GOL: A General Ontological Language [1]

Wolfgang Degen
IMMD, Universität Erlangen
degen@informatik.uni-erlangen.de

Barbara Heller
IMISE, Universität Leipzig
heller@imise.uni-leipzig.de

Heinrich Herre
Institut für Informatik
Universität Leipzig
herre@informatik.uni-leipzig.de

Barry Smith
Department of Philosophy
SUNY Buffalo, NY 14260
phsmith@buffalo.edu

Abstract:
Every domain-specific ontology must use as a framework some upper-level ontology which describes the most general, domain-independent categories of reality. In the present paper we sketch a new type of upper-level ontology, which is intended to be the basis of a knowledge modelling language GOL (for: 'General Ontological Language'). It turns out that the upper-level ontology underlying standard modelling languages such as KIF, F-Logic and CycL is restricted to the ontology of sets. Set theory has considerable mathematical power and great flexibility as a framework for modelling different sorts of structures. At the same time it has the disadvantage that sets are abstract entities (entities existing outside the realm of time, space and causality), and thus a set-theoretical framework should be supplemented by some other machinery if it is to support applications in the ripe, messy world of concrete objects. In the present paper we partition the entities of the real world into sets and urelements, and then we introduce several new ontological relations between these urelements. In contrast to standard modelling and representation formalisms, the concepts of GOL provide a machinery for representing and analysing such ontologically basic relations.

1. Introduction

One important topic of formal ontology is the development of upper-level ontologies, which means: theories or specifications of such highly general (domain-independent) categories as: time, space, inherence, instantiation, identity, process, event, attribute, relation, and so on. Unfortunately, however, the upper-level ontologies of standard modelling languages such as KIF, F-logic and CyCL are confined to set-theoretical construction principles. Though set theory has considerable mathematical power and flexibility as a framework for modelling different sorts of structures it has at the same time the disadvantage that sets are abstract entities existing outside the realm of time, space and causality. When

FOIS'01, October 17-19, 2001, Ogunquit, Maine, USA.

we use set theory to model reality, this means that we divide the world into two sorts of entities. On the one hand are urelements, which form an ultimate layer of entities lacking any set-theoretic structure in their make-up. On the other hand are sets, which rise above these urelements in the familiar cumulative hierarchy. Are there relations among the urelements as these exist independently of the set-theoretic structures defined in their terms? We believe that the answer to this question is yes, and this means that there are ontological structures in reality which are not set-theoretical in nature. One may ask whether these ontological structures can be transformed into set-theoretical structures in such a way that the resulting set-theoretic objects capture the essence of the structures with which we begin. Philosophers have – in this spirit – attempted to reduce intensions to set-theoretic and therefore extensional entitites. We call this reduction-strategy *extensionalism* and consider it as an impediment for ontological research. All of the standard set-theoretic approaches are, in our opinion, essentially limited by the extensionalism of set theory, and so, too, are all the domain-specific and generic ontologies constructed with their aid. Illustrative examples of this phenomenon are presented und discussed in [9]. There have been several attempts to develop a more expressive upper-level ontology, for example by extending the ontology commonly associated with KIF [24]. Unfortunately, these attempts still employ the reduced ontological basis dictated by standard extensional set theory.

In the current paper we outline the upper-level ontology underlying the modelling language GOL (for General Ontological Language) [13]. GOL retains set theory as one part of its upper-level ontology [10]. Thus it accepts the set-theoretic membership relation as one ontologically basic relation. At the same time, however, it introduces several additional ontologically basic relations and entity-types. Thus, GOL is a genuine extension of KIF and of similar languages.

In section 2 we discuss and motivate what we take be the three most general ontologically basic categories of *set*, *individual* and *universal*. Section 3 is devoted to the basic classification of individuals into *moments*, *substances*, *chronoids*, *topoids* and *situoids*. Section 4 presents and motivates the system of ontologically basic relations of GOL. In section 5 the categories of *process*, *event* and *state* are analysed. In section 6 we formulate and defend a condition which we believe every upper-level ontology should satisfy, and we then compare the GOL-ontology to other upper-level ontologies.

2. Individuals, Universals, and Sets

In our approach, the entities of the real world are first of all partitioned into *sets* and *urelements*. Everything which is not a set is an urelement.

Urelements in turn are divided into *individuals* and *universals*. Thus neither individuals nor universals are sets according to the conception here defended. Individuals belong to the realm of concrete entities, which means that they exist within the confines of space and time. Universals, in contrast, are entities that can be instantiated simultaneously by a multiplicity of different individuals that are similar in given respects. We can think of universals as patterns of features which are realized by their instances. So we can say that universals exist *in* the individuals which instantiate them (they exist *in re*). This means that our conception of universals is broadly Aristotelian in spirit. We write $a :: u$ to denote that the individual a is an instance of the universal u. We assume that no individual can be a universal, and that the instantiation relation :: cannot be iterated, i.e. contexts of the form $a :: u \;\; :: u'$ are not admitted. On the other hand, there is the need in applications to admit universals whose instances are themselves universals including the universal 'Universal'. [25]. We propose to solve this problem by introducing universals of higher order. Ordinary universals are universals of first order and the instances of universals of (n+1)-th order are universals of n-th order. Instantiation relations of n-th order are then denoted by $::_n$, and the relation $::_1$ is also written ::. Since (as we shall argue) no universal is a set, it follows that all universals (of whatever order) are urelements.

We thus have three pairwise disjoint realms of entities: that of individuals, that of universals, and that of sets. In the philosophical tradition different conceptions of universals and individuals have been advanced. Of these, the most commonly accepted is the conception according to which universals are *sets of individuals*. Certainly, if u is a universal, then we can form the set of its instances, i.e. $\{a : a :: u\}$. Unfortunately however, to identify universals with the sets of their instances does not do justice to the intensional character of universals. Universals such as *man* and *featherless biped* differ because they have different intensions, even though the sets of their instances (their extensions) are identical. Richard Montague [15] and others have attempted to reduce intensions to set-theoretic and therefore extensional entities via appeal to the notion of functions across possible worlds. Universals are thereby reduced to sets, but only at the ontological price of admitting possible in addition to actual entities. We hope to show, by demonstrating the power of the GOL framework, that it is not neccessary to pay this price.

Some philosophers have held, contrariwise, that individuals can be conceived as sets (or "bundles") of universals. This, however, faces difficulties above all in dealing with the different temporal profiles of the entities identified. To put it simply: a man can die, but a set cannot die, since every set is outside space and time. This argument can be used to dispose also of another popular conception of individuals according to which individuals are *sets of individualized properties*, sometimes also called tropes.

3. Ontologically Basic Types of Individuals

As concerns individuals we begin with a tentative classification into *moments, substances, chronoids, topoids* and *situoids*, all terms which will be explained in more detail in what follows. The predicates: $Mom(x)$, $Subst(x)$, $Chron(x)$, $Top(x)$, $Sit(x)$ are then defined in the obvious way. Each corresponds to a universal, so that in particular $Subst(x)$ if and only if x belongs to the extension of the universal we shall call *Substance*, $Chron(x)$ if and only if x belongs to the extension of the universal we shall call *Time*, and $Top(x)$ if and only if x belongs to the extension of the universal we shall call *Space*.

Substances and Moments. Substances are individuals. A *substance* is that which can exist by itself, or does not need another entity in order to exist. Examples of substances are: you and me, the moon, a tennis ball. A *moment*,[2] in contrast, is an entity which can exist only in another entity (in the way in which, for example an electrical charge can exist only in some conductor).

Moments include actions and passions, a blush, a handshake, a thought. Moments thus comprehend what are sometimes referred to as events. Moments have in common that they are all dependent on substances. Some moments are one-place *qualities*, for example of colour or temperature. But there are also relational moments – for example kisses or conversations – which are dependent on a plurality of substances.

Every substance posesses material bulk. We can think of the world of substances as resting upon an underlying sea of matter (or matter-energy). Substances exist because the matter is formed in various ways which give rise to chunks separated off in more or less stable ways from their surroundings and possessing qualities of different sorts. This ultimate or prime matter, at least as Aristotle conceives it, is in a sense *bare*: it does not have moments of its own. Rather moments enter in only where prime matter is formed into substances, and it is, again according to Aristotle, only in and through such forms that matter can be apprehended in perception or in scientific inquiry.

Situoids. A *situoid* is, intuitively, a part of the world that can be comprehended as a coherent whole and does not need other entities in order to exist. An example is: John's kissing of Mary in a certain environment. This situoid contains the substances 'John' and 'Mary' and a relational moment 'kiss' which connects them. These entities in isolation do not yet form a situoid, we have to add a certain environment consisting of further entities and a location to get a comprehensible whole: John and Mary may be sitting on a bench or may be walking through a park. The notion of being comprehensible as a whole will be elucidated formally in terms of an association relation between situoids, all of which are indiviuals, and certain universals.

We are always, at every stage of our lives, in a plurality of situoids, we see them, we are constituents of them, and we have attitudes toward them. Every coherent part of the world has a location in space and time, and thus we assume that every situoid captures a certain spatial region (called a topoid) and a certain temporal interval (called a chronoid). Situoids take into account the courses and histories of the entities occurring in them. The predicate $Sit(x)$ will be used for situoids in what follows.

A situoid always involves a certain cut through reality, which means: a certain granularity and point of view [5]. To capture this idea we assume that every situoid s has associated with it a certain finite number of universals, which are (roughly) those universals which we need to grasp in order to grasp the situoid itself.

[2] The origin of the notion of *moment* – which is similar to the notion of trope favored by Australian realist ontologist – lies in the theory of individual accidents developed by Aristotle in his *Metaphysics* and *Categories*. An accident is an individualized property, event or process which is not a part of the essence of a thing. We here use the term "moment" in a more general sense and do not distinguish between essential and inessential moments [18].

Situations. Situations are special types of situoids: they are situoids at a time, so that they represent a snap-shot view of some part of the world. Situations can be conceived as projections of situoids onto times or equivalently as situoids with an atomic framing chronoid. Our approach to situations differs from that of *Barwise* [2], [3]. Barwise did not elaborate an ontology of relations; thus in particular, the ontologically basic relations to be described in section 4 are missing from his theory. There is nothing in his theory that corresponds to substances and the moments which inhere in them. In fact Barwise uses abstract situations in order to analyse, describe and classify real situations. Unfortunately, however, abstract situations are set-theoretical constructions which can capture only limited aspects of the ontology of real situations.

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. On one version of the theory chronoids and topoids have no independent existence; they depend for their existence in every case on the situations which they frame. For a situoid s let *chr(s)* and *tp(s)* be the chronoid and the topoid framing s. If $t \leq chr(s)$ then $s \downarrow t$ is the situoid which results from the projection of s onto the subinterval t. $\leq$ here signifies: is a proper or improper part of. Obviously, the projection of a situoid onto a subinterval is itself a situoid.

Every substance $x \in Sub(s)$ 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 relation moment connecting substances $\{x_1, \ldots, x_k\}$, then *lifetime(n)* $\leq$ *lifetime*(x_i), $i \leq k$.

Our approach to space and time is based on the ideas of Brentano [6], who developed and elaborated Aristotle's remarks in the *Physics* about boundaries and continua. Chisholm [7], [8] is a first step towards interpreting Brentano's ideas in a formal manner, and this work is continued and extended in [20] and [22].

4. Ontologically Basic Relations

4.1 Relations

Relations are entities which glue together the things of the real world. Without relations the world would fall asunder into so many isolated pieces. Every relation has a number of *relata* or *arguments* which it serves to connect together. The number of a relation's arguments is called its arity. We admit the possiblity of anadic relations, i.e. relations with an indefinite number of arguments. Relations can be classified also 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 classes, called *material* and *formal*, respectively. Intuitively, a material relation is an entity in its own right. Kisses, contracts, conversations, for example, are material relations which connect individual persons and include certain material relational events as part. We assume that material relations are individuals. A formal relation, in contrast, is not something which exists in its own right, but rather something which comes into being only because other entities are attached or related to each other. A formal relation is a relation which holds between two or more entities directly – without any further intervening individual. Examples are: *larger than*, *part-of*, *different from*, *dependent on*.

4.2 Holding Relation, Facts and Configurations

Holding Relation and Facts. One important formal relation is called the *holding relation*. If r is a material relation 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, symbolized by $:h(r, a_1, \ldots, a_n)$. 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*. Note that the a_i are not necessarily individuals, for example the fact *Mary is speaking about humanity* can be represented as the material fact $\langle speaking, Mary, humanity \rangle$, where the material relation "speaking" (in the sense of an individual speech act) connects *Mary* with the universal *humanity*. Material facts are in every case constituents of situoids, and situoids are collection of facts into wholes. A material fact $\langle r : a_1, \ldots, a_n \rangle$ has a duration, which depends on the lifetime of the material relation r.

Configurations. A configuration c in the situoid s is defined as some result of taking a collection of substances and other individuals occurring in s and adding moments and material relations from s which serve to glue them together. A configuration c over the subinterval $i \leq chr(s)$ is a configuration in the situoid $s \downarrow i$.

4.3 Relational Universals

A material relational universal is a universal whose instances are material relations. For every material relational 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 material relational universal R there exists a *factual universal* $F(R)$ whose extension equals the set *facts(R)*. Take, for example, the material relational universal u_K whose instances are individual kisses. Then we may form a factual universal $F(u_K)$ having the meaning *A person a kisses a person b* whose instances are all facts of the form $\langle k : a, b \rangle$, where k is an individual kiss and a, b are individual persons (k, a and b, here, are variable terms). There are sub-universals $F(u_K, J, M)$ of $F(u_K)$, say, with the meaning: *John kisses Mary*, whose instances are all facts of the form $\langle k : J, M \rangle$ where J, M are the individuals *John* and *Mary*. Natural-language sentences of the form *A man kisses a woman* or *John kisses Mary* can be interpreted as referring to factual universals. Their indexicalizations (*John* *is kissing May now*) refer to the corresponding instances.

4.4 Material Relations

Material relations can be classified with respect to their order. A material relation is said to be of first order if it relates substances exclusively. Examples of first-order material relations are those relational moments – for example kisses or handshakes – whose arguments are substances. A material relation is of $(n+1)$st order if the highest order of material relations it relates is equal to n. For example, if John kisses Mary, then there is an individual kiss k relating John and Mary. Hence k is of the first order. But there are two other material relations: an individual 'doing' and an individual 'suffering' relating John to k and k to Mary, respectively. Hence, individual doings and individual sufferings are material relations of second order. It is also possible that non-relational moments are connected by higher-order relational moments. For example the individual redness of my bruise is dependent on the bruise itself, which is in turn dependent on me.

4.5 Basic Relations

We can distinguish the following basic ontological relations, which are needed to glue together the entities mentioned above. The first and most familiar is that of membership, denoted by $\in$. Then come the part-of relations, denoted by $<$ and $\leq$ (for proper and reflexive part-of). We assume that the part-of relations $<, \leq$ have individuals in both arguments. Smith [19] considers a framework like GOL which recognizes in addition a part-of relation which holds between universals and the individuals in which they are instantiated.

Other basic relations include:

- the holding relation $:h$,
- the inherence relation, denoted by $:i$,
- the relativized ternary part-of relation, symbolized by $:<$,
- the instantiation relation, denoted by $::$,
- the framing relation, denoted by $\sqsubset$,
- the containment relation, denoted by $\rhd$, and
- the association relation, denoted by $:a$.

We shall discuss each of these in turn.

Inherence. 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 $:i$ – 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.

Relativized Part-Whole. The ternary part-whole relation $:<(x, y, u)$ has the meaning: "u is a universal and x is a part of y relative to u". Briefly, if *x is a u-part of y* in this sense, then x and y are parts of instances of the universal u and

$x \leq y$. But more is involved, since again the notions of granularity and point of view are at issue. We propose the following axiom: for every universal u there are universals $u_1, \ldots, u_n$ such that $:<(x, y, u)$ implies that x, y are instances of one of the u_i's and every instance of one of the u_i's is part of an instance of u.

Consider the following example, taken from the domain of biology. Let u_T be the biological universal whose instances are those organisms called trees. Then $:<(x, y, u_T)$ describes the part-whole relation which imposes upon the parts it recognizes a certain granularity, the granularity of *whole trees*. A biologist is interested in describing the structure of trees only in relation to parts of a certain minimal size. Thus 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, $1 \leq i \leq k$, or they can be decomposed into a finite number of parts, each of which satisfies this condition. Examples of relevant u_i would be *branch of a tree*, *leaf of a tree*, *trunk of a tree*, *root of a tree*, and so on.

Instantiation. The symbol :: denotes the instantiation relation. Its first argument is an individual, and its second a universal. If $x :: u$, then u is a certain time- and space-independent pattern of features and x is an individual in which this pattern of features is realized. x might be, for instance, a molecule of DNA, u a pattern of features shared by all exactly similar molecules, where the notion of exact similarity is determined by the granularity and point of view of genetic science.

Containment. The containment relation $\triangleright$ holds between the constituents of a situoid and the situoid itself. The constituents of a situoid s include, among other entities, the pertinent substances and the moments inhering in them. But also facts and configurations are constituents of situoids.

Framing. Every situoid, for example the fall of a stone in a certain environment, consumes an amount of time and occupies a certain space. The binary relation of framing $\sqsubset$ glues chronoids or topoids to situoids. We presume that every situation is framed by a chronoid and a topoid. The relation $x \sqsubset y$ is to be read: 'the chronoid (topoid) x frames the situation y'. Obviously, $\sqsubset$ is a formal relation (no further entity is needed to link the chronoid with the situoid it frames). Let s be a situation, then $chr(s)$ denotes the chronoid framing s; $tp(s)$, similarly, denotes the topoid framing s.

Location. The binary relation $:o(x, y)$ describes a fundamental relation between substances and topoids. $:o(x, y)$ can be read: the substance x occupies the topoid y (roughly: x is located in y).

Association. The relation $:a(s, u)$ has the meaning: s is a situoid and u is a universal associated with s. These universals determine which material relations and individuals occur as constituents within a given situoid and thus which granularities and viewpoints it presupposes. For example, a situoid s may be a part of the world capturing the life of a tree in a certain environment. If a tree is considered as an organism then the universals associated with s determine the viewpoint of a biologist and the associated granularity of included individuals (branches are included, electrons not).

The basic relations are summarized in the following table.

Symbol	Name	Definition
$x \in y$	membership	x is an element of the set y
$x < y$	proper part-of	x is a proper part of y
$:\!<(x, y, z)$	relativized part-of	x is a part of y relative to to the universal z
$x :: y$	instantiation	x is an instance of the universal y
$:\!i(x, y)$	inherence	the moment x inheres in the substance y
$x \sqsubset y$	framing	the topoid (chronoid) x frames the situoid y
$x \triangleright y$	containment	x is a constituent of the situoid y
$:\!o(x, y)$	location	the substance x occupies the topoid y
$:\!h(x, y_1, \ldots, y_n)$	holding	the material relation x connects the individuals $y_1, \ldots, y_n$ in this order
$:\!a(x, y)$	association	the universal y is associated with the situoid x

5. Processes

The notion of process rests on the idea of a transition from one configuration to another configuration within a situoid s. Let s be a situoid and $chr(s)$ the chronoid framing s and let i and j be two time intervals which are temporal parts of $chr(s)$ and let c_1, c_2 be configurations in s.

The interval i meets the interval j, denoted by $m(i, j)$, if the upper boundary of i is coincident with the lower boundary of j. Then a configuration c_1 goes over to the configuration c_2 with respect to (i, j), denoted by $(c_1, i) \Rightarrow (c_2, j)$, if c_1 is a configuration over i and c_2 is a configuration over j and $m(i, j)$.

A *process* over i is a sequence of configurations $\{(c_n, i_n) \mid n < \kappa\}$, where $0 < \kappa \leq \omega$, within the situoid s during the subinterval $i \leq chr(s)$ which is such that $(c_n, j_n) \Rightarrow (c_{n+1}, j_{n+1})$ and $j_n \leq i$. A process is assumed to be a constituent of a situoid. A typical example of a process is a football match. We may consider the universal "football match" denoted by u_F. Every instance of u_F is a sequence of configurations of twentytwo players and one ball within a suitable situoid and during a time interval of about 120 minutes (including the break). Another example is a disease, say malaria. Each instance of the universal *malaria* is a concrete process realized by a sequence of configurations containing a person (as a substance) within a situoid and taking into account certain changing moments associated with the disease. During the whole process there are intervals free of abnormal symptoms, and also events within the lifetime of the affected person which have nothing to do with the disease.

An *event* is a transition from a configuration c into a new configuration c_1 within a situoid s which is such that in c_1 something new (a new moment, a new substance) comes into existence or some present constituent of c goes out of existence. Examples are a plane crash, the becoming red of a cube of glass, the arriving of a train at a station, the death of a person. Among the processes are some which exhibit only very small changes during a given time. Examples are the processes intrinsic to a concrete thing such as a stone. The sequences of such configurations could be called invariant states. (At the subatomic level, of course, even a stone manifests many changes; thus here again the factor of *granularity* needs to be taken into account.)

An important open problem is how to define suitable equivalence relations between situoids. Such equivalence relations would allow us to understand, for example, what it means to say that an experiment can be repeated arbitrarily often. Here too granularity is an issue.

6. Upper-Level Ontologies

6.1 Conditions on Upper-Level Ontologies

An upper-level ontology must, we hold, satisfy the following criteria: it must include at least the three ontological categories: individuals, universals, and sets, together with a system of relations and predicates containing the basic relations described in the previous sections. These form the neccessary core of every ontology. It will need to be extended by further basic relations, including those treating *space*, *time*, and *shape* as well as topological relations such as *boundary* and *connectedness* [20]. The mentioned principles are the basis of the project GOL (General Ontological Language) [13]. How far are these criteria satisfied by other upper level ontologies?

6.2 Knowledge Interchange Format.

KIF, or *Knowledge Interchange Format*, is a formal language for the interchange of knowledge among computer programs written by different programmers at different times and in different languages. The ontology underlying *KIF* can be extracted from [12]; we summarize the main points as follows. The most general category of entity in *KIF* is that of *object*. This notion is quite broad: objects can be concrete (e.g. a lump of rock, Nietzsche, a molecule) or abstract (the concept of justice, the number two); objects can be simple or complex, and even fictional (e.g. a unicorn). In *KIF*, the only basic distinction is that between *individuals* and *sets*. A set is a collection of objects; an individual is any object that is not a set. The functions and relations in *KIF* are introduced as sets of finite lists. Obviously, the relations and functions in *KIF* correspond in *GOL* to the *extensional relations* belonging to the ontological region of sets. *KIF* does not provide ontologically basic relations like our inherence, part-whole and so forth. 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 set-theoretical part of *GOL*.

6.3 The Upper-Level Ontology of Russell and Norvig

The most general categories of the Russell-Norvig ontology sketched in [17] are *Abstract Objects* and *Events*. Abstract objects are divided into *Sets*, *Numbers*, and *Representational Objects*.

Events are classified into *Intervals*, *Places*, *Physical Objects*, and *Processes*. This ontology does not satisfy the criteria set forth in section 6.1, 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 the class of sets. The instantiation relation is identified with membership, implying again a purely extensional view of universals. Besides this the ontology includes the part-of-relation. An *event* in the Russell-Norvig ontology is what they call 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 our situoids are parts of the real world that can be comprehended as a whole. Morover universals are associated with situoids in a way which allows us to capture the fact that, for any given situoid, there is a certain granularity and a certain way of viewing the pertinent part of the world.

6.4 The Upper-Level Ontology of Sowa

John Sowa's ontology [23], too, does not satisfy the conditions laid down in section 6. Here again there is no clear distinction between sets, universals and individuals. Sowa draws a central distinction between classes and entities. Since these notions are interpreted in KIF they can be understood as corresponding to what, in GOL are referred to 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. Sowa's ontology uses two epistemic operators nec and poss, which are not found in KIF. But unfortunately he does not make clear the ontological character of these modal operators. In Sowa's ontology several classes are introduced, for example *relative*, *mediating*, *physical*, *abstract*, *continuant*, *occurrent*; these notions may be redefined within GOL.

6.5 The Upper-Level Ontology of LADSEB

In the LADSEB papers [11] and [14] some principles for an upper-level ontology are outlined. The rudimentary upper-level ontology implicit in these papers, partially satisfies our criteria of section 6.1.

Formal relations in the LADSEB framework are considered as relations which can hold between entities in all material spheres. This is distinct from the conception of formal relations defended here, where formal relations are understood as relators which hold without intermediaries. The examples of formal relations discussed in [11] include instantiation and membership, parthood, connection, location and extension, and dependence. The formal properties considered include concreteness, abstractness, extensionality, unity, plurality, dependence and independence. Instantiation, membership, and parthood are basic relations in our sense; the inherence relation is missing from the LADSEB framework. Its relation of spatial extension, defined by $E(x, y) = x$ *is the extension of* y, can be modelled by our relation $:o(x, y)$ (the entity x occupies the topoid y).

6.6 The SUO Project

SUO is a project sponsored by the Institute of Electrical and Electronic Engineers to develop a "Standard Upper-Level Ontology" based on KIF [24]. 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. SUO is in effect a conservative extension of J. Sowa's upper level ontology and Russell-Norvig's upper level ontology achieved by the addition of a number of further concepts. From this and the considerations advanced above in of sections 6.3 and 6.4, it follows that the SUO-ontology, too, does not satisfy our criteria for an upper level ontology.

7. Conclusions

The development of a well-grounded, axiomatized 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. We presented and discussed part of an ongoing project aimed at the construction of an ontological language GOL containing an upper level ontology powerful enough to serve as a framework for modelling complex domain-specific ontologies.

8. Acknowledgements

Smith's contribution to this work was partially supported by National Science Foundation Grant No. BSC-9975557 ("Ontology and Geographic Categories").

References

[1] Aristotle. *Complete Works*, edited by Jonathan Barnes, 2 vols., Princeton: Princeton University Press, 1984.

[2] Barwise, J. and Perry, J., *Situations and Attitudes*, Cambridge, MA: The MIT Press, 1984.

[3] Barwise, J., *Situations in Logic*, CSLI No. 17, 1989.

[4] Borgo, S., Guarino, N. and Masolo, C. Qualitative Spatial Modelling Based on Parthood, Strong Connection and Congruence; LADSEB-CNR, Technical Report 03/96 (1996).

[5] Bittner, T., Smith, B. A Taxonomy of Granular Partitions, in: Daniel Montello (ed.) *Spatial Information Theory*; Proceedings of COSIT' 2001, Santa Barbara, September 2001, Berlin/New York: Springer.

[6] Brentano, F. *Philosophische Untersuchungen zu Raum Zeit und Kontinuum*; Hamburg; Felix Meiner Verlag, 1976. English translation as

Philosophical Investigations on Space, Time and the Continuum, London: Croom Helm, 1988.

[7] Chisholm, R. M. Boundaries as Dependent Particulars, *Grazer Philosophische Studien*, 20, 87-96.

[8] Chisholm, R. M. *On Metaphysics*, Minneapolis: University of Minnesota Press, 1989.

[9] Copeland, J. B. CYC: A Case Study in Ontological Engineering, 1997, *Electronic Journal of Analytic Philosophy*, vol. 5 (1997), http://www.phil.canterbury.ac.nz

[10] Degen, W., Heller, B., Herre, H. Contributions to the Ontological Foundation of Knowledge Modelling, Report Nr. 02 (2001); Institute für Informatik, Universität Leipzig.

[11] Gangemi, A., Guarino, N., Masolo, C., Otramari, A. Understanding Top-Level Ontological Distinctions. Technical Report 04/2001, LADSEB-CNR.

[12] Genesereth, M. R., Fikes, R. E. Knowledge Interchange Format, Version 3.0, Reference Manual, Logic Group Report Logic-92-1, Computer Science Department, Stanford University.

[13] http://www.ontology.uni-leipzig.de.

[14] Guarino, N. Formal Ontology and Information Systems, in: N. Guarino (ed.) *Formal Ontology in Information Systems. Proceedings of FOIS' 98, Trento, Italy*, Amsterdam, IOS-Press.

[15] Montague, R. *Formal Philosophy*, New Haven: Yale University Press, 1974.

[16] Ramsey, F. R., Universals, in: *Foundations* (edited by D. H. Mellor), London, Routledge and Kegan Paul, 1978.

[17] Russell, S., Norvig, P., *Artificial Intelligence*, Prentice Hall, 1995.

[18] Smith, B. (ed.) *Parts and Moments. Studies in Logic and Formal Ontology*, Munich, Philosophia, 1982.

[19] Smith, B. On Substances, Accidents and Universals. In Defence of a Constituent Ontology. *Philosophical Papers* 26, (1997), 105-127.

[20] Smith, B. Boundaries: An Essay in Mereotopology, in L. Hahn, ed. *The Philosophy of R. Chisholm*, LaSalle: Open Court, 1997, 534-561.

[21] http://philosophy.buffalo.edu/faculty/smith.

[22] Smith, B. and Varzi, A.C. Fiat and Bona Fide Boundaries, *Philosophy and Phenomenological Research* 60:2, March 2001, 401-420.

[23] Sowa, J. http://www.bestweb.net/sowa/ontology/toplevel.htm.

[24] SUO: http://suo.ieee.org.

[25] Welty, A. C., Ferucci, D. A. Instances and Classes in Software Engineering, *Artificial Intelligence*, Summer 1999, 24-28.