On the General Ontological Foundations of Conceptual Modeling

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Abstract. As pointed out in the pioneering work of [WSW99,EW01], an upper level ontology allows to evaluate the ontological correctness of a conceptual model and to develop guidelines how the constructs of a conceptual modeling language should be used. In this paper we adopt the General Ontological Language (GOL), proposed in [DHHS01], for this purpose. We discuss a number of issues that arise when applying the concepts of GOL to UML class diagrams as a conceptual modeling language. We also compare our ontological analysis of some parts of the UML with the one proposed in [EW01].

1 Introduction

Conceptual modeling is concerned with identifying, analyzing and describing the essential concepts and constraints of a domain with the help of a (diagrammatic) modeling language that is based on a small set of basic meta-concepts (forming a *metamodel*). Ontological modeling, on the other hand, is concerned with capturing the relevant entities of a domain in an ontology of that domain using an ontology specification language that is based on a small set of basic, domain-independent ontological categories (forming an *upper-level ontology*). While conceptual modeling languages (such as *Entity-Relationship diagrams* or *UML class diagrams*)are evaluated on the basis of their successful use in (the early phases of) information systems development, ontology specification languages and their underlying upper level ontologies have to be rooted in principled philosophical theories about what kinds of things exist and what are their basic relationships with each other.

We adopt the position that conceptual modeling languages should be founded on an upper-level ontology referring to reality in a philosophically justified way.

Frequently, the goal of conceptual modelers is not to capture the real structure of some domain but merely to capture some conceptualization of it. It is, however, well-known that not all conceptualizations of a domain are equally suitable. The choice of an adequate upper-level ontology is crucial for achieving an adequate conceptualization. We adopt the General Ontological Language (GOL), proposed in [DHHS01], for this purpose. The upper level ontology of GOL is under development at the Institute for Formal Ontology and Medical Information Science at the University of Leipzig, Germany (http://www.ifomis.uni-leipzig.de). The project is a collaboration between philosophers, linguists and other cognitive scientists and computer and information scientists.

In section 2, we present an introduction to those parts of the GOL ontology that form the basis of conceptual modeling, summarizing [DHHS01] and adapting it for this purpose. In section 3, we briefly discuss a number of UML's class modeling concepts: object class, datatype, powertype, abstract class, and association from an ontological point of view. In section 4, we discuss the Bunge-Wand-Weber (BWW) Ontology, an important line of research that is closely related to ours. Finally, in section 5, we briefly mention some other important work.

2 Basic Elements of the Upper Level Ontology of GOL

The basic elements of the upper level ontology of GOL[5] can be visually described by means of the UML class diagram shown in Figure 1.

2.1 Urelements and Sets

One of the basic distinctions of GOL is the distinction between *urelements* and *sets*. We assume the existence of both urelements and sets in the world and presuppose that both the impure sets and the pure sets constructed over the urelements belong to the world. This implies, in particular, that the world is closed under all set-theoretical constructions.

Urelements are entities which are not sets. They form an ultimative layer of entities without any set-theoretical structure in their build-up. Neither the membership relation nor the subset relation can unfold the internal structure of urelements. In GOL, urelements are classified into two main categories: *individuals* and *universals*. There is no urelement being both an individual and a universal. This is expressed in GOL by the following axioms:

$$(U1)\ \forall x(Ur(x) \leftrightarrow Ind(x) \vee Univ(x))$$
$$(U2)\ \neg\exists x(Ind(x) \wedge Univ(x))$$

2.2 Individuals

Individuals may be *substances*, *moments*, *processes*, *chronoids*, or *topoids*. The pre-cognitive part of the GOL ontology, that is being developed at the Institute for Formal Ontology and Medical Information Science at the University of

[5] Also called *General Formal Ontology (GFO)* in [DHH02].

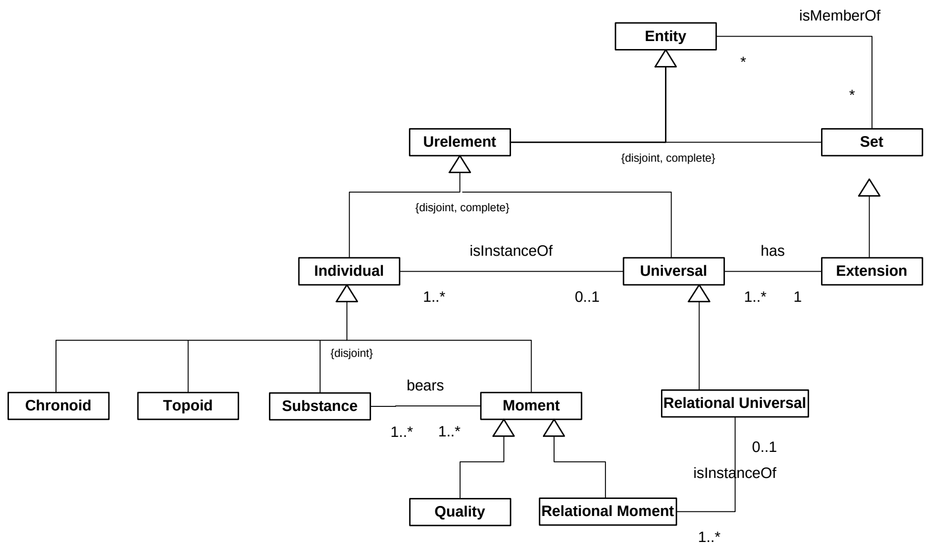

Fig. 1. A UML class diagram describing the basic concepts of GOL.

Leipzig, is called *Basic Formal Ontology (BFO)*. In BFO, a distinction is made between 3D-individuals and 4D-individuals. 3D-individuals are wholly present at every time at which they exist; they have no temporal parts. 4D-individuals are extended in space as well as in time: they have temporal parts. Examples of 3D-individuals are substances, qualities, forms, roles, and functions. 4D-individuals include processes, aggregates of processes, and temporal boundaries of processes, which are also called *Ingarden's events* [Ing64].

Substances and Moments A substance is that which can exist by itself; this implies that a substance is *existentially independent* from other individuals. Existential independence was introduced by E. Husserl: An individual A is existentially independent from an individual B if and only if it is logically possible for A to exist even if B does not exists.

Typical examples of substances are: an individual person, a house, the moon, a car. Every substance is founded on matter. Substances come into existence because the matter is formed in various ways which give rise to pieces separated off in more or less stable ways from their surroundings and possessing qualities of different sorts.

A *moment* is an individual which can only exist in other individuals (in the way in which, for example, an electrical charge can exist only in some conductor). Typical examples of moments are: a color, a connection, a purchase order. Moments have in common that they are all dependent on substances. Some moments are one-place *qualities*, for example color or temperature. But there are also *relational moments* – for example flight connections or purchase orders – which depend on several substances.

The inherence relation i glues moments to the substances which are their bearers. For example it glues your hair color to your hair, or the charge in a specific conductor to the conductor itself. Substances must bear moments, and moments must inhere in substances. This is axiomatically expressed as follows:

$$(SM1)\ Subst(x) \rightarrow \exists y(Mom(y) \wedge i(y,x))$$
$$(SM2)\ \forall x(Mom(x) \rightarrow \exists y(Subst(y) \wedge i(x,y))$$

GOL adopts the *non-migration principle*: it is not possible that a quality q inheres in two different substances a and b:

$$i(q,a) \wedge i(q,b) \Rightarrow a = b$$

This implies that the inherence relation i is functional.

Chronoids and Topoids Chronoids and topoids are instances of the universals *Time* and *Space*, respectively. Chronoids can be understood as temporal durations, and topoids as spatial regions having a certain mereotopological structure.

Every substance x has a certain maximal temporal extent, a chronoid which we denote by *lifetime(x)*. The substance x exists during *lifetime(x)*. Also, every moment m inhering in x has a lifetime, which is such that *lifetime(m)* $\leq$ *lifetime*(x). Moreover, if n is a relational moment connecting substances $x_1, \ldots, x_k$, then *lifetime(n)* $\leq$ *lifetime*(x_i), $i \leq k$.

2.3 Universals

A universal is an entity that can be instantiated by a number of different individuals which are similar in some respect. Following Aristotle, we assume that the universals exist in the individuals (*in re*) but not independently from them. Therefore any universal, in order to exist, must possess instances, implying that the poetic concept *Unicorn* does not correspond to a universal.

For every universal U there is a set $Ext(U)$, called its *extension*, containing all instances of U as elements. It is, however, not the case that every set is the extension of a universal (there is no such axiom in GOL).

There are two kinds of universals that are of particular interest: ***quality universals***, such as *Color* and *Weight*, and ***relational universals***, such as *Flight-Connection* ('...is connected with ...') or *Purchase* ('...purchases ...from ...').

Every universal has an *intension* which, in GOL, is captured by means of an axiomatic specification, i.e., a set of axioms that may involve a number of other universals representing its essential features. A particular form of such a specification of a universal U, called *elementary specification*, involves a number of universals $U_1, \ldots, U_n$ and corresponding functional relations $R_1, \ldots, R_n$ which attach instances from the U_i to instances of U, expressed by the following axiom:

$$\forall a(a :: U \rightarrow \exists e_1 \ldots \exists e_n \bigwedge_{i \leq n} (e_i :: U_i \wedge R_i(a, e_i)))$$

The universals $U_1, \ldots, U_n$ used in an elementary specification are called *features*. A special case of an elementary specification is a *quality specification* where $U_1, \ldots, U_n$ are quality universals, the attachment relations R_k correspond to the inherence relation i, and the instances of U are substances.

Humans, as cognitive subjects, grasp universals by means of concepts that are in their head and cannot capture the universals completely, but only as approximate views. We emphasize that universals whose instances are pre-cognitive individuals belong to the real world and are themselves independent from cognition. Concepts, on the other hand, are cognitive entities that refer to universals.

Meta-Universals of Finite Order Ordinary universals are universals of first order and the instances of universals of (n+1)-th order are univerals of n-th order. Instantiation relations of n-th order are denoted by $::_n$, and the relation $::_1$ is also notated as $::$. Since no universal is a set, it follows that all universals (of whatever order) are urelements.

2.4 Relations and Relational Universals

Relations are entities which glue together other entities. Without relations the world would fall into many isolated pieces. Every relation has a number of *relata* or *arguments* which are connected or related by it. The number of a relation's arguments is called its arity. Relations can be classified according to the types of their relata. 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.

We divide relations into two broad categories, called *material* and *formal*, respectively. The relata of a material relation are mediated by individuals which are called *relators*. Relators are individuals with the power of connecting entities; a *FlightConnection*, for example, is a relator that connects airports.

A formal relation is a relation which holds between two or more entities directly – without any further intervening individual. Examples of formal relations are: 5 *isGreaterThan* 3, this day *isPartOf* this month, N *isSubsetOf* Q.

Holding Relation and Facts One important formal relation is called the *holding relation*. If r is a relator connecting the entities $a_1, \ldots, a_n$, $n \geq 1$, then we say that $r, a_1, \ldots, a_n$ (in this order) stand to each other in the holding relation, symbolically $h(r, a_1, \ldots, a_n)$.

The fact that h holds directly suffices to block the obvious regress which would arise if a new material relation were needed to tie h to $r, a_1, \ldots, a_n$, and so on. Holding holds directly.

If r connects (holds of) the entities $a_1, \ldots, a_n$, then this yields a new individual which is denoted by $\langle r : a_1, \ldots, a_n \rangle$. Individuals of this latter sort are called *material facts*.

An example of a binary relator is the flight connection $c_3 427$ between Berlin and Paris. $c_3 427$, Berlin, Paris stand in the holding relation, symbolically expressed by $h(c_3 427, \text{Berlin}, \text{Paris})$, or by the fact $\langle c_3 427 : \text{Berlin}, \text{Paris} \rangle$. An example of a unary relator is an individual quality q which inheres in a substance s. We can express this by $i(q, s)$, or by $h(q, s)$, or by the fact $\langle q : s \rangle$.

A material fact $\langle r : a_1, \ldots, a_n \rangle$ has a duration, which depends on the lifetime of the relator r. We write $\langle r : a_1, \ldots, a_n ; t \rangle$ if t is a chronoid which is a part of the lifetime of r, i.e. this fact exists at least during the chronoid t.

Relators of Finite Order 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 is of $(n+1)$th order if the highest order of relators it conncects is equal to n.

For example, if John makes a reservation for a rental car, then there is an individual reservation r relating John and the car rental company. Clearly, r is a first order relator. There is another relator, say *assignment*, connecting a specific car to the reservation r. Then, this assignment relator is of second order.

Relator Universals A *relator universal* is a universal whose instances are relators. For every relator universal R there exists a set of facts, denoted by *facts(R)*, which is defined by the instances of R and their corresponding arguments. We assume the axiom that for every relator universal R there exists a *factual universal* $F = F(R)$ whose extension equals the set *facts(R)*. Take, for example, the relator universal *Conn* whose instances are individual flight connections. Then we may form a factual universal $F(Conn)$ having the meaning *'An airport X is connected to an airport Y'* whose instances are all facts of the form $\langle c : a, b \rangle$, where c is an individual connection and a, b are individual airports.

Formal Relations 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). If R is a formal relation and $[a, b] : R$ then $\langle R : a, b \rangle$ is called a formal fact.

Extensional Relations Extensional relations are sets (or set-theoretical classes) of lists. Obviously, every extensional relation is formal. We assume the axiom that for every relation universal R there is a set-theoretical class $Ext(R)$ being the extension of R. An extensional relation can be the extension of many different relation universals.

2.5 Basic Ontological Relations

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

- the proper and reflexive part-of relations, denoted by $<$ and $\leq$
- the contextual part-of relation, denoted by $<_U$, where the universal U denotes the context
- the holding relation h
- the inherence relation, denoted by i
- the instantiation relation, denoted by $::$

We discuss some of these basic ontological relations in more detail.

Part-Whole Relation There are many different part-whole relations between individuals. They can be classified by means of the axioms they satisfy. All part-whole relations are asymmetric and transitive. In addition to formal part-whole relations, there are also material part-whole relations.

Part-whole relations may be either proper (denoted by $<$) or reflexive (denoted by $\leq$). We use the following definitions:

overlap $ov(x, y) =_{df} \exists z(z \leq x \wedge z \leq y)$
reflexive part-whole $x \leq y =_{df} x = y \vee x < y$

A proper part-whole relation $<$ is a strict partial order, that is, it satisfies the following axioms:

irreflexivity $\neg x < x$
asymmetry $x < y \rightarrow \neg y < x$
transitivity $x < y \wedge y < z \rightarrow x < z$

In addition, it may satisfy some of the following axioms:

weak supplementation $x < y \rightarrow \exists z(z \leq y \wedge \neg ov(z, x))$
supplementation $\neg x \leq y \rightarrow \exists z(z \leq x \wedge \neg ov(z, y))$
exclusivity $(z < x \wedge z < y) \rightarrow (x \leq y \vee y \leq x)$

Contextual Part-Whole Relation The contextual part-whole relation $x <_U y$ has the meaning: "U is a universal and x is a part of y in the context of U". Briefly, if x is a U-part of y in this sense, then x and y are parts of instances of U and $x \leq y$. But more is involved, since again the notions of *granularity* and *point of view* are an issue. We propose the following axiom: for every universal U there are universals $U_1, \ldots, U_n$ such that $x <_U y$ implies that x, y are instances of one of the U_i and every instance of one of the U_i is part of an instance of U.

Consider the following example, taken from the domain of biology. Let T be the biological universal whose instances are those organisms called trees. Then

$x <_T y$ describes the part-whole relation based on the granularity of the context of whole trees. A biologist is interested in describing the structure of trees only in terms of parts of a certain minimal size. She is not interested in atoms or molecules. There is a finite number of universals $\{U_1, \ldots, U_n\}$ by which the biologically relevant parts of trees are demarcated. All such parts of trees are either instances of some U_i, $1 \leq i \leq n$, or they can be decomposed into a finite number of parts, each of which satisfies this condition. Examples of universals U_i within the granularity of the tree context would be *branch of a tree*, *leaf of a tree*, *trunk of a tree*, *root of a tree*, and so on.

We have the following axioms:

$$(CPW1)\ \forall xyU(x <_U y \rightarrow Univ(U) \wedge x < y)$$
$$(CPW2)\ \forall xyzU(x <_U y \wedge y <_U z \rightarrow< x <_U z)$$

3 Ontological Foundations of the UML

In the sequel, we refer to the *OMG UML Specification 1.4*, when we cite text in italics using page references in the form of [p.2-31].

For simplicity, we simply say *conceptual model* when we mean a conceptual model of a domain in the form of a *UML class model*. Whenever the context is clear, we omit the name space prefix and simply say 'universal', 'class', etc., instead of 'GOL:universal', 'UML:class', etc.

3.1 Classes and Objects

In the UML, "an object represents a particular instance of a class. It has identity and attribute values." While in the UML *objects* are instances of *classes*, *individuals* are instances of *universals* in GOL. The relationship between UML:classes and GOL:universals may be described by the following observation.

Observation 1 *A class may represent a universal by representing its quality specification (that captures its* intension*) in the form of a list of attributes, such that each quality universal is represented by a distinct attribute (a function that assigns a value from a value domain to an instance of the class). Since a function is a set, this representation of a quality universal by an attribute is a reduction (or approximation). While, according to the* non-migration priciple*, it is not possible that the same quality inheres in two different substances, it is quite common that two different instances of a class have the same attribute value*

A *"Class describes a set of Objects sharing a collection of Features, including Operations, Attributes and Methods, that are common to the set of Objects."* [p.2-26] *"The model is concerned with describing the intension of the class, that is, the rules that define it. The run-time execution provides its extension, that is, its instances."* [p.3-35] Attributes come with associated data types. Since in conceptual modeling, the behavior of objects is normally not taken into consideration, we exclude the 'operations' and 'methods' of an object from our discussion.

We may observe a direct correspondence between universals and classes of a certain kind, as stated in the following principles.

Principle 1 (Class) *In a conceptual model, any first-order universal U of the domain may be represented as a concrete class C_U. Conversely, for all concrete classes (of a conceptual model of the domain) whose instances are basic objects or links (representing individuals), there must be a corresponding first-order universal in the domain.*

Principle 2 (Attribute) *Any feature of a universal U that is captured by a quality universal in a quality specification for U may be represented by an attribute of the corresponding class C_U in a conceptual model of the domain.*

In a conceptual model, any individual of the domain that is an instance of a universal may be represented as an object (or link) of the class representing the universal. Notice that classes are not sets: while the latter are defined only in terms of their *extension*, the former are defined both in terms of their extension and in terms of their *intension*. In general, two classes C_1 and C_2 with identical extensions, $Ext(C_1) = Ext(C_2)$, even if they have the same set of attributes, are not equal, $C_1 \neq C_2$.

3.2 DataType

"A data type is a type whose values have no identity; that is, they are pure values. Data types include primitive built-in types (such as integer and string) as well as definable enumeration types (such as the predefined enumeration type Boolean whose literals are false and true)." [p.2-33]

Data types are sets. This means that two data types denoting the same set of possible values are equal, by the extensionality axiom of set theory. For instance, a C++ compiler may admit the data types *ULONG* and *DWORD*. Since both types denote the set of positive 32-bit-expressible integers, they are identical: $ULONG = DWORD$.

3.3 Powertype

"A Powertype is a user-defined metaelement whose instances are classes in the model." A powertype is a special class, designated with the stereotype 'powertype'. It represents a higher-order universal of order n whose instances are universals of order $n-1$. Unfortunately, the UML does not provide higher-order 'isInstanceOf' relationships.

3.4 Abstract Class

"Abstract constructs are not instantiable and are commonly used to reify key constructs, share structure, and organize the UML metamodel. Concrete metamodel constructs are instantiable and reflect the modeling constructs used by

object modelers (cf. metamodelers). Abstract constructs defined in the Core include ModelElement, GeneralizableElement, and Classifier. Concrete constructs specified in the Core include Class, Attribute, Operation, and Association." [p.2-12]

What is the status of abstract classes in an ontologically well-founded conceptual model? It seems that an abstract class does not denote a universal but rather a conceptual construction in the form of a hierarchy whose bottom elements denote universals.

3.5 Association

In the UML, the ER concept of a *relationship type* is called *association*. *"An association defines a semantic relationship between classifiers. The instances of an association are a set of tuples relating instances of the classifiers. Each tuple value may appear at most once."* [p. 2-19] *"An instance of an Association is a Link, which is a tuple of Instances drawn from the corresponding Classifiers."* [p. 2-20]

The *OMG UML Specification* is somehow ambiguous in defining *associations*. An association is primarily considered to be a 'connection', but, in certain cases (whenever it has 'class-like properties'), an association may be a class: *"An association class is an association that is also a class. It not only connects a set of classifiers but also defines a set of features that belong to the relationship itself and not any of the classifiers."* [p.2-21]

An association A between the classes $C_1, \ldots, C_n$ of a conceptual model can be understood in GOL as a relation R between the corresponding universals $U_1, \ldots, U_n$ induced by the relational universal whose extension consists of all relational moments corresponding to the links of A. Let $\phi(a_1, \ldots, a_n)$ denote a condition on the individuals $a_1, \ldots, a_n$. Then

$$[a_1, \ldots, a_n] : R_A(U_1, \ldots U_n) \longleftrightarrow \bigwedge_{i \leq n} a_j :: U_i \ \wedge \ \phi(a_1, \ldots, a_n)$$

An association is called *material* if there is a relator universal F such that the condition ϕ is obtained from F as follows:

$$\phi(a_1, \ldots, a_n) \longleftrightarrow \exists k(k :: F \ \wedge \ h(k, a_1, \ldots, a_n))$$

An example of a ternary material association is *purchFrom* corresponding to a relator universal *Purchase* whose instances are individual purchases. These individual purchases connect three individuals: a person, say John, an individual good, e.g. the book *Speech Acts* by Searle, and a shop, say Amazon. Thus,

$$[\text{John}, \text{SpeechActsBySearle}, \text{Amazon}] : R_{\text{purchFrom}}(\text{Person}, \text{Good}, \text{Shop}),$$

since *John::Person*, *SpeechActsBySearle::Good* and *Amazon::Shop*, and there is a specific purchase event *p::Purchase* such that

$$h(p, \text{ John}, \text{ SpeechActsBySearle}, \text{ Amazon}).$$

We obtain the following definition for the triple $[a_1, a_2, a_3]$ being a link of the association *purchFrom* between `Person`, `Good` and `Shop`:

$$
\begin{aligned}
&[a_1, a_2, a_3] : R_{\text{purchFrom}}(\text{Person}, \text{Good}, \text{Shop}) \\
&\longleftrightarrow a_1 :: \text{Person} \wedge a_2 :: \text{Good} \wedge a_3 :: \text{Shop} \\
&\qquad \wedge \exists p(p :: \text{Purchase} \ \wedge \ h(p, a_1, a_2, a_3))
\end{aligned}
$$

4 The Bunge-Wand-Weber (BWW) Ontology

The approach found in the literature that is closest to the one presented here is the approach by Evermann and Wand [EW01] and Wand, Storey and Weber [WSW99]. In these two articles, the authors report their results in mapping common constructs of conceptual modeling to an upper level ontology. Their approach is based on the BWW ontology, a framework created by Wand and Weber on the basis of the original metaphysical theory developed by Mario Bunge in [Bun77] and [Bun79].

In this section we will make a comparison between GOL and BWW in terms of their theories and of their corresponding mapping approaches.

4.1 Things and Substances

The concepts of substance (in GOL) and of thing in BWW are both based on the Aristotelian idea of substance, i.e.,

1. an essence which makes a thing what it is;
2. that which remains the same through changes;
3. that which can exist by itself, i.e., which does not need a 'subject' in order to exist.

In BWW, a thing is defined as a substantial individual with all its substantial properties: "a thing is what is the totality of its substantial properties"[Bun77]. As a consequence, in BWW, there are no bare individuals, i.e., things without properties: a thing has one or more substantial properties, even if we, as cognitive subjects, are not or cannot be aware of them. Humans get in contact with the properties of things exclusively via the thing's attributes, i.e. via a chosen representational view of its properties.

A thing in BWW can be directly mapped to the concept of substance in GOL. The axiom (SM1) dictates that a GOL:substance has a non-empty appearance, i.e. every substance bears at least one moment. As it will be explained in the next section, qualities and relational moments in GOL are equivalent to the concepts of intrinsic and mutual properties in BWW, respectively. Not only the two theories confirm each other regarding this issue but the mapping directive presented in this paper also conforms to the BWW-to-UML mapping presented in [EW01].

4.2 Properties and Moments

In BWW, a thing has necessarily at least one property. Likewise, a property exists only in connection with things. A property whose existence depends only on a single thing is called an *intrinsic property* (e.g. the height of a person). A property that depends on two or more things is called a *mutual property* (e.g. being a student is a mutual property between a person and an educational institution). In BWW, only things possess properties. As a consequence, a property cannot have properties. This dictum leads to the following modeling principle: "Associations should not be modeled as classes", (Rule 7) in [EW01]. Contrary to this principle, GOL allows associations, representing relational universals, to have attributes and to participate in second or higher-order associations. Thus, while the BWW approach prohibits to use association classes in conceptual modeling, they are allowed in GOL.

There is an important distinction between the properties possessed by a thing and the representations of these properties by means of attributes. Attributes are characteristics assigned to things according to human perception or conceptualization. Attributes are state functions that provide a mapping from a thing to 'co-domains' whose members can be substantial (attributes representing mutual properties) or conceptual (attributes representing intrinsic properties). In other words attribute functions are used to represent both, intrinsic and mutual properties.

The strong distinction between properties and their representations helps clarifying a common misinterpretation of what a mutual property means. When we say, for example, that "John and Mary are married to each other", we acknowledge the existence of "being married to each other" as a mutual property of John and Mary. At first glance, one could find it counterintuitive to classify this as a mutual property since "being married to Mary" would be the property of John while "being married to John" would be the property of Mary. However, one should notice that we can only get in contact with properties of things via their attributes. Thus, "being married to Mary" is actually an attribute function that represents this mutual property from John's point of view, and not a property.

Again the concepts of BWW-property and GOL-moment can directly be related. Like a property, a moment can only exist if it inheres in an individual substance (axiom SM2). Moments are bound to their associated substances via the inherence relation. This relation can only link moments to substances, i.e. like a property, a moment cannot have moments.

Substances come into existence because matter is formed in specific ways possessing qualities of different sorts. Based on this, we can say that substances have qualities independently of our perception or consideration of these qualities. However, we can only reason about these qualities through their representations as moments. Thus, we can conclude that qualities and relational moments in GOL are, actually, the equivalent of BWW intrinsic and mutual properties, respectively.

In [EW01], it is also proposed that attribute functions representing BWW intrinsic and mutual properties are represented as attributes and associations in UML, respectively.

So, some BWW concepts have a direct counterpart in GOL:

BWW concept	*GOL concept*
substantial thing	substance
intrinsic property	quality
mutual property	relational moment

4.3 Natural Kinds and Universals

In BWW, the definition of a class is based on the notion of the scope of a property. A scope S of a property p is a function assigning to each property that exists in a domain a set of things from that domain, i.e., $S(p)$ is the set of things in the domain that possess property p. A *class* is then defined as the scope of a property.

If we have a non-empty set P of properties, the intersection of the scopes of all members of P is called a *kind*. Finally, a kind whose properties satisfy certain 'laws' (in the sense of integrity constraints) is called a *natural kind*.

In [EW01], a set of attributes (defined as *state functions*) that describe things with common properties is called a *functional schema*. A UML-class cannot be mapped to any of the BWW concepts class, kind or natural kind, because the latter are defined extensionally (as special sets), while the former is defined intensionally and has an extension at run-time. Evermann and Wand therefore propose that "a UML-class is equivalent to a functional schema" of a natural kind.

While in the BWW ontology, the part-whole relation may only hold between substances ('a composite thing consists of other things'), it holds more generally between individuals in GOL. For example, processes can have temporal parts, such as the lifecycle of a product may consist of a design, a production and a maintenance phase.

5 Other Related Work

For a comparison between GOL and other upper-level ontologies, such as the IEEE Standard Upper Ontology, the reader is referred to [DHHS01].

The ONTOCLEAN methodology proposed in [GW02] proposes a number of tests for identifying ill-defined generalization relationships. It is based on a formal ontological framework derived from philosophical ontology the authors have previously presented in a number of papers. The goals of ONTOCLEAN are similar to those of GOL: the process of building ontologies to be used for information systems engineering must become a rigorous engineering discipline based on scientific principles.

6 Conclusions

This paper is only a first step in the attempt to use the General Ontological Language (GOL) and its underlying upper level ontology to evaluate the ontological correctness of UML as a conceptual modeling language, and to develop guidelines that assign well-defined ontological semantics to UML constructs. One important issue for future work is the correct treatment of UML's aggregation concept on the basis of a suitable formalization of the part-whole relation.

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