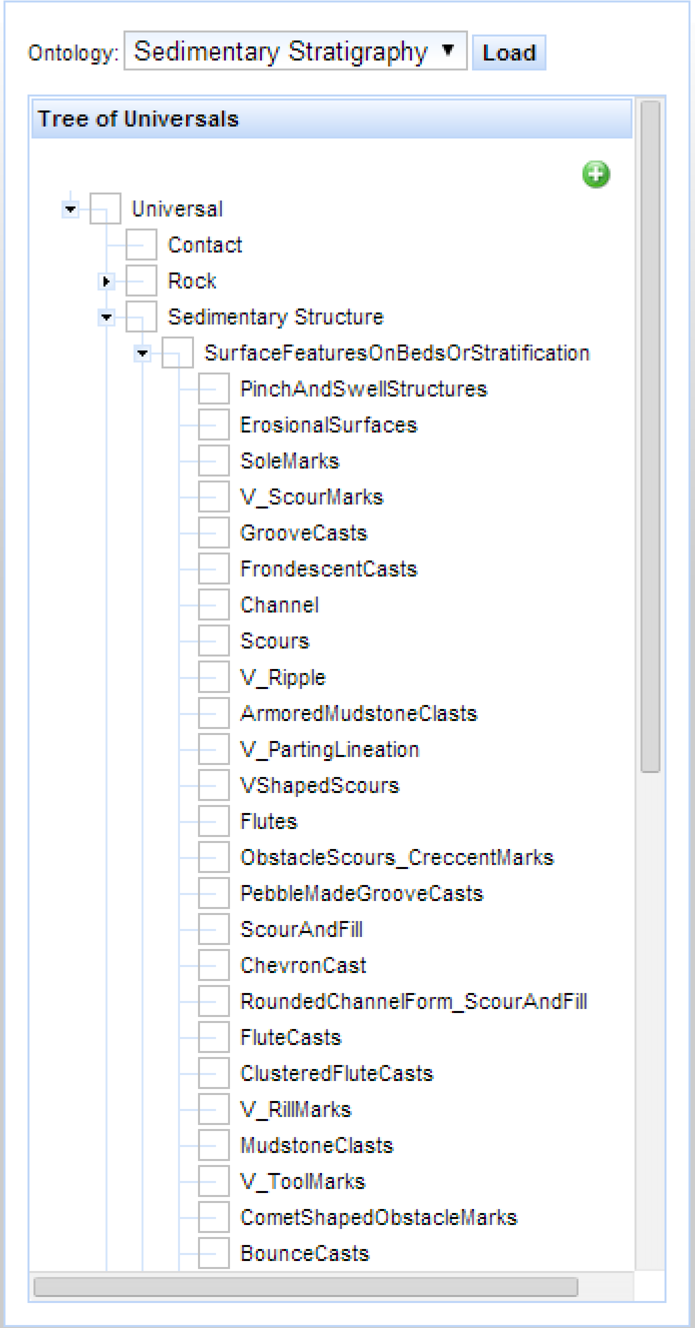
First level:



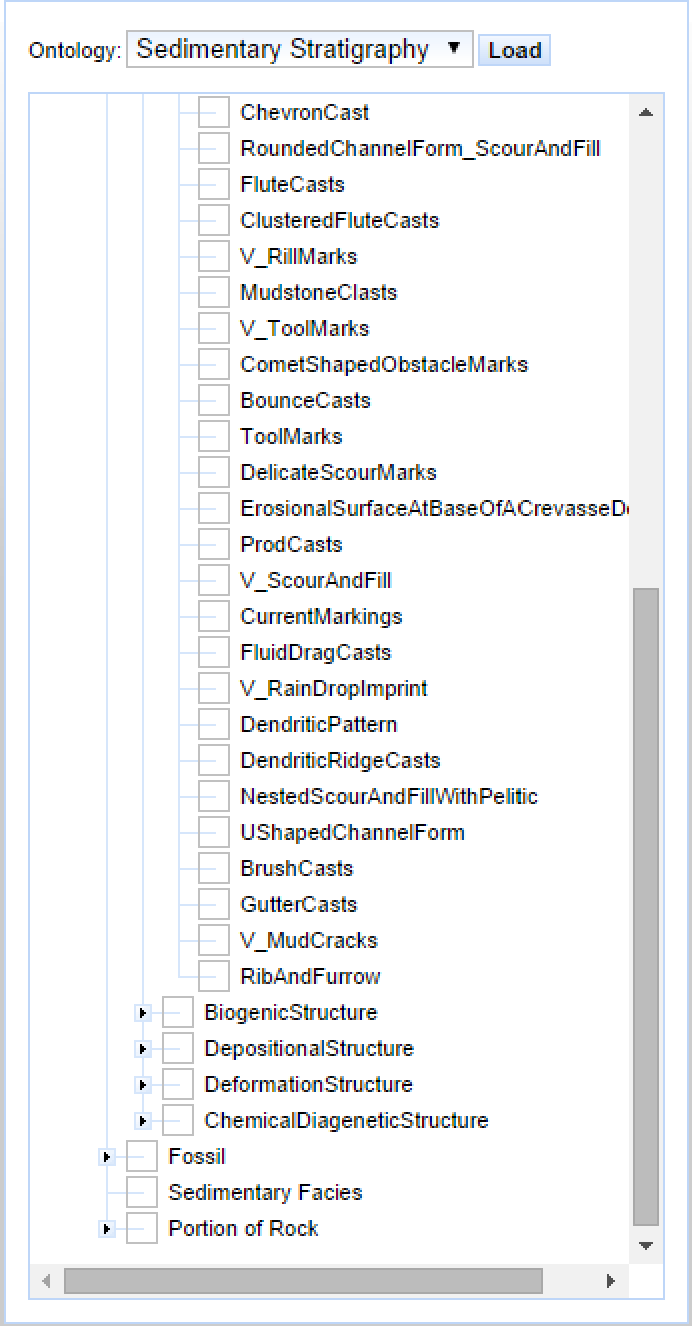
All levels (except Sedimentary Structure):



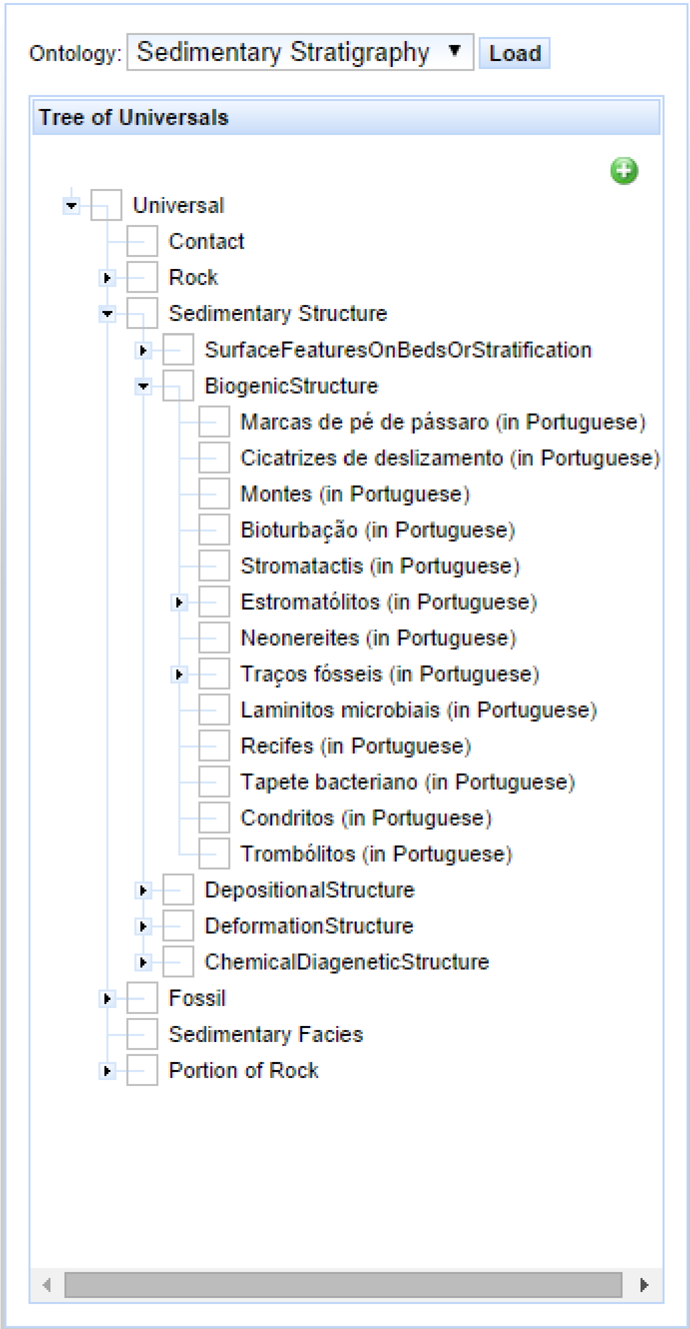
Sedimentary Structure / SurfaceFeaturesOnBedsOrStratification:



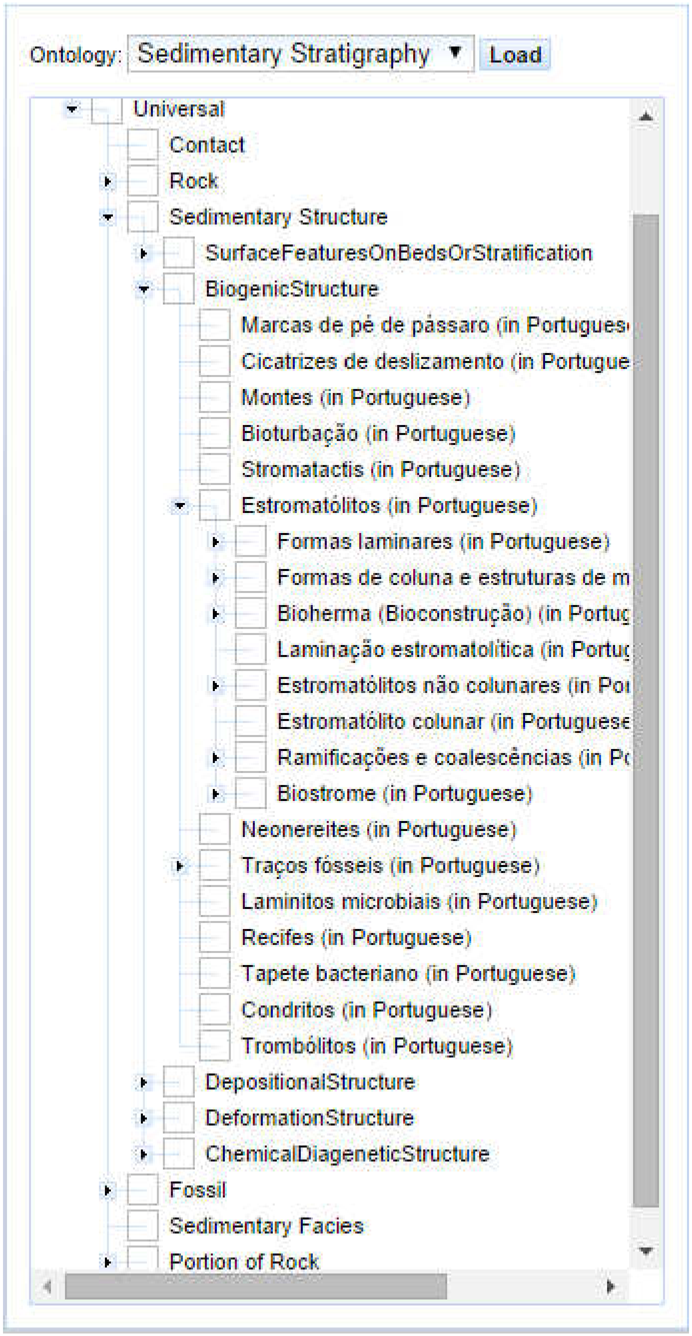
Sedimentary Structure / SurfaceFeaturesOnBedsOrStratification (continued):



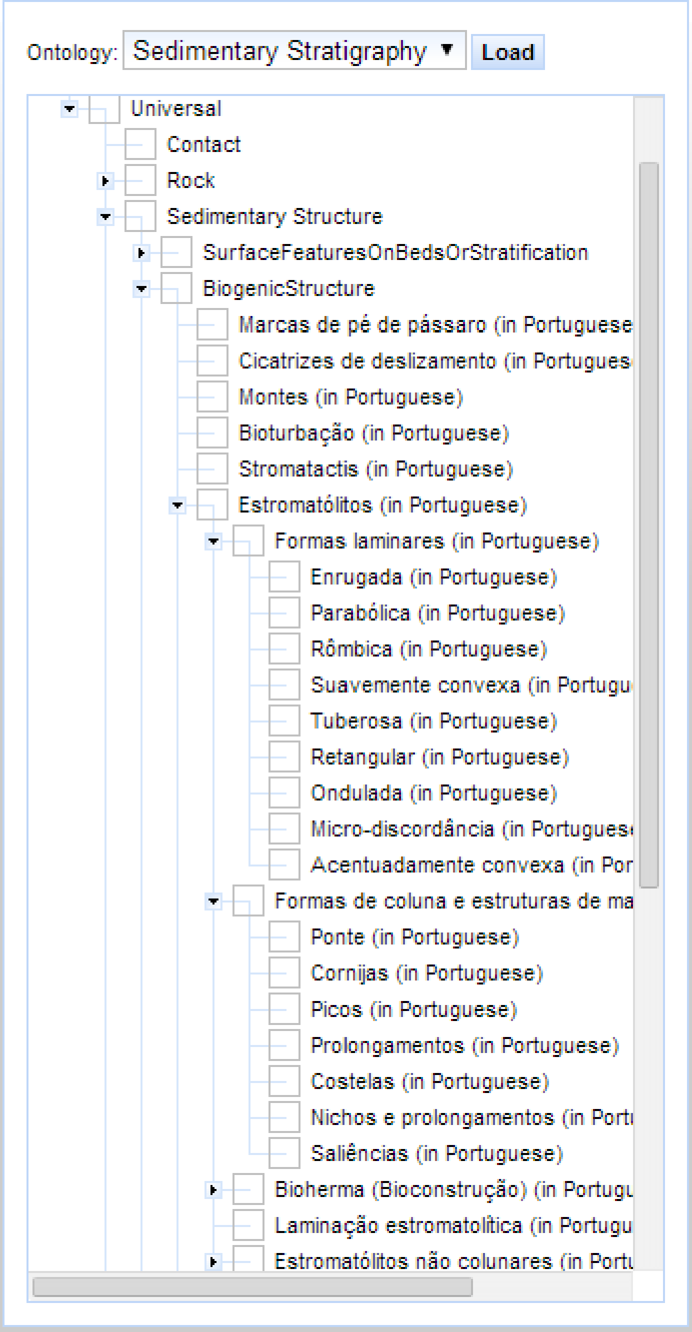
Sedimentary Structure / BiogeneticStructure:



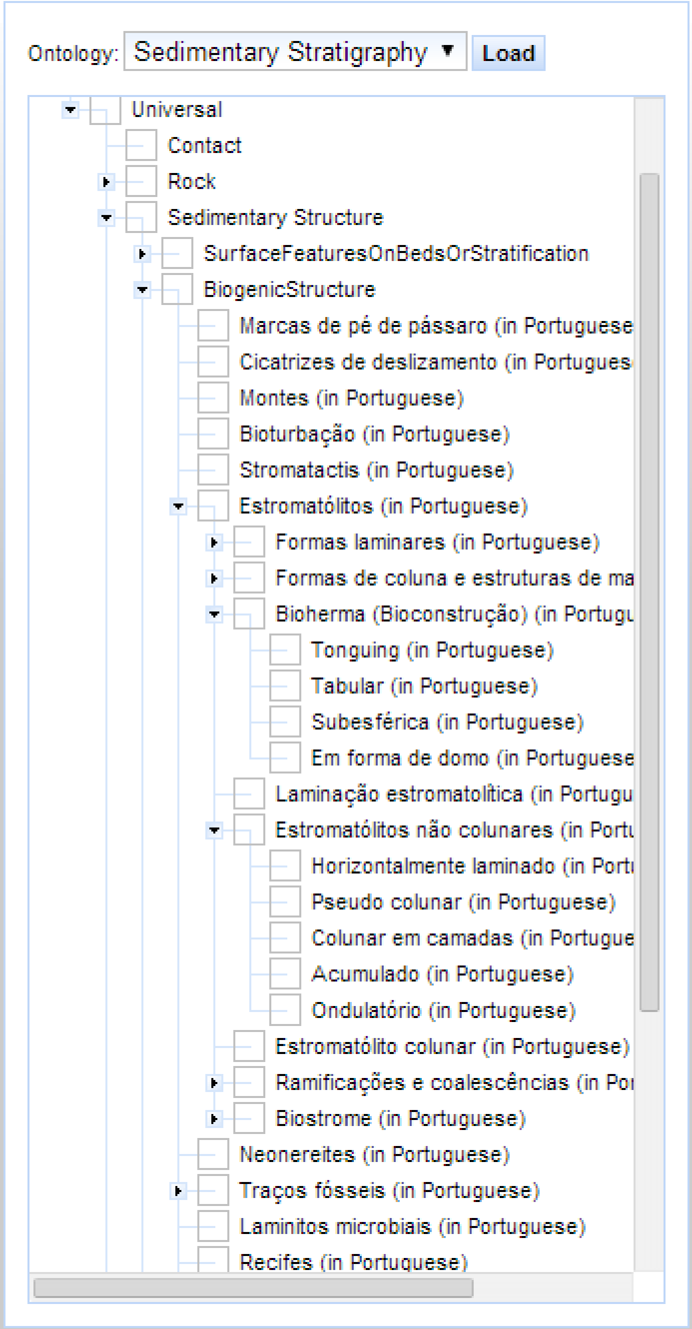
Sedimentary Structure / BiogeneticStructure / Estromatólitos (in Portuguese):



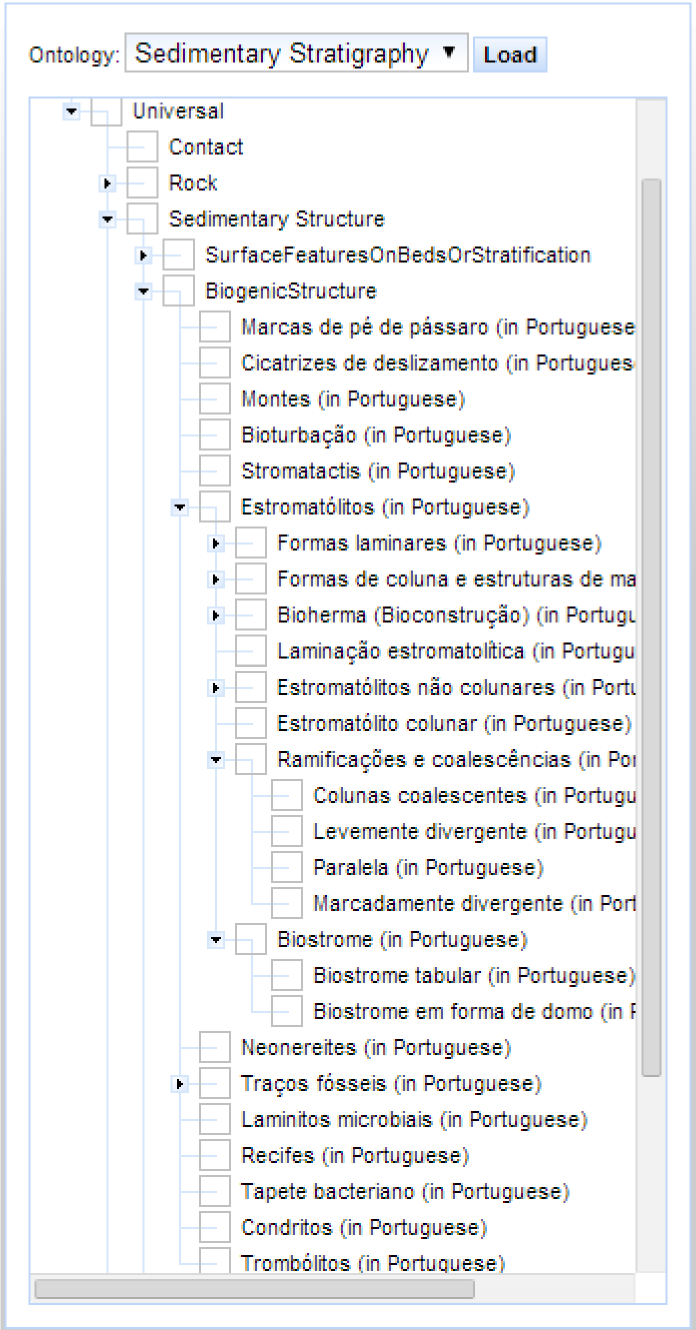
Sedimentary Structure / BiogeneticStructure / Estromatólitos (first and second sub-types):



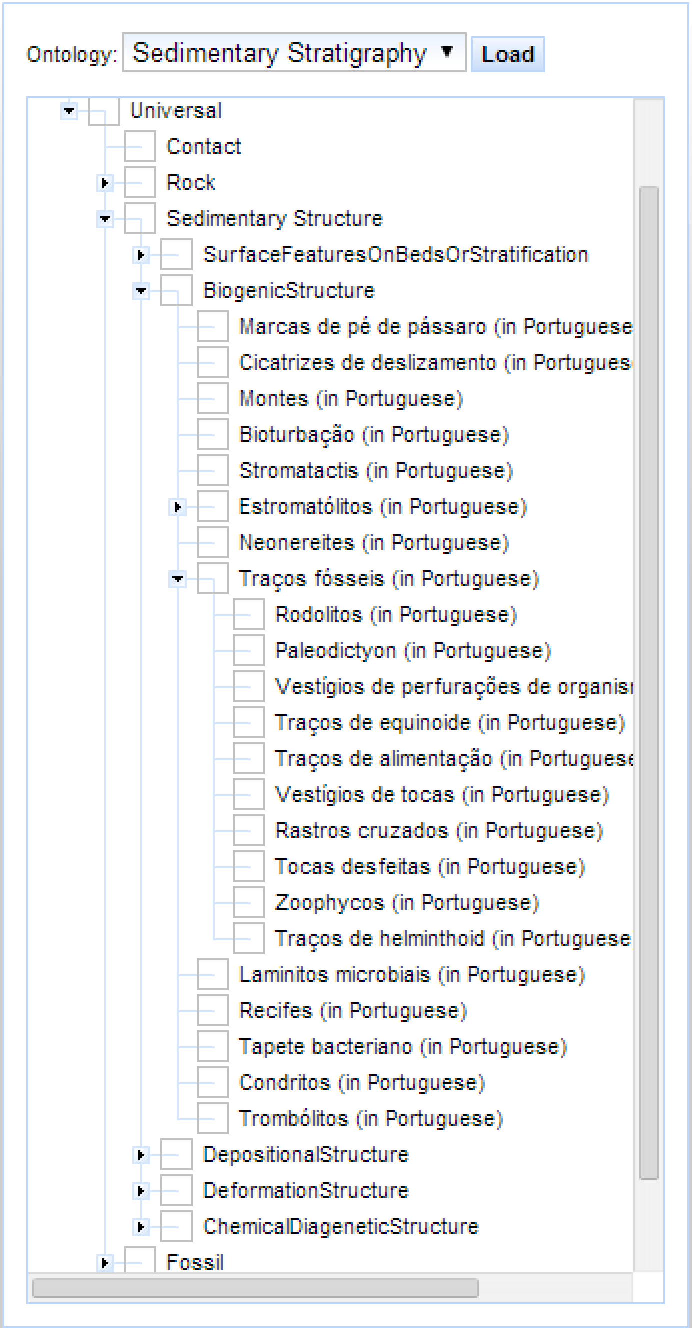
Sedimentary Structure / BiogeneticStructure / Estromatólitos (third and fourth sub-types):



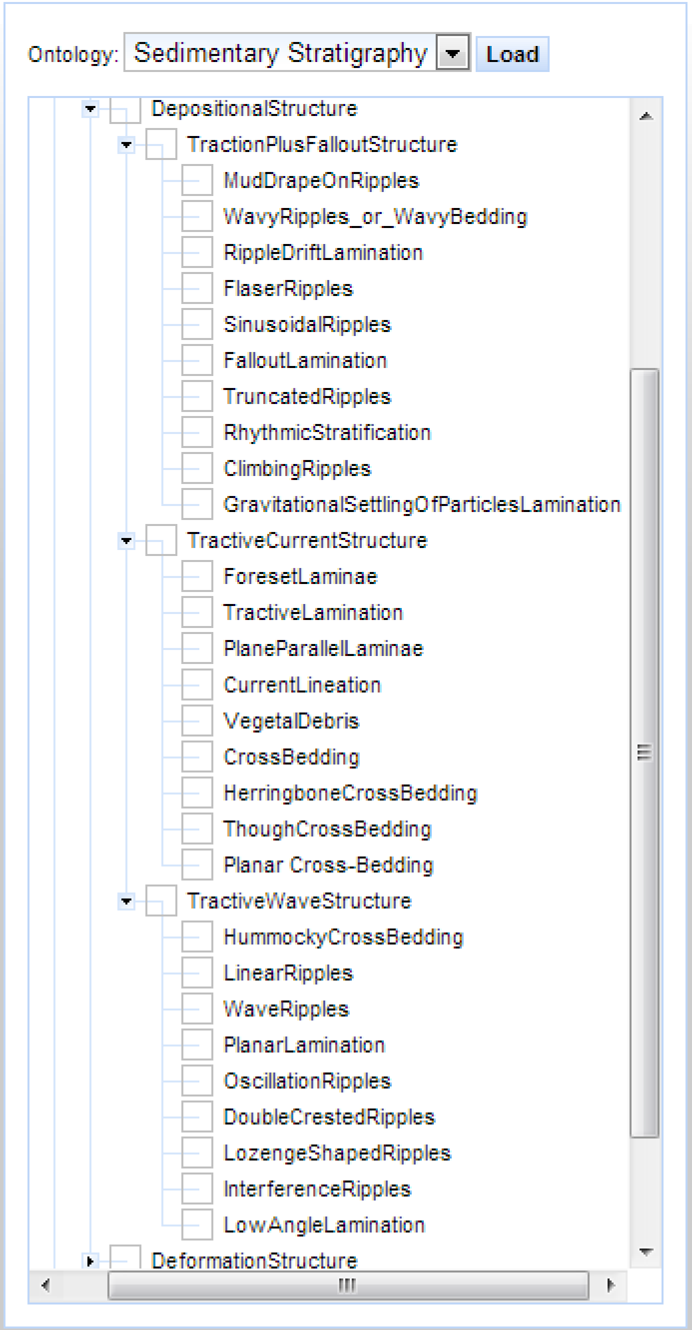
Sedimentary Structure / BiogeneticStructure / Estromatólitos (fifth and sixth sub-types):



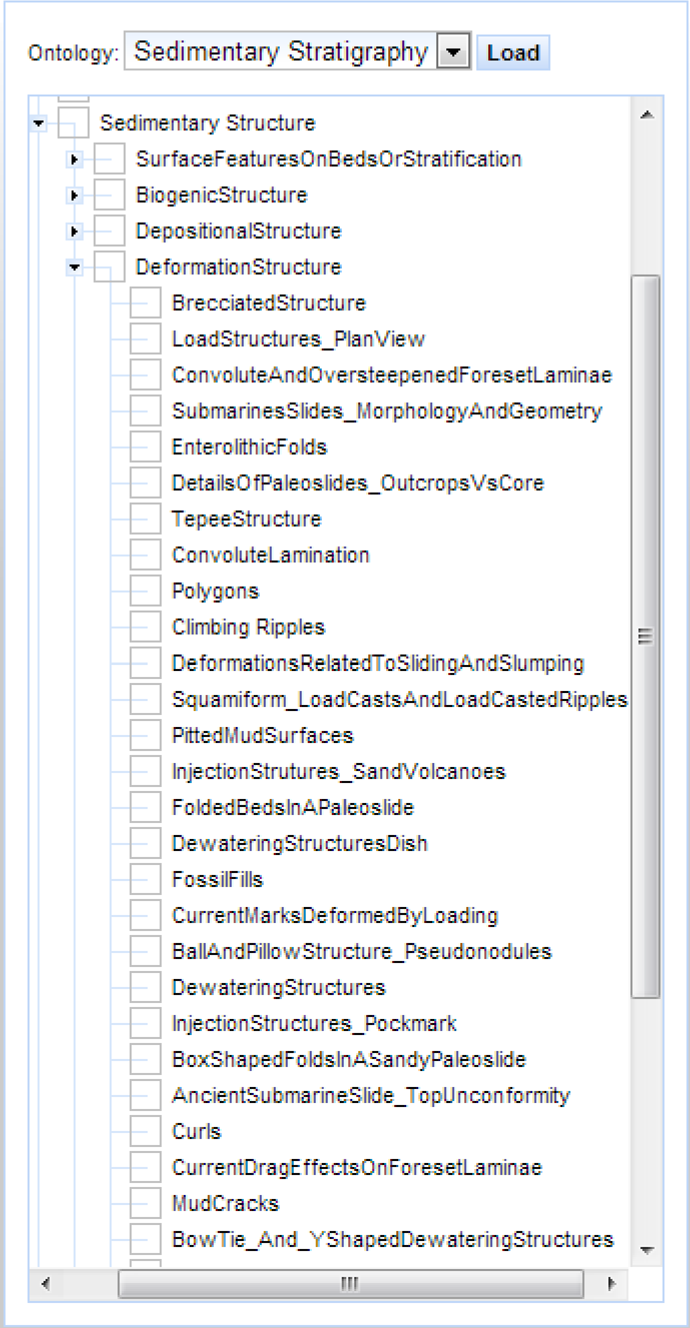
Sedimentary Structure / BiogeneticStructure / Traços fósseis (in Portuguese):



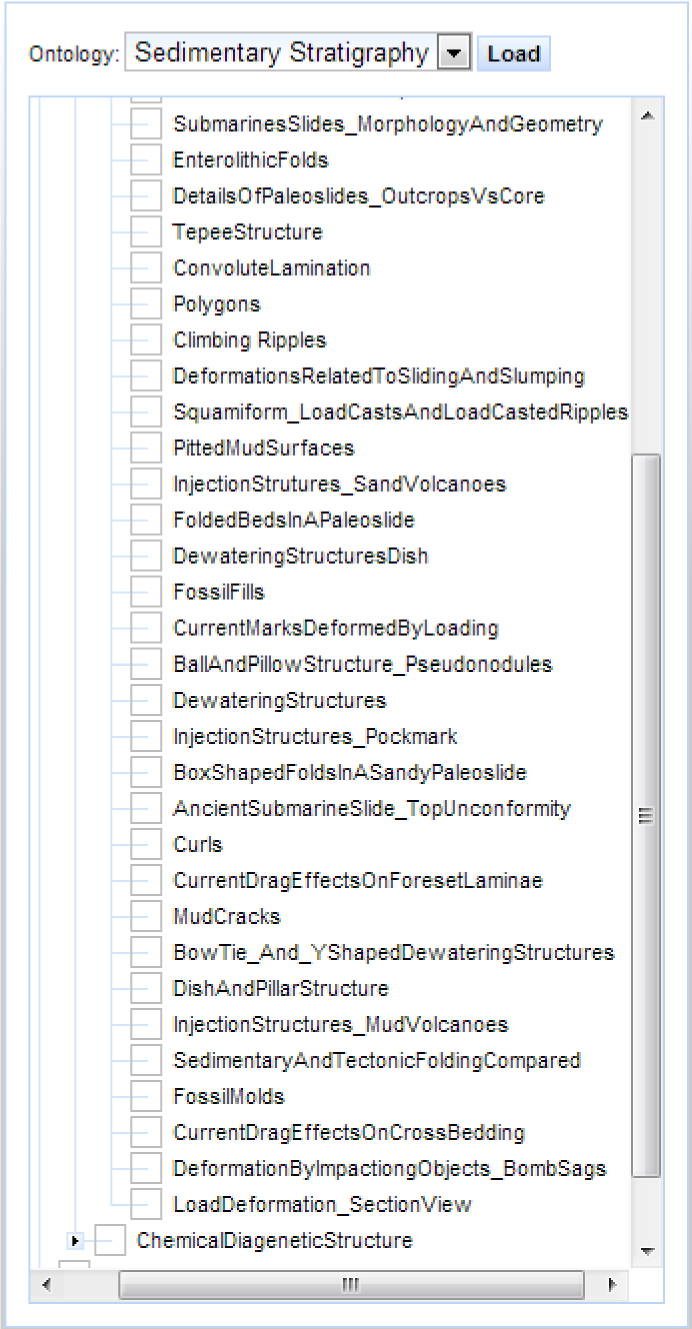
Sedimentary Structure / DepositionalStructure:



Sedimentary Structure / DeformationStructure:



Sedimentary Structure / DeformationStructure (continued):



Sedimentary Structure / ChemicalDiageneticStructure: