BARBARA HELLER and HEINRICH HERRE

ONTOLOGICAL CATEGORIES IN GOL

ABSTRACT. *General Ontological Language* (GOL) is a formal framework for representing and building ontologies. The purpose of GOL is to provide a system of top-level ontologies which can be used as a basis for building domain-specific ontologies. The present paper gives an overview about the basic categories of the GOL-ontology. GOL is part of the work of the research group *Ontologies in Medicine* (Onto-Med) at the University of Leipzig which is based on collaborative work of the *Institute of Medical Informatics (IMISE)* and the *Institute for Computer Science (IfI)*. It represents work in progress toward a proposal for an integrated family of top-level ontologies and will be applied to several fields of medicine, in particular to the field of *Clinical Trials*.

1. INTRODUCTION

In recent years research in ontology has become increasingly widespread in the field of information systems science. Ontologies provide formal specifications and computationally tractable standardized definitions of the terms used to represent knowledge of specific domains in ways designed to enhance communicability with other domains (Gruber 1995). The importance of ontologies has been recognized in fields as diverse as e-commerce, enterprise and information integration, qualitative modelling of physical systems, natural language processing, knowledge engineering, database design, medical information science, geographic information science, and intelligent information access. In all of these fields a common ontology is needed in order to provide a unifying framework of communication. The GOL-project started in 1999 as a collaborative research project of the *Institute for Medical Informatics* (IMISE) and the *Institute for Computer Science* (IfI). The project is aimed, on the one hand, at the construction of an ontological language powerful enough to serve as a formal framework for building and representing complex ontological structures, and, on the other hand, at the development and implementation of domain-specific ontologies in several fields, especially medical science (Heller *et al.* 2003b).

The term *Formal Ontology* has its origin in philosophy (Husserl) but here we use it in a special sense to designate a research area in theoret-

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ical computer science which is aimed at the systematic development of formalized axiomatic theories of all forms and modes of being, and at the elaboration and design of formal specification tools to support the modeling of complex structures of the real world. Ontologies have different levels of generality, and thus the question arises whether top-level ontologies, i.e. ontologies of the most general level, are needed in applications. Some people believe that top-level ontologies are important, others prefer to focus on domain-specific ontologies which are intuitively adequate for the needs of a special group or community. We assume as a basic principle of our approach that every domain-specific ontology must use as a framework some upper-level ontology which describes the most general, domain-independent categories of reality.

General Ontological Language (GOL) is a formal framework for building and representing ontologies. The purpose of GOL is to provide a system of formalized and axiomatized top-level ontologies which can be used as a framework for building more specific ontologies. GOL consists of a syntax, and of an axiomatic core which captures the meaning of the introduced ontological categories. The system of top-level ontologies of GOL is called GFO (General Formal Ontology). There is a debate whether the top-level ontology should be a single, consistent structure or whether the top-level ontology should be considered as a lattice of theories each of which may be inconsistent with theories that are not situated on the same path. There are arguments for and against the lattice approach. The arguments for a lattice of theories are, first, that there are multiple, incompatible, and – under certain assumptions – equally acceptable views on how to describe the world. Second, it seems to be possible that the adequateness of a top-level ontology depends on the domain of application. Against a multiple ontology one might argue that such lattices are more difficult to maintain and to use.

On the lattice approach ontologies are distinguished in two ways. On the one hand, ontologies may differ with respect to the basic categories of entities postulated. On the other hand, even if two ontologies use the same basic categories they may differ with respect to the axioms pertaining to these categories. Our general approach is to admit a restricted version of the lattice approach. We restrict the selection of top-level ontologies with different systems of basic categories but we are more liberal with respect to the admitted systems of axioms within a fixed system of ontological categories. In our opinion the investigation of a system of axioms with respect to its possible consistent extensions is an important research topic for its own.

2. SETS, CLASSES, AND URELEMENTS

In what follows we will discuss the ontologically basic entities and certain basic relations between them. The main distinction we draw is between *urelements*, *sets* and *classes*. Sets, classes and urelements constitute a metamathematical superstructure above the other entities of our ontology, but we also consider them to be entities in the world rather than mere formal tools. At the bottom of the class hierarchy we have the class U of urelements conceived as the realm of existing things in the world which are not sets.

Sets and Classes. The entities of the world are classified according to type. Sets and urelements are entities of type 0, and $C[0]$ is the class of all entities of type 0. Let $\tau_1, \ldots, \tau_n$ be types, and $C[\tau_i]$ the class of all classes of type τ_i, respectively. Then $C[\tau_1, \ldots, \tau_n]$ is the class of all classes of relations whose arguments are classes of types $\tau_1, \ldots, \tau_n$, respectively. A class is of finite type if it can be generated by a finite number of iterative steps. Let C_{FT} be the class of all classes of finite type. In our class hierarchy, C_{FT} is the top-most node.

Urelements. Urelements are entities which are not sets. Urelements form an ultimate layer of entities lacking set-theoretical structure in their composition. Neither the membership relation nor the subclass relation can reveal the internal structure of urelements. (Degen et al. 2001)

Lists. Let U be a class of entities. Then `List`(U) is the smallest class containing the empty list [] and closed with respect to the following condition: if $l_1, \ldots, l_k \in$`List`(U) $\cup$ U then $[l_1, \ldots, l_k] \in$ `List`.

We shall assume the existence of three main categories of urelements, namely *individuals, universals*, and *spatio-time entities*. Besides urelements there is the class of *formal relations*. We assume that formal relations are not universals, but classes of certain types. Besides these entities there are language-depended entities such as *definable relations* and *definable predicates*.

An *individual* is a single thing which is in space and time. A universal is an entity that can be instantiated by a number of different individuals. The individuals which instantiate a universal are similar in some respect. We assume that the universals exist in the individuals (*in re*) but not independently from them; thus our view is Aristotelian in spirit. A universal can also be understood as a *content of thought*.

For every universal U there is a set $Ext(U)$ containing all instances of U as elements. We assume the following axioms: that the class of urelements is the disjoint union of the class of individuals, the class of universals, and the class of space-time entities.

There are some refinements of the ontology of universals. We may assume that there are universals which can be instantiated by universals. Such *meta-universals* are of practical importance; an example is the concept of a *power class* in UML (Booch *et al.* 1999). In GOL meta-universals (and universals of higher order) are presented by classes of higher order, and the class hierarchy of GOL allows for arbitrary finite towers of meta-universals; these are needed in Software Engineering (Welty 1999).

3. SPACE-TIME

There are several basic ontologies about space and time. In the first top-level ontology of GOL which is reviewed in this paper chronoids and topoids represent kinds of urelements. Chronoids can be understood as connected temporal intervals, and topoids as spatial regions with a certain mereotopological structure. Chrono-topoids are four-dimensional space-time manifolds. On one version of our theory chronoids and topoids have no independent existence; they depend for their existence in every case on the situoids which they frame.

We assume that time is continuous and endorse a modified and refined version of an approach which is sometimes called the *glass continuum*. Chronoids are not defined as sets of points, but as entities *sui generis*. Every chronoid has boundaries, which are called time-boundaries and which depend on chronoids, i.e. time-boundaries have no independent existence and every chronoid has exactly two time-boundaries. The class TE of temporal entities consists of two disjoint sub-classes: the class Chr of chronoids and the class TB of time-boundaries; thus $TE = Chr \cup TB$. Every chronoid has inner time-boundaries which arise from proper sub-chronoids of a chronoid; $TB(c)$ denotes the class of all time-boundaries of the chronoid c. By a *temporal structure* we understand a sub-class of TE, i.e. the class TS of all temporal structures is defined by $TS = \{K : K \subseteq TE\}$. We assume that temporal entities are related by certain formal relations, in particular the *part-of relation between chronoids*, the relation of *being a time-boundary of a chronoid*, and the relation *of coincidence between two time-boundaries* which is denoted by *coinc*(x, y). In this approach to an ontology of time we are adapting ideas of Brentano (1976) and Chisholm (1983) and advance and refine the theory of Allen *et. al.* (1989).

A class K of chronoids is bounded if there is a chronoid c which contains every member of K as a temporal part. We stipulate a *continuity* *axiom* stating that for every bounded class K of chronoids there exist a least unique chronoid c containing every member of K as a temporal part. A *generalized chronoid* is the mereological sum of a class of chronoids. The *part-of relation* between chronoids is naturally extended to a part-of relation between generalized chronoids. There are two kinds of time boundaries: time-bondaries *looking in the future* and time boundaries *looking in the past*. We use the term *time-point* to denote entities consisting of two coinciding time boundaries: a *future boundary* and a *past boundary*. A *now* can be considered as a time point of this kind because from a *now* we may look in the future and in the past. There is the following branching point for axioms. One axiomatic system claims that there are no atomic chronoids, another system assumes that every non-atomic chronoid has an atomic part.

Our theory of topoids uses ideas from Brentano (1976), Chisholm (1983), Smith *et al.* (2000). Similar as in Borgo *et al.* (1996) we distinguish three levels for the description of spatial entities: the *mereological level* (mereology), the *topological level* (topology), and the *morphological level* (morphology). Topology is concerned with such space-relevant properties and relations as connection, coincidence, touching, and continuity. Morphology (also called qualitative geometry) analyses the shape, and the relative size of spatial entities. To describe the form of an object we adopt a relation of *congruence* between topoids holding between topoids with the same shape and size. For every topoid t we introduce a universal $U(t)$ whose instances are topoids that are congruent with t. This leads to a theory of shapes of pure topoids, separated from the theory of substances.

4. BASIC CATEGORIES OF INDIVIDUALS

Individuals are entities which are in space and time. That means that there are certain dependency relations relating individuals to spatio-temporal entities. Individuals can be classified with respect to their relation to space and time. The main distinction in the (first) GOL-ontology is between endurants and processes.

4.1. *Endurants and Processes*

There is a debate among philosophers concerning the distinction between processes and objects. According to the *endurantist* view there is a categorical distinction between objects and processes, while, according to the *perdurantist* view there are only processes in the most general sense of four-dimensionally extended entities. Endurantism and perdurantism have their respective advantages and disadvantages. One of the advantages of perdurantism is its simplicity; on the other hand, the advantage of endurantism is that it captures the intuitive distinction between objects and processes. In the top-level ontology of GOL reviewed in the current paper we assume the endurantist point of view. However, given our pluralist research commitments, we are also exploring perdurantist versions of top-level ontologies, as well as the 'recurrence view of persistence', a third option between endurance and perdurance (Seibt 1997, 2003).

The difference between endurants (elsewhere called 'continuants') and processes is their relation to time. An endurant is an individual which is in time, but of which it makes no sense to say that it has temporal parts or phases. Thus, endurants can be considered as being wholly present at a time-boundary. For endurants time is in a sense a *container*, thus endurants are *in time*, and endurants may be indexed by time boundaries. We use a relation $at(x, y)$ with the meaning *the endurant x exists at time-boundary y*. Let *Endur* be the class of all endurants and TB the class of all time-boundaries. Then we stipulate that *at* is a functional relation from *Endur* into TB, i.e. we assume the following axioms:

$$\forall x(Endur(x) \rightarrow \exists y(at(x, y))$$

$$\forall xy(at(x, y) \rightarrow Endur(x) \wedge TB(y))$$

$$\forall xyz(at(x, y) \wedge at(x, z) \rightarrow y = z)$$

These axioms raise the question of what it means that an endurant persists through time. We pursue an approach which accounts for the persistence of endurants by means of a suitable universal whose instances are endurants. Such universals might be called *abstract endurants*. A similar idea is pursued by Simon (2000) where he considers a continuant as an abstractum over occurrents under a certain equivalence relation.

Processes, on the other hand, have temporal parts and thus cannot be present at a time-boundary. For processes time *belongs to them* because they *happen in time* and the time of a process is built into it. The relation between processes and temporal structures is determined by a projection function $prt(x, y)$ saying that *the process x is projected onto the temporal entity y* or that y is the *temporal projection* of x. We assume that the temporal entity which a process is projected onto is a mereological sum of chronoids, i.e. is a generalized chronoid. Again, $prt(x, y)$ is a functional relation from the class *Proc* of all processes into the class GC of generalized chronoids, and we say also that *y frames x*. Thus,

$$\forall xyz(prt(x, y) \wedge prt(x, z) \rightarrow y = z).$$

There are yet two other projection relations, one of them projects a process p to a temporal part of the framing generalized chronoid of p. The relation $pr(p, c, q)$ has the meaning: p is a process, c is a temporal part of the chronoid which frames p, and q is the projection from p onto c. q can also be understood as the restriction of the process p to the generalized sub-chronoid c. The temporal parts of a process p are exactly the projections of p onto temporal parts of the framing generalized chronoid of p. The other relation projects processes onto time-boundaries; we denote this relation by $prb(p, t, e)$ and call the entity e onto which p is projected the *boundary of p on t*. Let *be* $B(p, t) = e$ if and only if $prb(p, t, e)$. As a bold basic tenet of the present version of GOL we postulate that the projection of a process to a time-boundary is an endurant.

Processes belong to a category which we call *occurrents*. The above projection relation $prt(x, y)$ will be generalized to arbitrary occurrents x; then y is – in the most general case – a temporal structure. Other types of occurents are: *histories, states, change, locomotion*, and *boundaries of processes*. Boundaries of processes are projections of processes to time-boundaries. Histories are families of endurants which are indexed by time-boundaries. Drawing on abstract endurants, histories and projections of processes to time-boundaries we explicate systematically the most important relationships between endurants and processes. All these entities will be considered in section 4.4.

4.2. *Substances*

In our ontology the notion of substance plays – in relation to time – three different roles: when we speak of *substances* simpliciter, we refer to endurants; *abstract substances* are universals which have substances as instantiations; finally, by *substance-processes* we refer to processes of a certain type.

Substances are individuals which satisfy following conditions: they are endurants, they are bearers of properties, they cannot be ‘carried by’ other individuals, and they have a spatial extension. The expressions ‘x carries y’ and ‘x is carried by y’ are technical terms which we define by means of an ontologically basic relation, the *inherence relation* which connects properties to substances. Inherence is a relation between individuals which implies that inhering properties are themselves individuals. We call such individual properties *moments* and assume that they are endurants. Moments include qualities, forms, roles and the like. Examples of substances are: an individual person, a house, the moon, a tennis ball (all of them considered at a time-boundary).

Every substance S has a spatial extension, which is called the *extension-space of* S, and occupies a certain spatial entity which is called the *spatial location of* S. Here we use a formal relation $occ(x, y)$ which means *the substance x occupies the spatial location y*. We consider the extension-space of S and the spatial location of S as different entities. The extension-space e of a substance S can be – in a sense – understood as an individual moment of S, similar as for example the individual weight or individual form of S. The formal relation $exsp(S, e)$ has the meaning: *e is the extension-space of S*, and we assume the following condition about this relation: $\forall \mathrm{S}e(exsp(S, e) \wedge exsp(S', e) \rightarrow \mathrm{S}= S')$.

We assume that the spatial location occupied by a substance is a topoid which is a 3-dimensional space region. A *physical object* is a substance with unity, and a closed substance is substance whose unity is defined by the strong connectedness of its parts. Substances may have (substantial) boundaries; these are dependent entities which are divided into surfaces, lines and space-points. Every (substantial) surface is the boundary of a substance, every line is the boundary of a surface, and every spatial point is the boundary of a line (Brentano 1973). We emphasize that the boundary of a substance is not the same entity as the boundary of its spatial location. Boundaries of two different substances are touching if parts of the boundaries of their occupied spatial locations coincide. In our *theory of substantial boundaries* two 'bona fide boundaries' may touch which is impossible in the approach of Smith *et al.* (2000). A topoid T *frames* a substance S if the location which is occupied by S is a part of T. We introduce the *convex frame f* of a substance S, denoted by the relation *convf(S,f)*, as the convex closure of the spatial location which is occupied by S.

Substances are related to time by the relation *at* (S, t) having the meaning that *S exists at time-boundary t*. But there is yet another relation between substance and time. What does it mean that a *substance persists through time* or that a *substance has a life-time*? To clarify the problem let us consider a term *John* which denotes a certain individual person *den(John)*. What kind of entity is *den(John)*? If we consider it as a substance then there is a time-boundary t such that *at(den(John),t)*. Because $at(x, y)$ is assumed to be a functional relation the entity *den(John)* depends on the time-boundary t, i.e. we have to add the parameter t to *den(John)*, which we denote by *den(John)(t)*. Obviously – with respect to this interpretation – the term *John* denotes an endurant for certain time-boundaries. Let *TB(John)* be the class of all time-boundaries t at which the term *John* denotes the endurant *den(John)(t)* and let $E(John) = \{den(John)(t)\ :\mathrm{t}\in TB(John)\ and\ at\ (den(John)(t),t)\}$.

To ensure that all these different endurants *den(John)(t)* present the *same* John we introduce a ontologically basic relation with the meaning that the substances x and y are *ontically connected*, and a universal *endur(John)* whose instances are just all elements of the class *E(John)*. Then we stipulate that two endurants $e(1)$ and $e(2)$ are equivalent with respect to *John*, i.e. represent the *same John*, if $ontic(e(1), e(2))$ and both $e(1), e(2)$ are instances of *endur(John)*. The relation $ontic(x, y)$ should satisfy – at least – the conditions of *spatio-temporal continuity* which are discussed by Le Poidevan (2002).

The *history of John*, denoted by *history(John)*, is defined by the class $\{$*(den(John)(k)*: $k \in TB(John)\}$ and a time-ordering $<$ on the set *TB(John)*. We say that a universal *U persists through the history of John* if every term of *history(John)* instantiates U. In this framework the *substance John* can be understood as an abstractum *endur(John)* which – by definition – persists trough time. We call the universal *endur(John)* an *abstract substance*. We hold a similar position as Simons (2000) that abstract substances are invariants amid diversity, and that what is true of them is true of their associated class of concrete instances.

Many opponents of endurantism claim that those terms that traditionally have been taken to denote substances denote processes. Thus Lewis (1983, pp. 76 ff.) claims that human beings have temporal parts. In our opinion there is no real incompatibility between substances as we define them and processes. Thus, the term *John* designates also a process having temporal parts, denoted by *process(John)*. We call processes of this kind *substance-processes*. As noted above, the projection of *process(John)* to a time-boundary t is a substance *John(t)*; projections of a process p to time-boundaries are called hereafter 'boundaries of p.' By definition the class of all boundaries of *process(John)* coincides with the full history of *John*. The connection between the time-boundaries is given, then, by the process itself. In general, we assume that time-indexed histories of endurants are entities which depend on processes. There is a close relation between the three kinds of entities representing the notion of substance: *substance-processes, substances (as endurants), and abstract substances (as universals)*. This relation is considered in more detail in section 4.4.

Every substance-process x has a temporal projection which is a chronoid y. The temporal projection y of a substance-process x can be understood – in a sense – as the lifetime of x. The formal relation *lifetime(x,y)* has the meaning *x is a substance-process and y is the temporal projection of x*. We use the functional abbreviation $lf(x)$ which is defined by the condition $lf(x) = y \Leftrightarrow$ *lifetime*(x, y). If x is an abstract substance then the lifetime of x is defined as the minimal chronoid containing all time-boundaries which are associated to the instances of x.

4.3. *Moments*

Moments are endurants; in contrast to substances, moments are entities which can exist only in another entity (in the same way in which, for example an electrical charge can exist only in some conductor). Moments are property particulars: this color, this weight, this temperature, this thought. According to one version of our ontology moments have in common that they are all dependent on substances, where the dependency relation is realized by inherence. Some moments are one-place *qualities*, for example of color or temperature, but there are also relational moments – for example relators founded on kisses or on conversations – which are dependent on a plurality of substances. Moments can be classified in qualities, forms, roles, relators, functions, dispositions and others.

Every endurant is either a substance, or a moment, or a more complex entity as for example a situation. We call substances or moments *primitive endurants* and suppose that the inherence relation connects primitive endurants only. Obviously, substances are those individuals which do not inhere in any endurant.

As for substances there is a relation $at(m, i)$ stating that the moment m exists at time-boundary t. Also there are classes of moments indexed by time-boundaries which we call histories, and analogously to abstract substances there are *abstract moments*, i.e., moment-universals.

The relation of moments to space seems to be more involved. In general, we may say that a moment is *located at a region* which is itself related to the spatial location occupied by the substance bearing this moment. For example, the spherical form inheres in a ball and is located at the surface-boundary of the ball. But where are color and weight located?

Similar as for substances the notion of moment plays also the role of process of certain type, for example an individual red inhering in an apple during one hour. Such a *moment-process* is connected to a substance-process by the inherence relation.

4.4. *Occurrents*

To restate, we use the notion of *occurents* to cover several categories of individual entities related to processes. *Occurrents* comprise *processes, histories, locomotions, changes, boundaries of processes*, and *states*. A *connected process* is an individual which has temporal parts and whose projection onto time is a chronoid (which is a connected time-interval). An important subcategory of connected processes is formed by the class of *co-*

herent processes. A process p is coherent if, intuitively, its boundaries (and temporal parts) are ontically connected by the basic relation $ontic(x, y)$ and if there are causal relationships between the temporal parts of p. The category of coherent processes needs an elaboration in the spirit of the approach of Le Poidevan (2002). A characterization of coherent processes is beyond the scope of the present paper.

Boundaries of processes are dependent entities, they depend on the processes they bound. Let $B(p)$ the class of boundaries of the process p. A process p is not the aggregate of its boundaries; hence, boundaries of a process are different from entities which are called sometimes *stages* of a process. A process cannot be understood on the basis of its boundaries. Hence, our theory of process-boundaries differs from the stage-theory in the versions of Lewis (1983) and of Sider (2001). In addition, there are some differences between boundaries and stages. A boundary is not a temporal part of a process p, because every temporal part of p has a temporal projection which contains a chronoid. According to Lewis a stage – in contradistinction to a boundary – has a temporal duration but 'only a brief one, for it does not last long'. A stage begins to exist abruptly, and it abruptly ceases to exist soon after. Finally, a stage d' in the sense of Lewis or Sider – seems to have a relatively independent existence, which is impossible for boundaries.

A boundary of a process is – in general – the beginning or the ending of a process. An entity e is an inner boundary of a process p if e is the beginning or the ending of a temporal part of p whose framing chronoid is properly included in the chronoid which frames p. Two boundaries of a process *meet* if their associated time-boundaries coincide. The boundaries of a process are – in general – parts of situations (to be considered in section 5).

A *change* is a pair $(e1, e2)$ of meeting boundaries where one of them is the ending of a past process and one the beginning of a future process, and $e1, e2$ instantiate different universals. To be more precise, changes are relative to a basic universal u such that the change is exhibited by certain proper sub-universals of u. Take for example the universal *color* as the basic universal and *red* and *blue* as discriminating sub-universals. Then, obviously, the change in color from blue to red can be understood in this framework. Changes proper we call also extrinsic changes. In order to understand the essence of a change the above mentioned relation of ontological connectedness $ontic(x, y)$ must be extended to moments and defined in such a way as to exclude the possibility that an individual color may change to an individual temperature. We hold that *changes* are entities which depend on processes. Note that in our approach universals do persist, and change means instantiation of different proper sub-universals by ontically connected endurants. The movement of a body is an example of an *intrinsic* change. Intrinsic changes cannot be captured by universals. We introduce the process category of *locomotions* covering the most important type of processes based on intrinsic changes.

A *state* is a connected process without any extrinsic or intrinsic changes. Obviously, this is a relative notion, because changes are related to universals. It might be that processes are states with respect to certain universals, but with respect to others they contain changes.

Histories are (arbitrary) classes of endurants which are indexed by their time-boundaries at which they exist. Thus, histories h may be presented as partial functions from *Endur* into the class TB of time-boundaries realized by the relation $at(x, y)$. Let $TB(h)$ be the class of time-boundaries which are associated to the history h. Then we need – in addition – a time-ordering $<$ between the elements of $TB(h)$. Thus, a history is more precisely specified by a pair $(h, (TB(h), <))$. We assume that every endurant is contained in a boundary of a process or *is* the boundary of a process. Not every history in this very general sense is a reasonable entity, because no connection between the constituents of such histories is postulated.

We now clarify – on the basis of our framework – some relations between the endurants, processes and space. By assumption every boundary of a process is an endurant, i.e. for every process $p \in \mathit{Proc}$ the condition $B(p) \subseteq \mathit{Endur}$ is satisfied. Let *Mom* be the class of all moments (as endurants), and let *Subst* be the class of all substances (as endurants). Then $\mathit{Mom} \cup \mathit{Subst}$ is a proper sub-class of *Endur*. A process p is said to be *substance-process* if every boundary of p contains a substance, it is said to be *moment-process* if $B(p) \subseteq \mathit{Mom}$. How are processes related to space? Let e be an endurant and let S be the collection of all substances carrying the moments which occur in e. S is said to be the *substantial closure* of e, and the relation which associates S to e is denoted by $\mathit{substcl}(e, S)$. This relation may be extended to processes. If p is a process and $\mathit{substcl}(p, q)$ then q is a process with the same temporal projection as p and such that for every time-boundary t of p the process-boundary $q(t)$ is the substantial closure of the process-boundary $p(t)$; the process q is called the substantial closure of p. Let f be the convex frame of the localization of S; the association between S and f is denoted by the above introduced relation $convf(S, f)$. Then we may introduce a topoid T which is defined as the convex closure of the class $\{f : \mathit{convf}(S, f)$ *and* $\mathit{substcl}(S, e)$ *and* $e \in B(p)\}$. We say that the process p is projected onto T and denote this accociation by the relation $prs(p, T)$.

What does it mean to say that a *substance participates in a process*? If (a) by substance we mean an endurant then a substance s participates in a process p if there is boundary of p whose substantial closure contains s, or (b) if ‘substance’ means ‘abstract substance’ then the abstract substance S participates in a process p if the substantial closure of every boundary of p contains an instance of S.

We conclude this section with an analysis of the movement of a solid body b; processes of this type are called *locomotions*, i.e. movements in space. The movement is a process p such that the associated history of p is a sequence of time-indexed endurants $\{b(t) : t \textit{ time-boundary of } p\}$. What is a boundary of this process, i.e. the projection of p onto a time-boundary? It is a substance $b(t)$ – a body at this time-boundary – which occupies a certain topoid denoted by $tp(t)$. If we consider two coinciding time-boundaries t_1 and t_2, then there is no universal to discriminate the endurants $b(t_1)$ and $b(t_2)$ (we assume that there are no extrinsic changes concerning qualities of $b(t_1), b(t_2)$). How is it possible that the body moves without extrinsic changes? There are three possible ways to conceive of movement within our setting:

(1) The spatial locations $tp(t_1)$ and $tp(t_2)$ of $b(t_1)$ and $b(t_2)$ are different; then there is a jump from $tp(t_1)$ to $tp(t_2)$.
(2) The spatial locations $tp(t_1)$ and $tp(t_2)$ are different but they are considered as coinciding boundaries (in the spirit of Brentano (1976)).
(3) The spatial locations $tp(t_1)$ and $tp(t_2)$ are the same, but the extension-spaces $exsp(b(t_1)$ and $exsp(b(t_2))$ are different.

Case (1) is not a viable option if we are to assume the continuity of space. Case (2) would be possible if the spatial locations could be taken to be boundaries. Since spatial locations are 3-dimensional they would have to be boundaries of 4D-manifolds. This is problematic, however, because there is an asymmetry between time and space. Topoids are not endurants and they cannot move like a body. This leaves us with case (3). In this case $exsp(b(t_1))$ is contained in the end of a process and $exsp(b(t_2))$ is contained in the beginning of a process and both endurants meet (i.e. the associated time-boundaries coincide). From our point of view case (3) is reasonable; there is – at least – a change of the extension-space at a pair (t_1, t_2) of two coinciding time-boundaries. This change is not a proper change because their meeting boundaries can not be discriminated by universals. But this kind of change is also true for a motionless, resting body b, because the extension-space of b considered as a process – i.e. extended in time – is a moment-process and the substantial closure of this moment-process exhibits the same kind of changes. Thus, we are facing the problem how to distinguish a motionless body from a moving body.

This Zeno-like problem may be analysed as follows. The movement of a body in space cannot be understood locally, i.e. with respect to time-boundaries, but only with respect to chronoids, i.e. extended temporal entities. The following condition holds: for every chronoid c which is a part of the temporal projection of p and the associated boundaries t_1 and t_2 it is $tp(b(t_1)) \neq tp(b(t_2))$. Processes of this kind could be called *continuous* movements in space, and it does not make sense to say that a body moves at a time-boundary or between coinciding time-boundaries. Our analysis of Zeno's problem is not surprising in our framework: a process is not the aggregate of its boundaries. On the other hand, Zeno's basic assumption is that time is continuous and that time is the sum of its time-points.

The most important ontological category treated in this section is the category of connected processes. In applications many other categories of occurrents are relevant. In formalizing the notion of blood-pressure Heller *et al.* (2003c) used histories. There are processes, which are disconnected, i.e. processes whose temporal projection is not a (connected) chronoid. Disconnected processes may be used to describe, for example, diseases as Malaria. All these kinds of occurrents may be analysed in the framework of a particular category of entities, the category of situoids.

5. SITUOIDS, SITUATIONS, AND CONFIGURATIONS

The entities discussed in the preceding sections have no independent existence. Substances and moments presuppose another, and both constitute complex units or wholes of which they are aspects. Such integrated wholes of substances and moments are themselves endurants, and we call them *configurations*. Configurations are classified in *simple* and *non-simple*. A simple configuration is a unit which is made up from one substance and only monadic moments inhering in that substance. A configuration is said to be non-simple if it is made up from more than one substance and relational moments connecting them. A *situation* is a special configuration which can be comprehended as a whole and satisfies certain conditions of unity imposed by certain universals associated with the situation. Situations present the most complex endurants of the world. In the world of endurants they have the highest degree of independence. The convex frame of a situation s is defined by the convex closure of the localizations occupied by the substances which occur in s. There are differences between our *Ontological Theory of Situations* and the *Situation Theory* of Barwise *et al.* (1983). Situations in our sense are build up from substances, universals and from material and formal relations; these notions are missing in situation theory.

On the other hand, according to the basic assumptions of GOL , endurants have no independent existence, they depend on processes. Since configurations are endurants they, too, depend on processes. We call such processes *configuroids*. They are – in a sense – integrated wholes made up from substantial processes and moment-processes. We claim that substance-processes and moment-processes presuppose each other. Surely a moment-process depends on a substance-process, on the other hand we may assume that a substance-process needs an extension which includes a moment-process.

Finally, there is a category of processes whose boundaries are situations and which satisfy certain principles of coherence and continuity. We call these entities *situoids*; they are the most complex integrated wholes of the world, and they have the highest degree of independence. As it turns out, each of the considered entities (including processes) is embedded into a suitable situoid. A *situoid* is, intuitively, a part of the world that is a coherent and comprehensible whole and does not need other entities in order to exist. Every situoid has a temporal extent and is framed by a topoid. An example of a situoid is *John's kissing of Mary* in a certain environment which contains the substances 'John' and 'Mary' and a relational moment 'kiss' connecting them. Taken in isolation, however, these entities 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 walking through a park. The notion of being a coherent and comprehensible whole is formally elucidated in terms of an *association relation* between situoids and certain universals. The relation $ass(s, u)$ expresses that the universal u is associated to the situoid s.

How are situoids related to time and space? We use here two relations $chron(s, x)$, and $top(s, z)$, where x is the chronoid framing the situoid s and z is the topoid framing s. The topoid framing a situoid is a fiat object (i.e. given by convention); it can be understood – in a sense – as defined by a local coordinate system. But also the boundaries of the framing chronoid are conventional. Note, that the relation $chron(s, x)$ coincides with $prt(s, x)$ if the situoid is considered as a process; the relations $prs(s, x)$ and $top(s, x)$ are different. The following relation is satisfied:

$$\forall sxy(prs(s, x) \wedge top(s, y) \rightarrow x \leq y)$$

Every temporal part of a situoid is itself a situoid. The temporal parts of a situoid s are determined by the full projection of s onto a parts of the framing chronoid c of s. Boundaries (including inner, fiat boundaries) of situoids are projections to time-boundaries. We assume that projections of situoids to time boundaries are situations. In every situation occurs a substance, and we say that an endurant e is a constituent of a situoid S iff there is a time-boundary t of S such that the projection that is a situation containing e.

Situoids have a rich structure which can be analysed by using some further notions. A *substantial layer* P of the situoid S is a 'portion' of S satisfying the following conditions:

(a) P is a connected process,
(b) P and S are framed by the same chronoid,
(c) every boundary of P contains a substance,
(d) Recall that for a connected process P and t a time-boundary of the chronoid c which frames P, $B(P, t)$ denotes the boundary of P at t. For all time-boundaries p, q of S holds: if a is a substance which is contained in $B(P, p)$ and b is a substance which is contained in $B(S, q)$, $p < q$, and a, b are ontically connected, i.e. $ontic(a, b)$, then b is contained in $B(P, q)$ too.

The notion of a *moment-layer* of a situoid is introduced in similar fashion.

Situoids can be extended in two ways. Let S, T be two situoids; we say that T is a *temporal extension* of S, if there is an initial segment c of the chronoid of T such that the projection of T onto c equals S. We say that T is a *substantial extension* of S if S is a substantial layer of T. Both kinds of extensions can be combined to the more general notion of a *substantial-temporal extension*. The whole reality can be – in a sense – understood as a web of situoids which are connected by substantial-temporal extensions. The notion of an extension can be relativized to situations. Since there cannot be temporal extensions of situations an extension T of the situation S is always a substantial extension. As an example consider a fixed single substance a which occurs in situation S. Every extension of S is determined by adding further monadic or relationary moments to S to the the intrinsic properties of a. A moment-bundle which is unified by the substance a is called *saturated* if no extension of S adds new moments. Is there an extension T of S such that every substance a in T unifies a saturated bundle of moments?

Configuroids. A *configuroid* c in the situoid S is defined as the projection of that substantial layer of S onto a chronoid which is a part of the time-frame of S. In particular, every substantial layer of S is itself a configuroid of S. Obviously every configuroid is a coherent process. But not every coherent process is a configuroid of a situoid because not every process satisfies the substantiality condition.

Occurrents and Situoids. We postulate as a basic axiom that every occurrent is – roughly speaking – a 'portion' of a situoid, and we say that every occurent is embedded in a situoid. Furthermore, we defend the position that processes should be analysed and classified in the framework of situoids. Also, situoids may be used as ontological entities representing contexts. A rigorous typology of processes in the framework of situoids is an important future project. Occurrents may be classified with respect to different dimensions, among them we mention the *temporal structure* and the *granularity* of a occurrent. We conclude this section with an outline of some classification principles.

Temporal structure of occurrents. Let o be an occurrent, then o is embedded in a situoid S. Let y be the temporal projection of o, i.e. it holds $prt(o, y)$. Occurrent o may be classified with respect to the type of the temporal structure y.

(1) Let o be a history and $TB(o)$ the class of time-boundaries which are associated with the constituents of o; then $prt(o, TB(o))$. The history o is said to be dense if $TB(o)$ contains a dense subset. Otherwise o is called discrete. There is a complete classification of all order types of linear orderings which are associated with countable sets $TB(o)$ (Erdös 1964). It is a practical question which of these order types are of use in applications.
(2) A process p is *disconnected* if the projection of p onto time is not connected. We assume that the temporal projection of a disconnected process does not contain isolated time-boundaries. Then the temporal projection of p, denoted by $TP(p)$, is a class of chronoids. There is a natural linear ordering between the chronoids $i, j \in TP(p)$, denoted by $i < j$. The temporal structure of p may be classified with respect to the order type of the system $(TP(p), <)$. Note, that this ordering can be dense.
(3) A occurrent p is said to be *hybrid* it its temporal projection contains chronoids and isolated time-boundaries.

The practical relevance of these distinctions may differ for different applications.

Granularity of Processes. Let p be a connected process, and c the chronoid which frames p. In many cases it is useful to have coarser granularity of p. This can be made precise by using partitions of the the framing chronoid c. A partition of c is a set of chronoids satisfying the following conditions: any two different chronoids $i, j \in Part(c)$. do not overlap and every time-boundary of c is time-boundary (including inner boundaries) of suitable $i \in Part(c)$. We restrict in the following on such partitions $Part(c)$ which are finite or has order type ω. Now we assume a set $PU = \{u(1), \ldots, u(k)\}$ of processual universals. We say that $Part(c)$ is a *PU-partition* of p if every $i \in Par(c)$ instantiates one of the universals from PU. By using suitable partitions of p and collections PU coarser processes may be abstracted from p. This idea of *PU-partitions* of processes has to be tested on practical applications. Here we will use the ideas of Becher *et al.* (2000).

6. CONCLUSION AND FUTURE RESEARCH

One of the aims of the group *Onto-Med* is the application of the GOL-ontology (called GFO) in the field of medical science, but also in other domains. GOL is intended to provide a formal framework for building, representing and evaluating domain-specific ontologies. For this purpose *Onto-Med* is elaborating a *methodology of ontological reduction* (Heller *et al.* 2003a). One of the computer-based applications (called *Onto-Builder*) is the development and implementation of Software tools to support the standardization and reusability of terms in the field of clinical trials (Heller *et al.* 2003d).

The basic categories and basic relations of GOL will be characterized – in the spririt of the axiomatic deductive method – by a family Ax(GFO) of axiomatic systems. By adding new categories and relations from the field of medicine GOL will be extended to GOL-Med and GOL-CTrials. The axioms and categories of GOL-CTrials for example refer to the class of all clinical trials.

Another area of application is the ontological foundation of conceptual modelling. First examples of applying GOL to UML (Unified Modelling Language) are demonstrated by Guizzardi *et al.* in (2002a), (2002b).

REFERENCES

Aristotle: 1984. *The Complete Works*, translated and edited by J. Barnes, Princeton University Press, Princeton.

Allen, J. and P. J. Hayes: 1989. 'Moments and Points in an Interval-Based Temporal Logic', *Computational Intelligence* **5**, 225–238.

Barwise, J. and J. Perry: 1983. *Situations and Attitudes*. Bradford Books, The MIT Press.

Becher, G., F. Clerin-Debart and P. Enjalbert: 2000. 'A Qualitative Model for Time Granularity', *Computational Intelligence*, pp. 137–168.

Borgo, S., N. Guarino and C. Masolo: 1996. 'A Pointless Theory of Space Based On Strong Connection and Congruence', in *Principles of Knowledge Representation and Reasoning (KR96)*, Boston, MA. pp. 220–229.

Booch, G., J. Rumbauch and I. Jacobson: 1999. *The Unified Modeling Language*. Addison Wesley.

Brentano, F.: 1976. *Philosophische Untersuchungen zu Raum, Zeit und Kontinuum*. Hamburg: Felix Meiner Verlag. English translation as *Philosophical Investigations on Space, Time and Continuum*. London: Croom Helm, 1988.

Chisholm, R. M.: 1983. 'Boundaries as Dependent Particulars', *Grazer Philosophische Studien* **20**, 87–96.

Degen, W., H. Heller and H. Herre: 2001a. 'Contributions for the Ontological Foundation of Knowledge Modelling', *Report Nr. 02. Institut für Informatik*, Universität Leipzig.

Degen, W., H. Heller, H. Herre and B. Smith: 2001b. 'GOL: A General Ontological Language', *Formal Ontology in Information Systems*. Collected Papers from the Second International Conference. New York, pp.34–46.

Degen, W., H. Heller and H. Herre: 2002a. 'GOL: A Framework for Building and Representing Ontologies', in B. Heller, H. Herre and B. Smith (eds.), *Ontological Spring* (A Reader in Formal and Applied Ontology), IFOMIS Reports 1 Leipzig, pp. 182-203, 2002.

Degen, W., B. Heller and H. Herre: 2003b. GOL-Manual (Version 1.0α) *OntoMed-Report-3*.

Erdös, P. and R. Rado: 1964. 'A Partition Calculus in Set Theory', *Bull. Amer. Math. Society* **15**, 495–503.

Genesereth, M. R. and R. E. Fikes: 1992. Knowledge Interchange Format, Version 3.0, Reference Manual, Logic Group Report Logic-92-1, Computer Science Department, Stanford University, Stanford, California.

Gruber, T. R.: 1995. 'Towards Principles for the Design of Ontologies Used for Knowledge Sharing', *International Journal of Human and Computer Studies* **43**, 907–928.

Guarino, N.: 1998. 'Formal Ontology and Information Systems', In N. Guarino (ed.), *Formal Ontology in Information Systems*, Proc. of FOIS' 98, Trento, Italy, Amsterdam, IOS-Press.

Guarino, N.: 1998. 'Some Ontological Principles for Designing Upper Level Lexical Resources',. *First Conference on Language Resources and Evaluation*.

Guarino,N. and C. Welty: 2002. 'Evaluating Ontological Decisions with OntoClean', *Communications of the ACM* **45**(2), 61-65.

Guizzardi, G., H. Herre and G. Wagner: 2002a. 'On the General Ontological Foundation of Conceptual Modelling', in S. Spaccapeitra *et al.* (eds.), 2002. Conceptual Modelling, ER,Tampere, Proceedings of the 21st International Conference on Conceptual Modelling, vol. 2503, LNCS, 65-78. Springer Verlag.

Guizzardi, G., H. Herre and G. Wagner: 2002b. 'Towards Ontological Foundations for UML Conceptual Models', in Meersmann *et al.* (eds.), International Conference ODBASE Irvine, California. LNCS vol. 2519, 1100–1117, Springer Verlag.

Heller, B. and H. Herre: 2003a. 'Formal Ontology and Principles of GOL', *OntoMed-Report-1*.

Heller, B., H. Herre and M. Löffler: 2003b. 'Research Projects of Onto-Med', *OntoMed-Report-2*.

Heller, B., H. Herre and M. Löffler: 2003c. 'Formal Specifications in GOL – A Case Study in the Field of Clinical Trials', *OntoMed-Report-6*.

Heller, B., K. Kühn and K. Lippoldt: 2003d. 'OntoBuilder', *OntoMed-Report-5*.

Inwagen, P. V.: 2000. 'Temporal Parts and Identity Across Time', *The Monist* **89**, 437-459.

Johansson, I.: 1989. *Ontological Investigations*. Routledge.

Lewis, D. K.: 1983. *Collected Papers*. Vol. I. Oxford: Blackwell.

Musen, M.: 1992. 'Dimensions of Knowledge Sharing and Reuse', in *Computer and Biomedical Research*, vol. 25, pp. 435–467.

La Podevin, R.: 2000. 'Continuants and Continuity', *The Monist* **83**, 381–398.

Russel, S. and P. Norvig: 1995. *Artificial Intelligence*. Prentice-Hall, Inc.

Seibt, J.: 1997. 'Existence in Time: From Substance to Process', in J. Faye *et. al.* (eds.), *Perspectives in Time*, pp. 143–182.

Seibt, J.: 2001. Formal Process Ontology. *Formal Ontology in Information Systems*. Collected Papers from the Second International Conference. New York, pp. 333-345.

Seibt, J.: 2003. 'Process and Particulars', in M. Weber (ed.), *Process Metaphysics*, Philosophia Verlag, forthcoming.

Sider, T.: 2001. *Four-Dimensionalism. An Ontology of Persistence and Time*. Oxford: Clarendon Press.

Simons, P.: 1994. 'Particulars in Particular Clothing: Three Trope Theories of Substance', *Philosophy and Phenomenological Research* **LIV**(3), 553–575.

Simons, P.: 1998. 'Farewell to Substance: A differentiated leave-taking', *Ratio (new series)*, pp. 235–252.

Simons, P.: 2000. 'How to Exist Without Temporal Parts', *Monist*, pp. 419–436.

Smith, B. and A. Varzi: 2000. 'Bona Fide and Fiat Boundaries', *Philosophy and Phenomenological Research* **60**, 401–420.

Sowa, J. K.: 2000. *Knowledge Representation*. Brooks/Cole.

Varzi, A. C.: 1996. 'Parts, Wholes, and Part-Whole Relations: The Prospects of Mereotopology', *Data and Knowledge Engineering* **20**, 259–286.

Varzi, A. C.: 1997. 'Boundaries, Continuity, and Contact', *Nous* **31**, 26–58.

Welty, A. C. and D. A. Ferucci: 1999. 'Instances and Classes in Software Engineering, Artificial Intelligence', *Artificial Intelligence*.