Contributions to the Axiomatic Foundation of Upper-Level Ontologies

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Abstract. In the present paper we make some contributions to the theory of upper level ontologies. Every domain-specific ontology must use as a framework some upper-level ontology which describes the most general, domain-independent categories of reality. It turns out that the top-level ontology of the well-known standard modelling languages KIF (Knowledge Interchange Format), F-logic (Frame-Logic), and CyCL, is based on set-theoretical construction principles, so that the latter are essentially limited by the extensionalism of set theory. In the current paper we outline a new approach to upper-level ontologies which is based on recent results in formal ontology. We formulate some criteria which any upper-level ontology should satisfy although we shall not give a definite definition. Every such ontology should include the three ontological categories of *sets*, *universals*, *individuals* and a system $\mathcal{R}$ of *formal relations.* $\mathcal{R}$ contains, among others, membership, part-whole and inherence. The individuals are divided in substantoids, moments and situoids. We review a modelling language GOL (General Ontological Language) whose top-level ontology satisfies these criteria. Finally, we compare our top-level ontology to others, in particular to KIF, and to the ontologies of Russell-Norvig, J.Sowa, and to the standardization project SUO.

1 Introduction

The current paper is devoted to an analysis of upper level categories. Upper level ontologies are concerned with theories of such highly general (domain-independent) categories as: time, space, inherence, instantiation, identity, processes, events, attributes, etc. The development of a widely accepted and well-established upper level ontology is an important and ambitious task, important because it determines a framework for the construction of domain-specific and generic ontologies, ambitious because it is concerned with highly debated philosophical problems. An upper level ontology could be considered as an integral part of a knowledge modelling and representation language. In our approach we assume the point of view of realism, i.e. the position that the kind of things we are speaking about have objective existence; hence, ontological research should address reality itself. Thus, ontological research is not limited to building up conceptual schemes. We believe that the real world itself plays an important role to achieve a unified and consistent top-level ontology. We use the term *category* to denote collections of entities. We classify the collection of all entities into the categories *sets*, *individuals*, *universals*, and *formal relations*. In section 2 we study the categories of sets, individuals, and universals. Section 3 is devoted to formal relations. The categories of section 2 and section 3 present the highest level of generality. In section 4 the category of individuals is further classified and some formal relations are considered in more detail. In section 4.2 conditions are formulated that - in our opinion- should be satisfied by every upper level ontology, and in section 4.3 a formal modelling language GOL is reviewed whose ontological basis satisfies the criteria of an upper level ontology. GOL is an ongoing research project at the University of Leipzig, [10]. In section 5 we compare our ontology to other upper-level ontologies.

2 Individuals, Universals, and Sets

In our approach the entities of the real world can be partitioned in sets and urelements. Urelements are entities which are not sets, and urelements are classified into *individuals* and *universals*. Individuals are thought of as a realm of concretely existing things in the world (not sets), within the confines of space and time. An individual is a single thing located in some single region of space-time. A universal is an entity that can be instantiated by a number of different individuals which are similar in some respect. Universals are patterns of features which are not related to time and space. We assume that universals exist *in* the individuals which instantiate them (thus they exist *in re*); thus, our attitude is broadly Aristotelian in spirit. Individuals are correlated with universals via the formal relation of *instantiation*. We write $a :: u$ to denote that the individual a is an instance of the universal u. In the philosophical tradition there are several conceptions of universals and individuals, respectively, [13].For example, universals have been conceived as *sets of individuals*; and individuals have been conceived as *sets of universals*. If one adopts both conceptions, then individuals are sets of sets of individuals; and universals are sets of sets of universals. And so on. We conclude that not both conceptions are admissible. Which of the two conceptions has to be given up? We think that both have to be given up. A detailed justification of this view is long and will be expounded in the full version of the paper.

We assume that sets are neither in Space nor in Time. Hence, sets are not individuals. A universal is determined by its intention which captures among others a certain granularity and a certain view of its instances. We assume the basic axiom that sets, individuals and universals are pairwise disjoint categories.

3 Formal Relations

According to the present standard doctrine, every n-ary relation is a set (or class) of ordered n-tuples. This conception is applied indiscriminately to both so-called empirical and mathematical relations. Thus, when John is kissing Mary, the ordered pair $\langle$*John, Mary*$\rangle$ is an element of a certain set A of ordered pairs that is denoted by "kissing". Also, that $2 < 5$ is analysed by $\angle 2, 5\rangle \in B$ where B

is the set $\{\angle x, y\rangle : x < y\}$ of ordered pairs. This uniform analysis harmonizes with conceiving of both sentences as having the same syntactic form, namely $R(a, b)$. The usual semantics of first-order logic, i. e. the semantics with respect to which Gödel's completeness theorem is proved, interprets any sentence $R(a_1, \ldots, a_n)$ as stating that $\langle a_1, \ldots, a_n\rangle \in R$.

Admittedly, the sentences "John is kissing Mary" and "$2 < 5$" have sufficient superficial similarity to warrant the same syntactic and semantic analysis. However, these sentences have radically different linguistic environments. For instance, "John is kissing Mary" can be extended to "John is kissing Mary twice", but "$2 < 5$" cannot be extended to "$2 < 5$ *twice*". Furthermore, the sentence "John is kissing Mary" is implied by "John is kissing Mary twice". We have therefore to use a logical form that will support this implication. While for 2 and 5 to be related as $2 < 5$ no further entities are required to exist, there have to exist entities beyond John and Mary if "John is kissing Mary (twice)" is to be true, namely at least one (at least two) kiss(es). A plausible formulation is the following:

1. $\exists x(x\ is\ a\ kiss \wedge does(J, x) \wedge suffers(M, y))$
2. $\exists x, y(x\ is\ a\ kiss \wedge x\ is\ a\ kiss \wedge \neg x = y \wedge does(J, x) \wedge it\ does(J, y) \wedge suffers(M, x) \wedge suffers(M, y))$

Obviously 2. implies 1. in first-order predicate logic. These considerations lead to the distinction between formal and material relations. A relation is *formal* if it holds as soon as its relata are given. Formal relations are called equivalently *immediate relations* since they hold of their relata without mediating additional individuals. The smaller-than relation $<$ for numbers, the instantiation relation, and membership are formal relations. Also the relations denoted by "does" and "suffers" in (1) and (2) are formal. In contradistinction to this, the kissing relation does not hold as soon as its relata exist; a kiss (understood as an individual event) must happen in addition to its relata. Therefore, we call the kissing relation a *material* relation. Formal relations may be classified with respect to the main categories: sets, universals and indviduals. *Membership* is a formal relation between sets and between urelements and sets, and *instantiation* is a formal relation between individuals and universals. Universals and sets are connected by the formal relation of *extension*. Examples of formal relations between individuals are *inherence, occupation, framing, containment* which will be explained in section 4.1.

4 Top Level Categories and Upper level Ontologies

In this section further categories of individuals are introduced, and some formal relations are considered in more detail. We call all these categories as ontologically basic because they are the most fundamental.

4.1 Ontologically Basic Categories

The individuals are further subcategorized into *moments, substantoid, chronoids, topoids* and *situoids*[1] -terms which will be explained in more detail in what follows. This yields (at least) the following ontologically basic predicates (also called basic types): *Mom(x), Subst(x), Sit(x), Chron(x), Top(x).* Chronoids can be understood as temporal durations, and topoids as spatial regions with a certain mereotopological structure. A substance is that which bears individual properties or is connected to other substances by relational moments. Every substance possesses matter. The ultimate (or prime) matter of a substance has no moments or qualities. This implies that an ultimate matter cannot appear since every appearance has to take place via individual moments inhering in the appearing matter. We use the term *substantoid* to cover the whole range between prime matter and those pieces of matter (called substances in the proper sense) which possesses moments including forms, motions and qualities. An *alignment* $\langle a_1, \ldots, a_n \rangle$ is a sequence of substantiods $a_1, \ldots, a_n$, the a_i's are called *components*. An alignment is an individual in contradistinction to a list which is a set.

The origin of the notion of *moment* lies in the theory of "individual accidents" developed by Aristotle in his *Metaphysics* and *Categories* [1]. An accident is an individualized property, event or process which is not a part of the essence of a thing. We use the term "moment" in a more general sense and do not distinguish between essential and inessential moments. Moments include individual qualities, actions and passions, a blush, a handshake, thoughts and so on; moments thus comprehend what are sometimes referred to as "events". The loss of a moment in this more general sense may change the essence of a thing. Moments have in common that they are all dependent on substantoids. Relational moments are dependent on a plurality of substantoids.

A *situoid* is a part of the world that can be comprehended as a whole and which takes into account the courses and histories of the ontological entities occurring in it. Situations are special types of situoids: they are situoids at a time, so that they present a snap-shot view of parts of the world. Situations can be defined as projections of situoids onto atomic (or very small) time intervals or equivalently as situoids with an atomic (or very small) framing chronoid. An *elementary situation* is composed of individual substances and the relational moments which glue them together. Situations are constituted by using further ontologically basic relations such as causality and intentionality. Analogously, we distinguish elementary situoids from situoids. We assume that every situoid is framed by a chronoid and by a topoid. For every situoid s there is a finite number of universals which are associated with s. $ass(s,u)$ has the meaning: s is a situoid and u is a universal associated with s. There is a basic predicate $Sitel(x)$ for elementary situoid, and a predicate $Sit(x)$ for situoids in general. Our approach to situations differs essentially from that of *Barwise* [2], [3]. Barwise did not elaborate an ontology of relations; thus in particular, the relation of inherence is missing from his theory.

[1] This classification is, of course, tentative.

What are the ontologically basic relations needed to glue together the entities mentioned above? Basic relations are membership denoted by $\in$, and part-of relations, denoted by $<$, $\leq$ (reflexive part-of). Other basic relations are denoted by symbols starting with a colon. In the current paper we additionally consider the basic relation of inherence, denoted by $:\succ$, the relativized ternary part-of relation, symbolized by $:\mu$, the instantiation relation, denoted by $::$, the framing relation, designated by $:\sqsubset$, the containment relation, denoted by $:\triangleright$, and the foundation relation, denoted by $:\perp$.

The phrase "inherence in a subject" can be understood as the translation of the Latin expression *in subjecto esse*, in contradistinction to *de subjecto dici*, which may be translated as " predicated of a subject". The inherence relation $:\succ$ - sometimes called ontic predication - glues moments to the substances, which are their bearers, for example it glues your smile to your face, or the charge in this conductor to the conductor itself. The part-of relations $<, \leq$ should have in every case an individual as its second argument, i.e. if $a < b, a \leq b$, then b is an individual. The ternary part-whole relation $:\mu(x, y, z)$ has the meaning: "z is a universal and x qua instance of z is a part of y". Obviously, $:\mu(x, y, z)$ implies $x \leq y$, but not conversely. These universal-dependent part-whole relations are important in applications. The symbol $::$ denotes the instantiation relation, its first argument is an individual, and its second a universal. The instances of a universal u are "individualizations" of the time- and space-independent pattern of features captured by u. The containment relation $:\triangleright$ captures the constituents of a situoid. $x:\triangleright y$ means "x is a constituent of the situoid y". Among the constituents of a situoid s belong the occurring substantoids and the moments inhering in them, but also the universals associated to s.

The binary relation $:\sqsubset$ glues chronoids or topoids to situations. We presume that every situation is framed by a chronoid and a topoid, and that every chronoid or topoid frames a situation. The relation $x:\sqsubset y$ is to be read "the chronoid (topoid) x frames the situation y". The defined binary relation $:\perp(x, y)$ expresses the foundation relation between a substance and a moment. $:\perp(x, y)$ has the meaning that x is the foundation of y or x founds the moment y, as for example your hair founds the moment of your *being hairy*, and the moment of *being hairy* inheres in your person. The defined binary relation $:occ(x, y)$ describes a relation between substances and topoids having the meaning: the substantoid x occupies the topoid y.

4.2 Upper Level-Ontologies

We formulate certain neccessary criteria which an upper level ontology - in our opinion- should satisfy.

Upper-Level Ontology. Every upper level ontology includes at least the three ontological categories: sets, individuals and universals and a system $\mathcal{R}$ of relations and predicates containing the basic relations and basic types described in section 4.1.[2]

We consider the described system of basic categories as a constituent core ontology because individuals are composed of substances and moments or are contained in situoids. This system has to be extended by further basic relations for treating space, time, and shapes. One possibility is to introduce the relation *x is boundary of y*, and the *coincidence relation* [17].

The core ontology should be extended by *unity conditions* and *comprehension principles*. Unity conditions are universals capturing kinds of wholes. An example of a unity condition is the universal *substantoid having a boundary*. Comprehension principles allow to construct new universals from given universals. One method to define comprehension principles is to introduce a language $\mathcal{L}$ whose expressions can be used to formally specify universals. Then, certain expressions can be understood as formal representations of universals. A $\mathcal{L}$-comprehension principle determines which of the $\mathcal{L}$-expressions represent (specify) universals.

Using the core ontology (extended by some mereotopological notions) one may introduce following categories: *substrate* , *process*, *event*, *state*, and *continuant*. Here, *substrate* is a universal, and *processes*, *events* and *states* are parts of situoids. A continuant can be understood as a substantoid with boundary.

4.3 Ontology of GOL

In this section we expound the partially axiomatized ontology underlying the modelling language GOL (General Ontological Language). GOL is an ongoing research project at the university of Leipzig [6] which is carried out in collaboration with ontologists at the University of Buffalo [15]. GOL includes the categories which are considered in section 4.1. The modelling language *GOL* is formalized in a first-order language. We presume a basic ontological vocabulary, denoted by Bas, containing the following groups of symbols:

Unary basic symbols.

$Ur(x)$	(urelement)	$Set(x)$	(set)	$Ind(x)$	(individual)
$Univ(x)$	(universal)	$Mom(x)$	(moment)	$Subst(x)$	(substantoid)
$Sit(x)$	(situoid)	$Top(x)$	(topoid)	$Chron(x)$	(chronoid)

Symbols for binary and ternary basic relations.

$\in$	(membership)	$::$	(instantiation)	$:\succ$	(inherence)
$<$	(part-of)	$:\mu(x,y,z)$	(rel. part-of)	$:\sqsubset$	(framing)
$:ass(x,y)$	(y ass. to y)	$:\triangleright$	(is contained in)	$:occ(x,y)$	(x occupies y)
$ext(x,y)$	(is extension)				

2 We emphasize that this (neccessary) criterion is not sufficient for an ontology to be upper level.

Furthermore, we use the following symbols: *Sub* (for the universal "substance"), *Time* (for the universal "time"), *Space* (for the universal "space"). To the basic vocabulary we may add further symbols used for domain specific areas; the domain specific vocabulary is called an *ontological signature*, denoted by Σ. An *ontological signature* Σ is determined by a set S of symbols used to denote sets (in particular extensional relations), by a set U of symbols used to denote universals, and by a set K of symbols used to denote individuals. An ontological signature is summarized by a tuple $\Sigma = (\mathsf{S}, \mathsf{U}, \mathsf{K})$.

The syntax of the language $GOL(\Sigma)$ is defined by the set of all expressions containing the atomic formulas and closed with respect to the application of the logical functors $\vee, \wedge, \rightarrow, \neg, \leftrightarrow$, and the quantifiers $\forall, \exists$. We use untyped variables $x, y, z, \ldots$; terms are variables or elements from $\mathsf{U} \cup \mathsf{S} \cup \mathsf{K}$; r, s, s_i, t denote terms. Among the atomic formulas are expressions of the following form: $r = s$, $t \in s$, $r :\succ \langle s_1, \ldots, s_n \rangle$, $v :: u$, $t{:} \sqsubset s$, $t{:} \rhd s$.

The language includes an axiomatization capturing the semantics of the ontologically basic relations. We do not present the axiomatization in full here, but rather illustrate the main groups of axioms by selecting some typical examples. We introduce three groups of axioms, whose union form the axioms $Ax(GOL)$ associated with the language GOL. Besides the logical axioms we have the following groups of axioms.

Axioms of Basic Ontology

(a) Sort and Existence Axioms

1. $\exists x(Set(x))$,
2. $\exists x(Ur(x))$
3. $\forall x(Set(x) \vee Ur(x))$
4. $\neg \exists x(Set(x) \wedge Ur(x))$
5. $\forall x(Ur(x) \leftrightarrow Ind(x) \vee Univ(x))$
6. $\neg \exists x(Ind(x) \wedge Univ(x))$
7. $\forall xy(x \in y \rightarrow Set(y) \wedge (Set(x) \vee Ur(x)))$

(b) Instantiation

D. $ext(x,y) =_{df} Univ(x) \wedge Set(y) \wedge \forall u(u :: x \longleftrightarrow u \in y)$.

1. $\forall xy(x :: y \rightarrow Ind(x) \wedge Univ(y))$
2. $\forall x(Univ(x) \rightarrow \exists y(Set(y) \wedge \forall u(u \in y \longleftrightarrow u :: x)))$

(c) Axioms about sets

1. $\forall uv \exists x(Set(x) \wedge x = \{u, v\})$
2. $\{\phi^{Set} \mid \phi \in ZF\}$, where ϕ^{Set} is the relativization of the formula ϕ to the basic symbol $Set(x)$.[3]

[3] In the formula ϕ^{Set} all variables and quantifiers in ϕ are restricted to sets.

ZF is the system of *Zermelo-Fraenkel*. By 1. and 2. there exists arbitrary finite sets over the urelements. Furthermore, we may construct finite lists. Note, that lists and alignments are different sorts of entities.

(d) Axioms for Moments, Substances, and Inherence

1. $\forall x(Subst(x) \rightarrow \exists y(Mom(y) \wedge y :\succ x))$
2. $\forall x(Mom(x) \rightarrow \exists y y \wedge x :\succ y))$
3. $\forall xyz(Mom(x) \wedge x :\succ y \wedge x :\succ z \rightarrow y = z)$

Axiom 3 is called the *non-migration principle*: the substances (considered as an alignment) in which a moment inheres are uniquely determined.

(e) Axioms about Part-of
D1 $ov(x, y) =_{df} \exists z(z \leq x \wedge z \leq y)$, (overlap)

1. $\forall x(\neg x < x)$
2. $\forall xyz(x < y \wedge y < z \rightarrow x \leq z)$
3. $\forall xy(\forall z(z < x \rightarrow ov(z, y)) \rightarrow x \leq y))$
4. $\forall xyz(:\mu(x, y, z) \rightarrow Univ(z) \wedge x \leq y)$
5. $\forall xyzu(:\mu(x, y, u) \wedge :\mu(y, z, u) \rightarrow :\mu(x, z, u))$

(f) Axioms governing Chronoids and Topoids.

Topoids are three-dimensional spatial regions, chronoids are temporal durations.

1. $\forall x(Sit(x) \rightarrow \exists t_1 t_2(Chron(t_1) \wedge Top(t_2) \wedge t_1 \!: \sqsubset x \wedge t_2 \!: \sqsubset x))$
2. $\forall x(Chron(x) \rightarrow \exists x_1 \exists s(Chron(x_1) \wedge Sit(s) \wedge x \leq x_1 \wedge x_1 \!: \sqsubset s))$
3. $\forall x(Top(x) \rightarrow \exists x_1 \exists s(Top(x_1) \wedge Sit(s) \wedge x \leq x_1 \wedge x_1 \!: \sqsubset s))$
4. $\forall xt(occ(x, t) \rightarrow Subst(x) \wedge Top(t)) \wedge \forall x(Subst(x) \rightarrow \exists t(occ(x, t)))$

(g) Axioms about situations
D1. $Cont\ (s) =_{df} \{m \mid m \!: \rhd s\}$
D2. $s \sqsubseteq t =_{df} Cont(s) \subseteq Cont(t)$.

1. $\forall x(Mom(x) \rightarrow \exists s(Sit(s) \wedge x \!: \rhd s)) \wedge \forall x(Subst(x) \rightarrow \exists s(Sit(s) \wedge x \!: \rhd s))$
2. $\forall x(Sit(x) \rightarrow \exists y(Subst(y) \wedge y \!: \rhd x))$
3. $\forall xy(Sit(x) \wedge Sit(y) \rightarrow \exists z(Sit(z) \wedge x \sqsubseteq z \wedge y \sqsubseteq z))$
4. $\neg \exists x(Sit(x) \wedge \forall y(Sit(y) \rightarrow y \sqsubseteq x))$
5. $\forall x(Sit(x) \rightarrow \exists y(Univ(y) \wedge ass(x, y))$

Furthermore, we add the following axioms which are related to Σ. $Univ(u)$ for every $u \in \mathsf{U}$, $Set(R)$ for every $R \in \mathsf{S}$, $Ind(c)$ for every $c \in \mathsf{K}$. A knowledge base about a specific domain w.r.t. the signature Σ is determined by a set of formulas from $GOL(\Sigma)$ which are not basic axioms.

5 Comparison to other Upper-level Ontologies

5.1 Knowledge Interchange Format.

Knowledge Interchange Format (*KIF*) is a formal language for the interchange of knowledge among computer programs, written by different programmers, at different times, in different languages. *KIF* can be considered as a lower-level knowledge modelling language.

The ontological basis of *KIF* can be extracted from [9]; we summarize the main points. The most general ontological entity in *KIF* is an *object*. The notion of an object, used in *KIF*, is quite broad: objects can be concrete (e.g. a specific carbon, Nietzsche, the moon) or abstract (the concepts of justice, the number two); objects can be primitive or composite, and even fictional (e.g. a unicorn). There is no ontological classification of the basic entitities. In *KIF*, a fundamental distinction is drawn between *individuals* and *sets*. A set is a collection of objects; an individual is any object that is not a set. *KIF* adopts a version of the Neumann-Bernays-Gödel set theory, *GOL* assumes *ZF* set theory. The functions and relations in *KIF* are introduced as sets of finite lists; here the term "set" corresponds to the term "class". Obviously, the relations and functions in *KIF* correspond in *GOL* to the *extensional relations*. *KIF* does not provide ontologically basic relations like our inherence, part-whole and the like. Hence, the ontological basis of *KIF* is much weaker than that of *GOL*. *GOL* can be considered as a proper extension of *KIF*; *KIF* can be understood as the extensional part of *GOL*.

5.2 Upper Level Ontology of Russell and Norvig

The most general categories of this ontology are *Abstract Objects* and *Events* [14]. Abstract objects are divided into *Sets*, *Numbers*, *Representational Objects*; events are classified into *Intervals* , *Places*, *Physical Objects*, and *Processes*. This ontology does not satisfy the criteria of section 4 because there is no clear distinction between sets, universals, and individuals. Also, there is no category of formal relations. The class of universals (here called "categories") is a subclass of sets. This pure extensional view of universals seems to be not correct. Furthermore, numbers are considered as different from sets. But, it seems to be plausible to introduce numbers as special sets, as in GOL. Obviously, classical mathematics can be reduced to set theory. The instantiation relation is identified with membership. Besides this the ontology provides the part-of-relation. The categories of events may be reconstructed within the category of situoids in GOL. An event in the Russell-Norvig ontology is a "chunk" of a particular universe with both temporal and spatial extent. An interval is an event that includes as subevents all events occurring in a given time period. Such intervals can be, in a sense, understood as situoids. But the difference is, that situoids are parts of the real world that can be comprehended as a whole. This implies that to situoids are associated certain universals capturing the granularity and the view of this part of the world.

5.3 Upper Level Ontology of Sowa

Sowa's ontology [19] does not satisfy the conditions of section 4.2. There is no clear distinction between sets, universals and individuals. A main distinction is made between classes and entities. Since these notions are interpreted in KIF they can be understood within GOL as sets and urelements. There are the following two-place primitive relations: *has*, *instance-of*, *sub-class of*, *temp-part*, *spatial-part*. The instance-of relation is interpreted by the membership-relation, and the ontological status of the *has*-relation is unclear. Since these notions are interpreted in KIF they are considered as set-theoretical notions. We want to emphasize that formal relations of the real world are not relations in the sense of set-theory. Sowa's ontology uses further two epistemic non-KIF operators: nec and poss; but the ontological character of these modal operators is not clear. In our opinion, modal operators should be eliminated from ontology. In Sowa's ontology several classes are introduced, as for example *relative*, *mediating*, *physical*, *abstract*, *continuant*, *ocurrent*. These notions may be redefined within GOL giving them a clear ontological status.

5.4 Upper Level Ontology of LADSEB

In the papers [12] and [8] some principles for a top-level ontology are outlined. The rudimentary top-level ontology, implicitly given in these papers, partially satisfies our criteria of 4.2. Formal relations are considered in [8] as relations involving entities in all "material spheres"; these have a different meaning from formal relations in our sense which we understand as being "immediate". Then certain formal relations are discussed: intantiation and membership, parthood, connection, location and extension, and dependence. The considered formal properties include concreteness, abstractness, extensionality, unity, plurality, dependence and independence. Intantiation, membership, and parthood are basic relations in our sense; the inherence relation is missing. The extension relation $E(x, y)$ = x *is the extension of* y can be modelled by our relation *occ(x,y)* (the entity x occupies the topoid y). The *connections relation* from [8] can be defined in GOL by using the coincidence relation and the notion of boundary.

5.5 SUO-Project

SUO is a project recently intiated by the Institute of Electrical and Electronic Engineers to develop a "Standard Upper level Ontology" based on KIF [18]. This is designed to provide definitions for between 1000 and 2000 general purpose terms in such a way as to yield a common structure for low-level domain ontologies of much larger size and more specific scope. The ontologies were first divided into two classes, those defining very high-level concepts and those defining lower-level notions. The highest level contains J. Sowa's upper-level ontology and Russell-Norvig's upper-level ontology, and the second level contains a number of further concepts. From this and the above considerations of sections 5.2 and 5.3 follows that the SUO-ontology does not satisfy our criteria for an upper-level ontology.

6 Conclusions

The development of an axiomatized and well-established upper-level ontology is an important step towards a foundation for the science of Formal Ontology in Information Systems. Every domain-specific ontology must use as a framework some upper-level ontology which describes the most general, domain-independent categories of reality. For this purpose it is important to understand what an upper-level category means, and we proposed some conditions that every upper-level ontology should satisfy. The development of a well-founded upper-level ontology is a difficult task that requires a cooperative effort to make significant progress.

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