GOL: Towards an Axiomatized Upper-Level Ontology

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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, and we outline an associated knowledge modelling language called GOL (for: "General Ontological Language"). It turns out that the upper-level ontology underlying well-known standard modelling languages such as KIF, F-Logic and CycL is restricted to the ontology of sets. In a set theory which allows Urelements, however, there will be ontological relations between these Urelements which the set-theoretic machinery cannot capture. In contrast to standard modelling and representation formalisms, GOL provides a machinery for representing and analysing such ontologically basic relations. GOL is thus a genuine extension of KIF and of similar languages. In GOL entities are divided into sets and Urelements, the latter being divided in their turn into individuals and universals. Foremost among the individuals are things or substances, tropes or moments, and situoids (entities containing facts as components).

1 Introduction

One important topic of formal ontology is the development of upper-level (or top-most) ontologies, which means: theories or specifications of such highly general (domain-independent) categories as: time, space, inherence, instantiation, identity, processes, events, attributes, relations etc. It turns out that the upper-level ontology of the well-known standard modelling languages KIF, F-logic and CyCL are confined to set-theoretical construction principles, so that the latter are essentially limited by the extensionalism of set theory. All domain-specific and generic ontologies constructed within the framework of the aforementional standard languages also inherit the ontological weaknesses of set theory.[1]

There have been several attempts to develop a more expressive upper-level ontology, for example by extending the ontology of KIF. Unfortunately, the known projects still employ the reduced ontological basis dictated by standard extensional set theory.

In the current paper we outline a modelling language GOL (General Ontological Language) which adopts a new approach based on recent results in formal ontology. The modelling language GOL preserves set theory as a part of the upper-level ontology. Thus it accepts the set-theoretic membership relation as ontologically basic. At same time however it introduces several new types of ontologically basic entities and relations. Thus, GOL is a genuine extension of KIF and of similar languages.

GOL is an ongoing project which is aimed at the construction of an ontological language powerful enough to serve as a framework for modelling complex ontological structures, especially in the medical field. In section 2 we discuss and motivate several ontologically basic

[1] Illustrative examples of this phenomenon are presented und discussed in [9].

categories, and in section 3 a modelling language GOL is outlined. Section 4 presents some examples showing the benefit and use of some the introduced basic categories, and in section 5 we compare GOL to other languages.

2 Ontologically Basic Relations and Types

In this section we will introduce and discuss several ontologically basic types of entities and certain basic relations between them. Basic types of entities and basic relations are called in the sequel by the common name "basic categories". Our analysis draws on [21], but adds the idea of large ontological regions such as the region described by set theory. The ontological constituents of the real world are certain types of entities as individuals, universals, sets, and immediately connecting relations as inherence, instantiation, and membership. Immediately connecting relations hold of their relata without mediating additional entities; they hold as soon as their relata are given.

Ontologically Basic Types of Entities. Our main distinction is that between *urelements* and *sets*. We assume the existence of both urelements and sets and presuppose that both the impure sets and the pure sets constructed over the urelements belong to the world. Urelements are entities which are not sets. By a class we understand a collection of entities defined by a condition.

We shall assume the existence of two main categories of urelements, namely *individuals* and *universals*. An individual is a single thing located in some single region of spacetime. 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. For every universal u there is a set $\mathrm{Ext}(u)$ containing all instances of u as elements. The individuals are further subcategorized into *moments, substances, chronoids, topoids* and *situoids*[2] -terms which will be explained in more detail in what follows. This yields (at least) the following ontologically basic predicates: $Mom(x)$, $Subst(x)$, $Sit(x)$, $Chron(x)$, $Top(x)$. We assume, that $Subst(x)$ is the extension of a universal we shall call *Substance*, $Chron(x)$ is the extension of a universal we shall call *Time*, and $Top(x)$ is the extension of a universal we shall call *Space*.

Substances are individuals. A *substance* is that which can exist by itself, or does not need another entity in order to exist. A substance is that which bears individual properties or is connected to other substances by relational moments. A substance cannot be a bearer of arbitrary individual properties. By the *appearance* of a substance we understand the moments it bears and the relational moments connecting it to other substances. We assume the axiom that every substance has an (non-empty) appearance. An *alignment* $\langle a_1, \ldots, a_n\rangle$ is a sequence of substances $a_1, \ldots, a_n$, 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*. 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

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

common that they are all dependent on substances. Relational moments are dependent on a plurality of substances.

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. The notion of an object is not subjected to analysis, and there is nothing in his theory that corresponds to substances and the moments which inhere in them. Situation theory in the sense of [2] uses abstract situations in order to analyse, describe and classify real situations. However, abstract situations are set-theoretical constructions which can capture only limited aspects of the ontology of real situations.

Chronoids and *topoids* are instances of the universals Time and Space. Chronoids can be understood as temporal durations, and topoids as spatial regions with a certain mereotopological structure. Chronoids and topoids have no independent existence; they depend for their existence on the situations which they frame. Our approach to space and time is based on the ideas of *F. 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 idea in a formal manner, and this work is continued and extended in [22].

Ontologically Basic Relations. What are the basic ontological 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 and discuss 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 $:\rhd$, 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. We exclude the possibility that the relation $:\succ$ can be iterated, thus there are no moments inhering in moments; on the other hand it is conceivable that there are higher-order ontological dependency-relations between moments, but these are not covered by the present theory.

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 substances 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". Let s be a situation, then $chr(s)$ denotes the chronoid framing s.

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 substance x occupies the topoid y.

Note that none of these relations can be cashed out in set-theoretic terms. A universal, for example, is a pattern of features which cannot be captured by the set of its instances. There may be different universals with the same set of instances.

3 Outline of a Modelling Language

In this section we will outline a modelling language using the concepts which were expounded in the preceding sections.

3.1 Syntax and Axioms

Our intended modelling language *GOL* (General Ontological Language) 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)	$Subst(x)$	(substance)
$Sit(x)$	(situoid)	$Sitel(x)$	(elementary situoid)	$Chron(x)$	(chronoid)
$Top(x)$	(topoid)	$Align(x)$	(alignment)	$Aggr(x)$	(aggregate)

Symbols for binary and ternary basic relations.

$\in$	(membership)	$::$	(instantiation)	$:\succ$	(inherence)
$<$	(part-of)	$\leq$	(reflexive part-of)	$:\mu(x,y,z)$	(rel. part-of)
$:\sqsubset$	(framing)	$:\perp(x,y)$	(foundation)	$:\triangleright$	(is contained in)
$:occ(x,y)$	(x occupies y)	$:ass(x,y)$	(y ass. to y)	$:comp(x,y)$	(x component of y)

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: $r = s$, $t \in s$, $r :\succ \langle s_1, \ldots, s_n \rangle$, $v :: u$, $t \colon \sqsubset s$, $t \colon \rhd s$.

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

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]

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. $\forall x(Mom(x) \rightarrow \exists y(Align(y) \wedge x :\succ y))$
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] In the formula ϕ^{Set} all variables and quantifiers in ϕ are restricted to sets.

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. $\forall x(Sit(x) \rightarrow \exists t_1 t_2(Chron(t_1) \wedge Top(t_2) \wedge t_1 \colon \sqsubset x \wedge t_2 \colon \sqsubset x))$
2. $\forall x(Chron(x) \rightarrow \exists x_1 \exists s(Chron(x_1) \wedge Sit(s) \wedge x \leq x_1 \wedge x_1 \colon \sqsubset s))$
3. $\forall x(Top(x) \rightarrow \exists x_1 \exists s(Top(x_1) \wedge Sit(s) \wedge x \leq x_1 \wedge x_1 \colon \sqsubset s))$
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. $Cont\ (s) =_{df} \{m \mid m\colon \rhd s\}$
D2. $s \sqsubseteq t =_{df} Cont(s) \subseteq Cont(t)$.

1. $\forall x(Mom(x) \rightarrow \exists s(Sit(s) \wedge x\colon \rhd s)) \wedge \forall x(Subst(x) \rightarrow \exists s(Sit(s) \wedge x\colon \rhd s))$
2. $\forall x(Sit(x) \rightarrow \exists y(Subst(y) \wedge y\colon \rhd x))$
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.

3.2 Semantics of GOL

Let Σ be an ontological signature. An abstract Σ-interpretation is a first-order structure $\mathcal{W} = (W, \mathsf{Bas}^\delta, \Sigma^\delta)$, where W is a set, $\Sigma^\delta \cup \mathsf{Bas}^\delta$ are interpretations of the symbols from $\Sigma \cup \mathsf{Bas}$ in the set W, and $\mathcal{W}$ satisfies the axioms $Ax(GOL)$. $\mathcal{W}$ can be understood as a set-theoretical reflection of $\mathcal{R}$ (which is not a set). Truthmakers $\mathcal{T}$ are parts of the world $\mathcal{R}$ within which formulas from $L(GOL)$ may be satisfied. Then, $\mathcal{T} \models \phi$ means that the sentence $\phi \in L(GOL)$ is true in $\mathcal{T}$.

Here we consider truthmakers as situoids. Let $\mathcal{T}$ be a situoid and let $Cont(\mathcal{T}) = \{m \mid m \rhd \mathcal{T}\}$ (this is a class). Let ass($\mathcal{T}$)=$\{U_1, \ldots, U_n\}$ be the set of universals associated with $\mathcal{T}$. Let $\mathcal{C}(\mathcal{T}) = (Cont(\mathcal{T}), U_1, \ldots, U_n, \mathsf{Bas} \downarrow Cont(\mathcal{T}))$; where $\mathsf{Bas} \downarrow Cont(\mathcal{T}))$ is the restriction of the relations from Bas to the class $Cont(\mathcal{T})$.

Let $\phi \in GOL$ be an arbitrary formula and $\mathcal{T}$ be a situoid. A function ν is an *anchor* for ϕ in $\mathcal{T}$ if ν associates to every symbol in $sign(\phi)$ an element from $Cont(\mathcal{T})$. Here, $sign(\phi)$ is the set of all free variables in ϕ and all symbols denoting contants, universals or sets. The function ν has to preserve the type of the symbol to which it is applied. We may then define, using Tarski's definition of truth, the notion "The anchor ν satisfies the sentence ϕ in $\mathcal{C}(\mathcal{T})$", which is symbolized by $\mathcal{T} \models_\nu \phi$. This yields a semantics for GOL which can be used to give meanings also to many varieties of natural language sentences. Firstly, we will translate a natural language sentence ϕ into an expression $tr(\phi)$ of $L(GOL)$ and then we will interpret the formula $tr(\phi)$ using the semantics for $L(GOL)$ just sketched. We demonstrate this idea by an example.

Let us consider the sentence ϕ = "John is kissing Mary". The words "John" and "Mary" denote individuals (persons, human beings). The word "kissing" denotes a certain moment, an instance of the universal u_{KE} (for "kissing-event"). A suitable translation $tr(\phi)$ of ϕ to GOL gives the following sentence: $\exists x(x :: u_{KE} \wedge x :\succ \langle j, m \rangle)$, where the words "John" and "Mary" are replaced by the individual constants "j" and "m". Then, $tr(\phi)$ is satisfiable in a certain situoid $\mathcal{T}$ iff there is an anchor ν for $tr(\phi)$ in $\mathcal{T}$ such that $\mathcal{T} \models_\nu tr(\phi)$. The *ontological meaning* of a natural sentence ϕ of this simple form could be defined as the class of all situoids, denoted by $Ont(\phi)$, in which $tr(\phi)$ is satisfiable.

4 Examples

The following remarks show the usefulness of our ternary part-of-relation and of the category of situoids.

4.1 The relation $\nu(x, y, z)$

The ternary part-whole relation $:\mu(x, y, z)$ is domain specific and depends on the universal z. We demonstrate the usefulness of the relation $:\mu(x, y, z)$ by means of an example. Let U_T be a biological universal whose instances are trees (as plants); then $\nu(x, y, U_T)$ 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 of molecules. The description of the part-of relation related to the macroscopic biological structure of trees requires that we introduce a formal system of axioms $Ax_\nu(U_T; U_1, \ldots U_k)$ of the following kind. The universals $U_1, \ldots, U_k$ describe those entities which are admissible parts of the instances of U_T. The following axioms then capture the intention of "being a part of a tree in the sense of U_T".

1. $\forall xy(:\mu(x, y, U_T) \rightarrow \exists z(z :: U_T \ \wedge \ x \leq z \ \wedge y \leq z \ \wedge \ x \leq y))$
2. $\forall xy(:\mu(x, y, U_T) \rightarrow (\bigvee_{i \leq k} x :: U_i \vee x :: U_T) \ \wedge \ (\bigvee_{i \leq k} y :: U_i \vee y :: U))$
3. $\forall x(\bigvee_{i \leq k} x :: U_i \rightarrow \exists z(z :: U_T \ \wedge \ x \leq z))$.

Axiom 1 says that only such individuals a, b stand in the relation $:\mu(a, b, U_T)$ which are parts of a tree. Axiom 2 states that only such parts of a tree are considered which are described by the universals $U_1, \ldots, U_k, U_T$. Among the universals $U_1, \ldots, U_k$ are those describing the notions "branch of a tree", "leaf of a tree", "trunk of a tree", "root of a tree", etc.

4.2 Situoids.

Situoids can be used to analyse, to classify and to define dynamic phenomena and entities as change, processes, events and states. In the sequel we make some of the ideas in [16] more explicit and formal.

The elements of $\{a \mid a \triangleright \sigma\}$ are called constituents of the situoid σ. $chron(\sigma)$ is the chronoid belonging to the situoid σ. Let σ be a situoid and $t \leq chron(\sigma)$ then $\sigma \downarrow t$ is a situoid wich is defined by the projection of σ to the subinterval t. Obviously, the projection of situoid is itself a situoid. $Subst(\sigma)$ ist the class of all substances occuring in σ. Let $X \subseteq Subst(\sigma)$ a class of substances being constituents of σ. A configuration of X is defined by taking the substances of X and adding some moments from σ gluing them together. Every configuration in σ has a *history* determined by the changes of this configuration during the chronoid of σ (or during some of its subintervals).

A *process* can be understood as a history of a configuration within a situoid. Then, also a situoid itself can be interpreted as a process, but not every process is a sitoid. A typical example of a process is a football match. We may consider the universal "football match" denoted by U(fbm). Every instance of U(fbm) is a history of a configuration of a number of players and a ball within a suitable situoid and during a time interval of about 120 min (including the break). Another example is a disease, say malaria. An instance of the universal Malaria is is a concrete process realized by a history of a person within a suitable situoid and taking into account certain changing moments associated to the disease *malaria*.

During the whole process there are intervals free of symptoms, and events within the life of the person which have nothing to do with the disease.

An *event* is an instantaneous change of a configuration x into a new configuration x_1 within a situoid σ which is such that in x_1 something new (a new moment, a new substance) appears which was not present in x. Examples are a plane crash, the becoming of 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 the time of a situoid. Examples are processes intrinsic to concrete things as a stone. The histories of such configurations could be called invariant states.

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.

5 Comparison to other Languages

In this section we compare our approach to that of *KIF*, [13] *F-logic*, [17], and the family of description logics. It turns out that these languages are rather weak because they are based on set theory, which is crippled by its extensionalism.

5.1 Knowledge Interchange Format.

Knowledge Interchange Format (*KIF*) is a formal language designed to serve as a single common framework for the interchange of knowledge between computer programs written by different programmers at different times and in different languages. *KIF* can be considered as a lower-level knowledge modelling language; when a program reads a knowledge base in *KIF*, it converts the data into its own internal form; when the program needs to communicate with another program, it maps its internal data structures into *KIF*.

The ontological basis of *KIF* can be extracted from [13]; we summarize here only 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 lump carbon, Nietzsche, the moon) or abstract (the concept of justice, the number two); objects can be primitive or composite, and even fictional (e.g. a unicorn). In *KIF*, as in GOL, 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. This distinction corresponds in *GOL* to the difference between urelements and sets. *KIF* adopts a version of the Neumann-Bernays-Gödel set theory, *GOL* assumes *ZF* set theory; but this difference is not essential. The functions and relations in *KIF* are introduced as sets of finite lists; here the term "set" corresponds to our term "class". Obviously, the relations and functions in *KIF* correspond in *GOL* to the ontology of sets. *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* is the set-theoretic part of *GOL*.

5.2 Frame-Logic.

The term "object-oriented approach" is only a loosely defined, and involves giving prominence to a number of notions, including those of complex objects, object identity, encapsulation, typing and inheritance. One of the main problems with the object-oriented approach is the lack of a logical semantics. Frame-logic is a language that accounts in a declarative fashion for most of the structural aspects of object-oriented and frame-based languages [17]. Furthermore, it is suitable for defining, querying, and manipulating database schemata. *F-logic* has a model-theoretic semantics and a sound and complete proof theory. *F-logic* stands in the same relationship to the object-oriented paradigm as classical predicate calculus stands to relational programming. The ontological basis of the language of F-logic is purely set-theoretical. The instantiation relation (for example between Tibbles and the universal cat) is modeled by the set-theoretic membership relation, the is-a-relation is explicitly defined in terms of instantiation. The ontological basis of this language seems to be even weaker than that of *KIF*, not least because full *ZF* or *GB*-systems are not available. Thus *F-logic*, too, captures only some extensional aspects of *GOL*.

5.3 Description Logic.

Description logics are specialized languages related to the *KL-ONE* system of Brachman and Schmolze [5]. They are designed for representing knowledge, and the general aim is to provide a small set of operations to describe pieces of information, together with efficient methods to make inferences. Description logics are generally considered to be variations of first-order logic involving some restrictions and perhaps some added operators. These variations are motivated by the undecidability of the inference problem for first-order logic and by the intention to preserve the structure of the knowledge to be represented.

The ontological basis of description logics is again set theory, in particular the semantics of the first-order predicate calculus. But in addition, as formulated in [18], the language has to be restricted to formulas of a certain form. The philosophy behind this is called in [11] the *restricted language thesis*. One argument is that general-purpose knowledge representation systems should restrict their languages by omitting constructs which lead to the undecidability of the classification problem. In [11] the position is taken that the restricted language assumptions are flawed. In wider practice the terminological facilities of such systems are so impoverished that the very purpose of general-purpose representational utilities is defeated.

5.4 CycL.

CycL was developed by Lenat and Guha [10] for the specification of common-sense ontologies. The semantics of the formal language *CycL*, too, is based exclusively on set theory, as *KIF* and F-logic. The language involves some additional notions for example four existential quantifiers (though these may be superflous since they can be reduced by explicite definitions to just one existential quantifier). The second-order quantification over predicates and functions captures only a restricted part of *ZF* or *GB-class theory* (which is used in *KIF*). Hence, the system *CycL* is weaker than *KIF* and the set-theoretic part of *GOL*.

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. 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. 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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