# General Ontological Language (GOL)

## A Formal Framework for Building and Representing Ontologies

Version 1.0

(Excerpt)

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**Abstract.** *General Ontological Language* (GOL) is a formal framework for representing and building ontologies. The purpose of GOL is to provide a library of top-level ontologies which can be used as a framework for building more specific ontologies. This report is a living document of the GOL-project of the University of Leipzig. GOL is part of the work of the Research Group Ontologies in Medicine (*Onto-Med*) which is based on the collaborative work of the *Institute of Medical Informatics, Statistics and Epidemiology* (*IMISE)* and the *Institute for Informatics (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*.

# Contents

# 1 Introduction

Research in ontology has in recent years 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 maximize intercommunicability with other domains. The importance of ontologies has been recognized in fields as diverse as e-commerce, enterprise and information integration, qualitative modeling 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.

[…]

## 1.1 Formal Ontology and Information Systems

*Formal Ontology* is the science which concerns itself with the systematic development of axiomatic theories of forms, modes, and views of being of different levels of abstraction and granularity. Formal ontology combines the methods of mathematical logic with the analyses and principles of philosophy, but also with the methods and principles of other sciences (artificial intelligence, cognitive psychology, and linguistics). Hence, the term *Formal Ontology* is used here in a sense different from that in philosophy; it is intended to be a research area in theoretical computer science which is aimed at the development of axiomatically founded theories which are represented by means of a formal language and which describe parts of the world. On the most general level of abstraction formal ontology is concerned with the kinds, modes, views, and structures which apply to every area of the world. We call this level of description *General Ontology*, in contrast to the various *Domain Ontologies* which are applicable to more restricted fields of interest. We assume that every domain-specific ontology must use as a framework some general ontology, sometimes called top-level ontology, which describes the most general categories of the world.

Recently, formal ontology is applied in various areas where the notion of an ontology is used in a very broad sense. In general, a particular ontology is understood to be a description of a given domain which can be accepted and reused in all information systems referring to this domain. Sometimes even terminologies are considered as ontologies, whereas we take a position which is more narrow. At least, usually the backbone of an application ontology is a taxonomy of concepts which is based on the subsumption link.

An ontology Ont – understood as a formal knowledge base - is given by an “explicit specification of a conceptualization” [Gruber, 1993]; it consists of a structured vocabulary V(Ont), called *ontological signature*, and a set of axioms Ax(Ont) about V(Ont) which are formulated in a formal language L(Ont). Hence, an ontology (understood as a formal object) is then a system Ont = (L,V,Ax); the symbols of V denote categories and relations between categories or between their instances. L can be understood as an operator which associates to a vocabulary V a set L(V) of expressions which are usually declarative formulas. We assume the following condition : $V \subseteq V_1$ implies $L(V) \subseteq L(V_1)$, and $L(L(V)) = L(V)$. An ontology may be augmented by a derivability relation, denoted by $\vdash$, and by a semantic consequence relation, denoted by $\vDash$. Then, such an ontology takes the form of a knowledge system (L,V,Ax, Mod(V), $\vdash$ , $\vDash$ ) which includes a class Mod(V) of interpretations which serves as a semantics for the language L(V).

## 1.2 General Architecture of GOL

*General Ontological Language* (GOL) is intended to be a formal framework for building and representing ontologies. The main purpose of GOL is to provide a library of formalized and axiomatized top-level ontologies which can be used as a framework for building more specific ontologies. The GOL-Framework consists of three components representing different levels of abstraction. Meta-GOL contains basic principles of semantic choice, a general view on categories and classes, methods of semantic transformations, and principles for meta-logical analyses. GOL-Software tools contain a number of systems which support the development, the evaluation, the mapping and the integration of ontologies, but also application software (Onco-Workstation, Onto-Builder, SOP-Creator) based on ontological principles.

GOL on the object level consists of a basic logic and a representation language RGOL which is specified, in this version of the document, by a syntax whereas the semantics has not been completely developed yet. RGOL has a built-in ontology which is called abstract core ontology, denoted by ACO. ACO contains the basic entities *categories*, including the category of concrete entities, and *classes*, and as relations *identity*, membership and *instantiation*; we believe that ACO is an indispensable part of every top-level ontology. The core of GOL is intended to be a library of top-level ontologies which extend ACO. The first of these ontologies, which is called General Formal Ontology (GFO), is described in the present document. 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 partial ordering of theories which may be inconsistent with theories that are not situated on the same path of the partial ordering [Niles, Pease, 2001]. Concerning the partial ordering approach there are different kinds of distinctions between such ontologies. One kind of distinction is based on the fact that different ontologies may use different basic categories of entities. But even if two ontologies use the same basic categories they may differ with respect to the axioms formulated about the categories. Then the question arises which of the axioms should be included in the top-level axiomatization. There is a similar phenomenon in mathematics: there are different consistent extensions of set theory with axiom of choice, we may assume the continuum hypotheses or an axiom rejecting the continuum hypothesis.

Our general philosophy is to admit a restricted version of the partial ordering approach. We want to have only a restricted selection of ontologies with different basic systems 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 and of other meta-logical properties is an important research topic of its own.

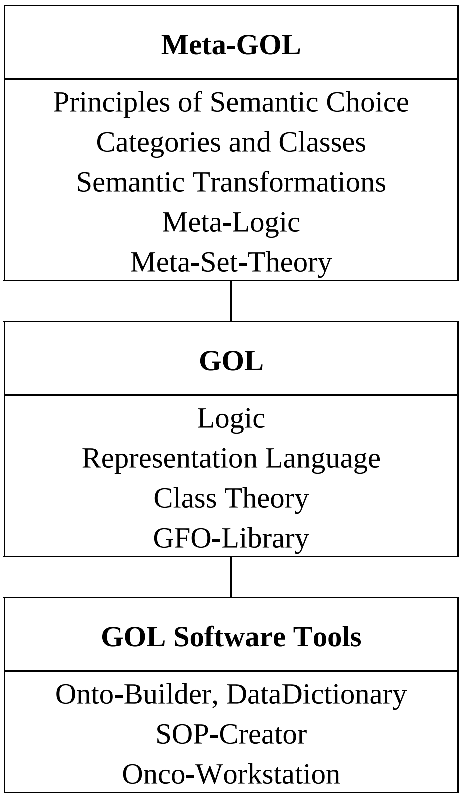


**Figure 1: Architecture of the GOL Project**

## 1.3 Applications

There is a wide range of intended applications for GOL. One aspect is the embodiment of the ontological results in the task of conceptual modeling. One the one hand, languages in use for conceptual modeling like the Unified Modeling Language (UML) [Booch, Jacobson, et al., 1999; Rumbaugh, Jacobson, et al., 1999], entity relationship modeling in the field of databases, or the Object-Process Methodology [Dori, 2002] can be examined according to their ontological commitments. Moreover, extensions of these languages in terms of GOL categories could be useful. Another branch with respect to modeling is the development of a methodology for modeling, again on the ontological foundations of GOL.

The next step leads from conceptual modeling to its application in the design of software applications. Against the background of the Research Group Ontologies in Medicine, several software tools for the clinical domain are already in development (cf. Figure 1)[1]. In later stages, there are two levels of influence exerted by GOL. On the one hand, modeling methodologies and languages can be used in the design of applications, directing developers to their ontological assumptions and allowing them to make these more explicit. Thereby, a higher degree of correct reuse is expected. On the other hand, the data processed by applications can be linked to or analysed in terms of the GFO. The Data Dictionary application plays a central role in the latter part, in particular as one of its major purposes is to support the harmonisation of several definitional alternatives among experts within some limited domain (e.g., in the domain of clinical trials, many variants of definitions exist and have to be carefully collected and organized in order to

[1] For more details of the individual applications, cf. the Onto-Med website: http://www.onto-med.de

allow for high-quality treatment within clinical trials and adequate reuse of results). A later version of the Data Dictionary may support the analysis of such definitions in terms of GOL.

A different mode of the use of GOL refers to the Semantic Web initiative[2]. One approach is the translation of the GFO into a Semantic Web language like the Web Ontology Language OWL [W3C, 2004] such that it can be used as a basis for domain-specific ontologies written in OWL. This allows for the reuse of reasoners and the collaboration with other groups sticking to this recommendation of the W3C. Another idea is the establishment of a new GOL-based language for the Semantic Web. At the moment, though, it is not clear whether there would be sufficient advantages justifying the required work to accomplish this task.

As illustrated by the points mentioned, GOL shall serve as the source for diverse applications spanning from theory to implemented software. Returning to the idea of a library of ontologies, this will multiply the ontological options. Similarly, further top-level ontologies will have to be considered with respect to their relationship to GOL and the question of their integration.

## 1.4 Related Work

Several groups tackle the development of top-level ontologies or certain aspects of top-level ontologies. Here, we only mention some important approaches. With respect to a more detailed comparison with these approaches we restrict to the Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) and an ontology proposed by John Sowa (cf. chapter 14).

The following approaches are fairly developed and they are partially used in the sequel as a source for our considerations. With Nicola Guarino an early proponent of the use of ontologies in the field of knowledge-based systems is involved in the construction of DOLCE [Masolo, Borgo, et al., 2003; Masolo, Borgo, et al., 2002]. This work is conducted in connection with the WonderWeb project, which is itself related to OWL mentioned above. Further, two other ontologies are presented in [Masolo, Borgo, et al., 2003], following the idea of an ontology library in the WonderWeb project. DOLCE itself is presented as a hierarchy of categories and several relationships between. The description is fairly extensive and an axiomatization is contained as well.

[Sowa, 2000] presents and extensively discusses a top-level ontology in the form of a polytree within a comprehensive book on knowledge representation issues, i.e., it is not a pure work introducing a top-level ontology.

The Standard Upper Merged Ontology (SUMO) is an effort of the P1600.1 Standard Upper Ontology Working Group at IEEE [SUO, 2004]. [Pease, Niles, 2002] provides the latest progress report. Thus far, there is no standard or draft standard for a Standard Upper Ontology (SUO) by this group. Instead, several draft proposals have been made, one of the more developed suggestions of which is SUMO. It adopts a polytree architecture of categories, i.e., there are cases of multiple supercategories, e.g., “Group” is a subcategory of “Collection” as well as of “Agent”. The way of its development may have contributed to the multiplicative approach, as SUMO originates from a merge of several top-level ontologies [Niles, Pease, 2001], e.g. one of Russell and Norvig [Russel, Norvig, 1995] and the one of John Sowa [Sowa, 2000], as well as several others.

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[2] Cf. the corresponding World Wide Web Consortium (W3C) website, http://www.w3.org/2001/sw/.

Similarly, a further important account of ontology in the field of computer science is given by Roberto Poli [Poli, 2001a]. In particular, the same author presents a theory of ontological levels which is acknowledged and adopted in chapter 3.3.

Apart from recent approaches to top-level ontologies, other fields offer contributions as well. In particular, issues related to those herein have been discussed in knowledge representation, knowledge-based systems research as well as database and object-oriented modeling. The focus in these areas may be a different one, but often some ontological questions are touched as well.

## 1.5 Structure of the Report

The remainder of this paper is structured as follows. Section 2 is devoted to meta-ontological principles and logical methods. Formal ontology is concerned with the analysis of categories, and we hold a view which is vindicated in [Gracia, 1999]. Our investigations are based, furthermore, on some logical methods, among them the axiomatic-deductive method and the method of interpretability. Section 3 gives a brief overview about the main classification of ontological entities in GFO, in particular, we emphasize the role of ontological levels. In our opinion a formal ontology is incomplete if it does not include levels of reality. Section 4 describes the main ideas of the ontology of time and space which is inspired by Brentano's investigations on time, space, and continuum [Brentano, 1976]. In section 5 the major ontological categories are discussed in some detail. Section 6 is devoted to the ontology of relations and facts (states of affairs). Thereafter, section 7 discusses the categories of situoids and related categories.

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# 2 Meta-Ontological Principles, Basic Assumptions, and Logical Methods

## 2.1 Categories

General ontology is concerned with the most general categories, with their analysis and axiomatic foundation. Categories are entities which satisfy at least the following conditions: they can be predicated of other entities and they are expressed and represented by terms of a language. Such terms are called *predicative terms*. Predicative terms are linguistic entities which may be used to specify the conditions to be satisfied by an entity. Categories are what predicative terms express, not the predicative terms themselves. Hence we have to distinguish: the category, the predicative term – as a linguistic item – expressing the category, and the entities which satisfy the conditions specified by the predicative term. We assume that categories are conceived in such a way that we are not forced to commit ourselves to realism, conceptualism, or nominalism [Gracia, 1999]. This approach is compatible with our pluralistic approach discussed in the introduction above (cf. section 1.2).

According to the approach of [Gracia, 1999] we derive several kinds of categories from philosophical basic assumptions. We restrict to the following basic kinds of categories: immanent categories (also called in the following universals), conceptual structures (sometimes referred to as concepts), and symbolic structures. We assume – at least – the basic relation of predication: *a category is predicated of an entity*. Usually, a set or class cannot be predicated of its members because it is not assumed that a set has a specification. For this reason sets and classes play a particular role in our ontology, we do not consider them as categories. Classes and the membership relation satisfy the principle of extensionality: two classes are equal if they have the same members. Extensionality is obviously not true for categories and the instantiation relation.

*Immanent categories* are not outside the world of human experience, but are constituents of this world. *Concepts* are categories which are expressed by linguistic signs and which are present in someone's mind. *Symbolic structures* are signs or texts which may be instantiated by *tokens*. Accordingly, the notions of token and symbol are subsumed under the notions of instance and category. There are close relations between these three kinds of categories: an immanent category is captured by a concept which is denoted by a symbolic structure. Texts and symbolic structures may be communicated by their instances which are physical tokens.

We assume that in every top-level ontology of GOL the entities *class* and *category* from Meta-GOL are included. Classes and categories are classified according to *type* and the admitted types are a part of a top-level ontology of GOL. The general method for specifiying a top-level ontology within GOL consists in introducing the basic categories and classifying them with respect to category types of Meta-GOL. The most important of these additional categories are *space*, *time*, and *individuals*.

## 2.2 The Axiomatic Deductive Method

A formal theory is a set of formalized propositions. The axiomatic method comprises several principles used for the development of formal knowledge bases and reasoning systems aiming at the foundation, systematization and formalization of a field of knowledge associated with a part or dimension of reality.

The axiomatic method deals with the specification of concepts and is motivated by the following considerations. On the one hand, a formal knowledge base contains primitive notions and axioms, on the other hand it includes defined notions and definitions. Moreover, proofs show the logical validity of theorems. It would be ideal if one were able to explain explicitly the meaning of every notion and to justify each proposition by a proof. When one tries to explain the meaning of a term, however, one necessarily uses other expressions, and in turn one has to explain these expressions, and so on. The situation is quite analogous for the justification of the proposition asserted within a knowledge base, for in order to establish the validity of a statement, it is necessary to refer to other statements, which leads again to an infinite regress.

The axiomatic-deductive method contains the principles necessary to treat this problem. If knowledge of a certain domain is to be assembled in a systematic way, one can distinguish, first of all, a certain small set of concepts in this field that seem to be understandable of themselves. We call the expressions in this set *primitive* or *basic*, and we employ them without formally explaining their meanings by explicit definitions.

Examples are the concepts of *identity* or of *part*. At the same time we adopt the principle of not employing any other term taken from the field under consideration unless its meaning has first been determined with the help of the basic terms and of expressions whose meanings have been previously explained. The sentence which determines the meaning of a term in this way is called an *explicit definition*.

How, then, can the basic notions be described; how can their meaning be characterized? Given the basic terms, we may construct more complex sentences which may be understood as descriptions of certain formal interrelations between them. Some of these statements are chosen as *axioms*; we accept them as true without in any way establishing their validity by means of a proof. By accepting such sentences as axioms we assert that the interrelations described are considered to be valid and at the same time we define the given notions in a certain sense implicitly, i.e., the meaning of the basic terms is to some extent captured and constrained by the axioms. On the other hand, we agree to accept any other statement as true only if we have succeeded in establishing its validity from the chosen axioms via admissible deductions. Statements established in this way are called *proved statements* or *theorems*.

Axiomatic theories have to be studied with respect to meta-theoretical properties. It is important that the basic axioms are consistent, because domain-specific axioms are to be built on them. Other important meta-theoretical properties are completeness and the classification of complete extensions. If several theories are considered, their interrelationships have to be studied which amounts to questions of how to interprete one theory in another and which is the more comprehensive or expressive theory. The next section is devoted to corresponding issues.

## 2.3 Semantic Transformation and Interpretability

The comparison of ontologies assumes a notion of semantic transformation and ontological mapping. Let Ont = (L, V, Ax) be an ontology and $V \subseteq V'$; we say that a sentence F from L(V´) is ontologically compatible with Ont if F is consistent with Ax. A *semantic mapping* (or *semantic transformation*) of an ontology $Ont_1 = (L_1, V_1, Ax_1)$ into the ontology $Ont_2 = (L_2, V_2, Ax_2)$ is a computable function $f: L_1 \rightarrow L_2$ such that $Ax_2 \vDash f(Ax_1)$. The most important semantical mappings are interpretations in the sense of logic and model theory [Tarski, 1944].

We sketch the main ideas of the method of interpretability the framework of theories in first-order logic (cf. also [Szczerba, 1977]). A theory S is said to be interpretable in the theory T if it is obtainable by means of some definitions from T. The question is which schemas of definitions are admitted, and what – in general – a definition is. The simplest case of definitions are explicit definitions which are assumed in the sequel. Let us assume that S, and T are theories in the (first-order) languages L(V), and L(W), respectively. Translations from L(V) into L(W) are defined by means of codes. A code in the sense of [Szczerba, 1977] – in the simplest case – has the form $c = (1, U(x), F_1, \ldots, F_n)$, where $U, F_1, \ldots, F_n$ are formulas of the language L(W) specified in the vocabulary W; here, a formula $F_i$ is associated to every relation symbol $r_i \in V$, such that the arity of $r_i$ equals the number of free variables of $F_i$. The formulas $F_i$ serve as explicit definitions of the relational symbols $r_i$. A translation tr from L(V) into L(W) associates to every formula of L(V) a formula of L(W). Translations based on a code c are defined recursively as follows.

$tr(x = y) =_{df} x = y$

$tr(r_i(x_1, \ldots, x_{n(i)})) =_{df} F_i(x_1, \ldots, x_{n(i)})$

$tr(\neg F) =_{df} \neg tr(F)$

$tr(F \wedge G) =_{df} tr(F) \wedge tr(G)$ $\quad$ $tr(F \vee G) =_{df} tr(F) \vee tr(G)$

$tr(\forall x\, F(x)) =_{df} \forall x\, (U(x) \rightarrow tr(F(x)))$ $\quad$ $tr(\exists x\, F(x)) =_{df} \exists x\, (U(x) \wedge tr(F(x)))$

A theory S is said to be (syntactically) c-interpretable in T if tr – which is based on the code c – satisfies the following condition:

(**C1**): For every sentence $F \in L(V)$ holds: $S \vDash F$ if and only if $T \vDash tr(F)$.

Generally, a theory S is interpretable in T if a code c exists such that the translation tr which is based on c satisfies condition (C1). Note that codes can be much more complicated than the simple version mentioned above.

A generalization of ontologies are *terminology systems*. In general, a terminology system TS = (L, Conc, Rel, Def) consists of a language L, a set Conc of concepts, a set Rel of relations between these concepts, and a function which associates to every concept $c \in Conc$ a definition Def(c) which is an expression of the language L. If L is a formal language then the set $\{Def(c) \mid c \in Conc\}$ can be understood as a system of axioms, and the terminology system TS becomes an ontology in the sense of section 1.1. The idea of ontological mappings can be generalized to terminology systems. Let TS = (L, Conc, Rel, Def) be a terminology system and Ont = (L´, V, Ax) an ontology called a reference ontology for TS. An ontological mapping from TS into Ont is a (partial) function f from L into L´ such that for every concept c in Conc the expressions Def(c) and f(Def(c)) are semantically equivalent with respect to Ax. In this case we may define a formal knowledge base $OntoBase(TS) = \{ f(Def(c)) \mid c \in Conc\} \cup Ax$ which explicitly extracts the content in TS and provides inference mechanisms. A more detailed discussion of this method is presented in section 9.

# 3 Categories, Classes, Individuals, and Levels

In what follows we will discuss ontologically basic entities and basic distinctions needed to structure the world. The main distinction we draw is between *classes, categories,* and *concrete entities.* Categories and concrete entities are *class-urelements*, i.e., they have no members and are different from the empty class. We classify concrete entities into *individuals* and *entities of space or time*. Individuals are further classified into *presentials* and *occurrents*. A category c is said to be primitive if its instances are concrete entities.

## 3.1 Types of Classes and Categories

The entities of the world are classified according to type. We start with the primitive types which are classified into the type *i* (for individuals), the type *st* (for space-time entities); both are united to the type *c* of concrete entities. Every primitive type is a type. If $t_1, \ldots, t_n$ are types then $[t_1, ..., t_n]$ and $[\{t_1, ..., t_n\}]$ are class-types, and $\langle t_1, \ldots, t_n\rangle$, $\langle\{t_1, ..., t_n\}\rangle$ are categorial types. Every categorial type or class-type is a type. Nothing is a type unless it follows the conditions mentioned. There are two basic relations related to classes and categories. An entity e belongs to a class S if e is a member of S, i.e., there is a membership relation between the class and its elements. An entity e belongs to a category C if e is an instance of C, i.e., the instantiation relation is the basic relation for categories. Let $e_1, \ldots, e_n$ be entities of type $t_1, \ldots, t_n$ respectively, and S an entity of type $[t_1, \ldots, t_n]$. Then we write $(e_1, \ldots, e_n) \in S$ to indicate that the n-tuple $(e_1, ..., e_n)$ belongs to the set S. If C is a category of type $\langle t_1, \ldots, t_n\rangle$, then we write $(e_1, ..., e_n) :: C$ to denote that $(e_1, ..., e_n)$ is an instance of C. Instantiation and membership are different relations.

Categories may be specified by definitions which depend on a language *L*. We call such categories *L-definable relations* or *L-definable predicates*; the content of the definitions themselves are concepts, and the symbolic representations as expressions of a formal language are symbolic structures. The concept is predicated of its instances, but note that there are concepts without any instance.

## 3.2 Individuals and Universals

An *individual* is a single thing thought of in contrast to universals, hence we assume that individuals cannot be instantiated but are instances of universals/categories. A primitive category is an entity that can be instantiated by a number of different individuals. There are several kinds of universals/categories: *immanent universals*, *conceptual structures* and *symbolic structures*[3]. Usually, the individuals covered by a universal are similar in some respect. We assume that the immanent universals exist in the individuals (*in re*) but not independently from them, thus, our view of the immanent universals is Aristotelian in spirit (cf. [Bonitz, Rolfes, et al., 1995]). Thus, immanent universals are considered as a subcategory of the category of immanent categories. On the other hand, humans as cognitive subjects conceive of universals of any sort by means of concepts that are in their mind. Hence we hold that mental notions cannot be eliminated from ontol-

[3] Note that the term "universal" is used either as a synonym for category or, in a narrower sense, to refer to "immanent universal". Immanent universals are always primitive categories.

ogy. Thus, we postulate a relation between immanent categories, concepts, and – concerning their representation – symbolic/linguistic structures.

In our framework non-instantiability is only a necessary – but not a sufficient – condition for being an individual. A category without instances is not an individual, the same holds for classes which have elements but no instances. There might be individuals which have no relation to time and space, for example the prime number 7. Hence we have to distinguish between concrete individuals and general individuals. In the scope of the present paper we consider only concrete individuals, i.e., the notions of individual and of concrete individual is used synonymously.

For every category U there is a class Ext(U) containing all instances of U as elements. We assume that the classes of individuals, of space-time entities, and of categories are pairwise disjoint.

In contrast to primitive categories, there are also categories of higher type, i.e., (some of) their instances are themselves categories. Such categories can be found in the biological domain, for example, and means of expressing categories of higher type have also found their way into UML, in the form of the UML elements “metaclass” and “powertype” (cf. [Rumbaugh, Jacobson, et al., 1999]).

*Example*. Hedgehog is an instance of species, Tony is an instance of hedgehog.

## 3.3 Levels

We assume that the world is organized into *strata*, and these strata are classified and separated into *layers*. We use the term *level* to denote strata and layers. According to [Poli, 2001b; 2002] (based on the philosopher Hartmann) we distinguish at least three ontological strata of the world: the material, the mental/psychological, and the social stratum. Every entity of the world participates in certain strata and layers. We take the position that the levels are characterized by integrated systems of categories. Among these levels specific forms of categorial and existential dependencies hold. For example, a mental entity requires an animate physical object as its existential bearer. According to [Poli, 2001b] we use the matter-form distinction to explain and understand certain relationships between certain kinds of entities. Thus, the atom may be understood as the matter of the molecule, the latter being already endowed with form, the molecules are the matter of the cell, and cells are the matter of multi-cellular entities. Every of these levels is captured by a system of categories, which imply certain granularities. Hence, granularity is a derived phenomenon. The passage from the material to the mental level cannot be understood as a matter-form dependency, here something new occurs with a new series of forms. The social stratum captures phenomena of communication, of economic and legal realities, language, science, technology, and morals etc.

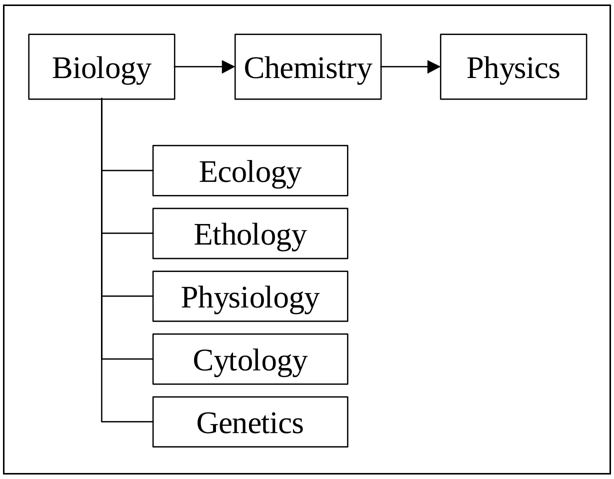


**Figure 2: Structure of the Material Stratum**

According to [Poli, 2001b], we outline the structure of the material stratum in figure 2. At the top, figure 2 shows the three main layers of the material stratum which can be further refined. Every sub-level has its own family of “objects”; according to table II, p.268, in [Poli, 2001b] there are:

| | | |
|---|---|---|
| ecology | ⇔ | ecosystem |
| ethology | ⇔ | population |
| physiology | ⇔ | organism |
| cytology | ⇔ | cell |
| genetics | ⇔ | gene |

In accordance with the work of R. Poli, we divide the psychological/mental stratum into the layer of awareness and the layer of personality. Awareness comprises most of what is studied by cognitive science (perception, memory, reasoning, etc). Personality on the other hand concerns the phenomenon of will and the way in which someone reacts to her experiences.

On the one hand, the social stratum is divided into Agents and Institutions. Agents are the bearers of the social roles that humans play. Institutions are defined as systems of interrelated social components. On the other hand, a social system can be seen as a network in which businesses, politics, art, language (and many more other facets) both present their own features *and* influence each other.

# 4 Space and Time

There are several basic ontologies about space and time. In the top-level ontology of GFO presented herein chronoids and topoids represent concrete entities. Chronoids can be understood as temporal intervals with boundaries, and topoids as connected spatial regions having boundaries too, as well as a certain mereotopological structure. We assume that every level, in particular every stratum, may have its own temporal and spatial structure. Then the following problems arise: which time- and space-structures are associated to the different strata (levels), and how are these different time- and space-structures related? We believe that the time- and space-structures which are considered in the sequel are adequate for the mental-psychological level, but we use them – at the present stage of our investigation – uniformly for every level of the world which is different from the physical layer.

## 4.1 Time

We assume that time is continuous and endorse a modified and refined version of an approach which is sometimes called the *glass continuum* [Hayes, 1995]. Following this approach, 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. Every chronoid has exactly two extremal time-boundaries. Besides chronoids we introduce time-regions TReg which are mereological sums of chronoids. The class TE of time entities consists of two disjoint sub-classes: the class TReg of time-regions and the class TB of time-boundaries; thus $TE = TReg \cup TB$. Every chronoid has infinitely many 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 $TS =_{df} \{ K \mid K \subseteq TE\}$. We assume that time entities are related by certain formal relations, in particular the part-of relation between chronoids and time regions, denoted by *tpart*($x$, $y$), the relations of being (an extremal) time-boundary of a chronoid, *lb*($x$, $y$) and *rb*($x$, $y$) indicating an ordering of the extremal boundaries of a chronoid, and the relation of coincidence between two time-boundaries which is denoted by *tcoinc*($x$, $y$). We assume that there are no atomic chronoids, i.e., every chronoid has proper parts. 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, Hayes, 1989].

Dealing with boundaries is especially useful if two processes are to be modeled as “meeting” (in the sense of Allens’ relation “meets”). In our opinion there are at least three conditons that a correct model must fulfill:

(a) There are two processes following one another immediately, i.e., without any gaps.

(b) There is a point in time where the first process ends and

(c) there is a point in time where the second process starts.

If, as is common practice, intervalls of real numbers are used to model time intervalls with reals as time points, there are four possibilities of modeling the meeting-point:

1. The first intervall is right-closed and the second is left-closed. This allows for two further options as the overlap of both intervalls is concerned:
   (i) The intervalls do not overlap. This conflicts with conditon (a) because a new intervall can be placed between the final point of the first and the starting-point of the second intervall.
   (ii) The intervalls overlap at the meeting-point. But then there may be properties which belong to the first process and which apply at the same time as properties to the second. This may lead to possible contradictions (cf. the examples below).
2. The first intervall is right-open and the second one is left-closed. However, this conflicts with condition (b).
3. The first intervall is right-closed and the second one left-open. This conflicts with condition (c).
4. The first intervall is right-open and the second left-open. This variant fails on all conditions (a), (b) and (c).

In contrast, the approach of the glass continuum allows for two chronoids following immediately after another *and* having proper starting- and ending-“points” by letting their boundaries coincide. Thus (a), (b), and (c) are preserved.

*Examples for conditions (a)–(c).*

| | |
|---|---|
| Office Domain: | “She draw a line with her fountain pen until there was no more ink left.” What do the conditions (a) – (c) mean in this example?<br>(a) There is no gap where there is neither ink in the tank nor no ink in the tank.<br>(b) There is a last point where the tank is not empty.<br>(c) There is a first point where the ink-tank is empty.<br>Note that a model with intervalls of reals according to 1.(ii) above would say: at the time of the meeting of the processes, the ink-tank is not empty as well as empty. |
| University Domain: | “Student X changed his course of studies from physics to computer sciences by filling out the appropriate form.” What do the conditions (a) – (c) mean in this example?<br>(a) There is no gap where X doesn’t study anything.<br>(b) There is a last point where X has the property of being a student of physics.<br>(c) There is a first point where X has the property of being a student of computer sciences. |

## 4.2 Space

Our theory of topoids uses ideas from Brentano [Brentano, 1976] and Chisholm [Chisholm, 1983]. We distinguish three aspects for the description of spatial entities covered by the fields of *mereology*, *topology* and *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 size of spatial entities. Mereology deals with questions about parthood.

Basic entities of space are three-dimensional space regions; connected regions are called topoids. Space regions are mereological sums of topoids. To describe the structure of space (or of regions, respectively) we employ the basic relations *spatial part-of*, *boundary-of*, as well as the *coincidence of boundaries*. Formally, we use *spart*(*x*, *y*) if x is a spatial part of y, *bd*(*x*, *y*) if x is a boundary of y, and *scoinc*(*x*, *y*) if two (spatial) boundaries x and y coincide. We call this approach to space *Brentano space*. Note that spatial boundaries can be found in a greater variety than point-like time-boundaries. Boundaries of regions are surfaces, boundaries of surfaces are lines, and boundaries of lines are points. As in the case of time-boundaries, spatial boundaries have no independent existence, but they depend on the spatial entity for which they are a boundary.

To describe the form of an object we adopt the relation of *congruence* between topoids whose intended meaning is “two topoids are congruent if they have the same shape and size.” For every topoid t we may introduce a universal U(t) whose instances are topoids that are congruent with t.

Similar to the problem of meeting processes, our approach with coinciding boundaries of topoids is useful in modeling two objects that are “right next to” each other (see examples below), i.e., with (a) no gap between them, (b) a true ending-point of the first object and (c) a true starting-point of the second. And again, a model using real numbers as representation of spatial entities fails to meet conditions (a) – (c) because it must use either two closed, one open and one closed, or two open intervalls of reals. As above, this violates at least one of the conditions (a), (b) and (c).

Using the proposed model each object with spatial extension is assigned to some topoid or spatial region in terms of the *occupation relation*, denoted by *occ*(*x*, *y*). This may be read as entity x occupies the spatial region y. If two entities touch each other, then parts of the boundaries of their assigned topoids coincide. So (a), (b) and (c) are preserved for the topoids and spatial regions. However, note that the boundaries of the physical entities themselves do not coincide (see sect. 5.2).

*Example for spatial coincidence*

| | |
|---|---|
| Office domain: | Consider “There is a table standing on the floor”[4].<br>(a) There is no gap between the (topoid assigned to the) table and the (topoid assigned to the) floor.<br>(b) There is a true last point of the (topoid assigned to the) tables leg.<br>(c) There is a true first point of the (topoid assigned to the) floor. |

[4] Note that this is merely a sentence given to be modeled. It might be that there is no such thing as “no space between” regarding a physical description on the level of elementary particles.

# 5 Basic Categories of Individuals

Individuals are entities which are in space and time; a major approach for the classification of individuals centers on their relation to space and time. There is the well-known philosophical distinction between endurants and processes. The difference between endurants and processes is their relation to time. Endurants are wholly present at any time of their existence. An endurant is an object which is in time, but of which it makes no sense to say that it has temporal parts or phases; hence it is wholly present at every time-boundary of its existence and it persists through time. In our approach we make a more precise distinction between *presentials* and *processes* because it turns out that the philosophical notion of endurant combines two contradictory aspects. Based on a different distinction, there are entities which characterize others: *properties*. Further, with presentials, processes and properties at hand, several “derived” categories can be discussed, among them more complex entities like *situoids* and *situations*. In this section, these categories are elaborated in some detail, expounding their major characteristics and interrelationships.

## 5.1 Presentials, Persistants, and Processes

The division of individuals according to time focusses on the notion of presence in time, which distinguishes presentials and processes. This corresponds to philosophical positions, to wit to the endurantistic view versus the perdurantistic view. Supporters of the former make a categorial distinction between objects and processes, while followers of the latter only acknowledge the existence of processes.

Herein persistence is accounted for by two distinct categories: presentials and persistants. A *presential* exists wholly at a time-boundary. We introduce the relation *at*(*x*, *y*) with the meaning “the presential x exists at time-boundary y”. Let Pres be the class of all presentials and TB the class of all time-boundaries. We stipulate that “at” is a functional relation from Pres into TB, i.e., the following axiom is stipulated: $at(x, y) \wedge at(x, z) \rightarrow y = z$. This axiom raises the question of what is meant by the claim that an endurant (seemingly a philosophical analogue of our presentials) persists through time. We pursue an approach which accounts for persistence by means of a suitable universal whose instances are presentials. Such universals are called *persistants*. These do not change and they can be used to explain how presentials which have different properties at different times can nevertheless be the same.

Let us make the relation between (philosophical) endurants and presentials clear. Endurants exhibit two aspects which contradict each other. If, for example, an endurant x is wholly present at two different time-points t and s, then there are two different entities “x at t” and “x at s”, denoted by x(t) and x(s), respectively. Now there is the claim that x persists from x(t) to x(s) (imagine the development of the newborn Caesar at time t, Caesar(t), and Caesar at the age of 50 at s, Caesar(s); both entities Caesar(s) and Caesar(t) are wholly present at these time-points, and they are obviously different. What should it mean to say that both are identical?). Our solution to this problem is the separation of endurants into wholly present presentials and persisting persistants. That means, x(t) and x(s) are not identical in a logical sense, but they are identical through being instances of the same persistant.

There is a connection to the presentistic approach to time. If we assume that only those things exist which exist at present (presence understood as a time-boundary without any extension), then presentials should be wholly present at the present time-boundary.

Of course, persistants are not arbitrary universals. They satisfy a number of conditions, among them the following: (a) every instance of a persistant is a presential; (b) for every time-boundary there is at most one instance which exists at this time-boundary; (c) there is a chronoid c such that for every time-boundary of c the persistant has an instance at this time-boundary. Further conditions should concern the ontic-relation and the relation of persistants to processes.

Forestalling some issues of section 5.4.1, let us consider the relationships between processes and time. Processes have temporal parts and thus cannot be present at a time-boundary. Time belongs to them, because they happen in time and the time of a process is built into it. The relation between a process and a chronoid is determined by the projection function *prt*(*x*, *y*) stating that "the process x is projected onto a chronoid y". Again we stipulate that prt(x, y) is a functional relation from the class Proc of all processes into the class Chron of all chronoids.

Yet there are two more projection relations, one of them projecting a process p to a temporal part of the framing chronoid of p. The relation *prt*(*p*, *c*, *q*) is to be understood as follows: p is a process, c is a temporal part of the chronoid which frames p, and q is that part of p which results from the projection of p onto c. That means, q can be seen as the restriction of the process p to the sub-chronoid c. The temporal parts of a process p – which are captured by the temporal parthood relation extended to processes, denoted *procpart*(*x*, *y*) – are exactly the projections of p onto temporal parts of the framing chronoid of p. The third relation projects processes onto time-boundaries; we denote this relation by *prb*(*p*, *t*, *e*) and call the entity e, which is the result of this projection, the boundary of p at t. We postulate that the projection of a process to a time-boundary is a presential. Moreover, presential even depend on processes since they cannot exist without being a part of the boundary of some process.

Note that individuals cannot be considered as completely separated from universals and categories. To understand – for example – the concept of persistence, one has to use universals in the form of persistants. Because of this reason this and the following sections on individuals also contain aspects of categories and universals.

## 5.2 Physical Structures

Physical structures are individuals which satisfy the following conditions: they are presentials, they are bearers of qualities (see sect. 5.3), but other entities cannot have them as qualities, and they are extended in space[5,6]. A physical structure consists of an amount of substrate and occupies space. One may assume that every space region is occupied by some physical structure which is usually composed of solid bodies, fluids and gaseous substrate.

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[5] As the term "physical structure" suggests, this chapter deals with entities of the material stratum. We expect that similar categories (being bearers of qualities, not being qualities of something else) can be found on other levels as well. However, then the requirement of extendedness in space will have to be omitted or adjusted.

[6] Some notion of saturatedness, unity or of being a whole may be used to separate simple physical structures (e.g. a mug) from the more complex category of configurations (e.g. the mug and the table below), which has the characteristics of bearing properties and of being extended in space too. For configurations see sect. 7.

*Examples*

| | |
|---|---|
| Rhinitis domain: | a nose, a mucosa, a bacterium |
| Office domain: | a pen, a table, a flat-screen monitor |
| Clinical trials domain: | a sheet of paper, a human body, a hospital building |
| University domain: | a door, a blackboard, a notebook |

### 5.2.1 Physical Structures and Properties

Let us examine each of the conditions on physical structures in some more detail. The term "to have a property" refers to a basic relation, a relative of which is distinguished for physical structures, called inherence relation[7]. Inherence connects qualities (i.e., property instances) and physical structures and we introduce the formal relation *inh*(*x*, *y*) with the meaning "the quality x inheres in the physical structure y". Qualities which inhere in physical structures are themselves regarded as individuals[8], thus inherence is a relationship between individuals. Qualities are constituents of physical structures; they have no isolated independent existence. Note that we consider some, but not all qualities to be presentials as well.

Physical structures have a higher degree of independence compared to qualities which inhere in them. Each quality is considered to depend on the physical structure it inheres in. Physical structures are of higher complexity and their constituents are related to each other by certain formal relations. The relation between physical structures and qualities (properties) is described more precisely in section 5.3.

Physical structures belong to the material stratum and the question arises whether there are analogous individuals in the psychological and social stratum. We generalize the notion of physical structure to the notion of *substance*; a substance is an individual which does not inhere in any other individual. Substances are – in a sense – urelements with respect to the inherence (has-property) relation. One of the open problems is to capture and to describe the participation of an individual in a stratum. We assume that every level has its own family of substances.

### 5.2.2 Physical Structures and Substrates

Every physical structure consists of an *amount of substrate*. An amount of substrate may be understood as a special persistant whose instances are distinct amounts at certain time-boundaries; these we call *presential amounts of substrate*. An amount of substrate at a certain time-boundary, i.e., a presential amount of substrate, is always a part of the substrate of a physical structure. We introduce the predicates Substr(x) and PSubstr(x) with the meaning "x is an amount of substrate" and "x is a presential amount of substrate". The basic relation consist(x, y) has the meaning: "the physical structure x consists of the (presential amount of) substrate y". There are several kinds of substrates, they may be classified into solid, fluid, and gaseous substrates.

Let x be an amount of substrate; in which way can one say that an amount of substrate persists, i.e., there is a persistant whose instances are amounts of substrate? Consider, for example, an

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[7] More precisely, inherence is a subrelation of has-quality. See section 5.3 and 6.3.3 for the interconnections of has-property, has-quality, and inherence.
[8] This resembles the notion of a "trope" in philosophy, cf. [Runggaldier, Kanzian, 1998].

amount G of gold. G may undergo several changes; many different forms may inhere in G at different time-boundaries. There may be rings, teeths, broochs, lumps etc. whose substrates contain the “same” G as parts. Furthermore, there is an ontological connectedness between this G at different time-boundaries. There are several properties which can be attributed to x (solidity, fluidity, gaseity). Hence, physical structures are constituted by (presential) amounts of substrates, boundaries, forms, and other presential qualities (color, weight). Then there are basic relations relating these constituents to each other.

### 5.2.3 Physical Structures and Space

Physical structures are related to space in two ways that must be kept apart: First, every physical structure S has a spatial extension, which is called the *extension-space* of S and is regarded as a quality of S, similar to its weight, for example. The formal relation *exsp*(*s*, *e*) has the meaning: “e is the extension-space of S”, which is a functional relation.

Secondly, every physical structure 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 physical structure x occupies the spatial location y”. We assume that the spatial location occupied by a physical structure is a space region, i.e., a 3-dimensional part of space (see section 4.2). It should be noted that we expect the occupation relation to depend on levels and granularities.

The region y which is occupied by a physical structure x is uniquely determined and we may ask whether for every spatial part of y there exists a uniquely determined physical structure z which occupies y. In this case z is called a *physical part* of x; this relation is denoted by *phpart*(*z*, *x*). This very strong condition is debatable because it might be that the substrate of which a physical structure consists has non-divisable atoms. It seems to be more adequate to introduce the relation phpart(z, x) as a new basic relation and stipulate the axiom that phpart(z, x) implies that the region occupied by z is a spatial part of the region occupied by x. Also, the uniqueness condition pertaining to the occupied space region is debatable. Because granularity plays a role here we stipulate this condition for every fixed occupation-relation separately. Another viewpoint which is not yet included in our ontology is the phenomenon of vagueness in defining the space region which is occupied by a physical structure.

Occupation covers a very precise notion of location, but we see the need for a relaxed version. A spatial region T *frames* a physical structure S if the location S occupies is a spatial part of T. It might be useful to introduce the *convex frame* f of a physical structure S, denoted by the relation *convf*(*S*, *f*), as the convex closure of the spatial location S occupies. We acknowledge that the notion of convex closure still has to be characterized more precisely (probably analogously to it’s use in analytic geometry).

Physical structures may be classified with respect to the mereotopological properties of their occupied space regions. A physical structure is said to be *connected* if its occupied region is a topoid. With recourse to the connectedness of the corresponding framing topoids, a notion of *unity* might be developed to single out *physical objects* among the physical structures. But connectedness alone seems to be not sufficient as a unity criterion for physical objects because one has to take the boundaries of a physical structure into consideration.

### 5.2.4 Boundaries of Physical Structures

Let x be a physical structure which occupies a topoid T and let b be the spatial boundary of T. Does there exist a physical structure y which occupies the boundary b? This seems to be impossible because physical structures occupy three-dimensional space regions. But, we assume that such physical entities exist, and we call them physical boundaries. These are dependent entities which are divided according to their spatial siblings into *physical surfaces*, *physical lines* and *physical points* (cf. sect. 4.2). Every physical surface is the boundary of a physical structure, every physical line is the boundary of a physical surface, and every physical point is the boundary of a physical line. We introduce the basic relation *physb*(*x*, *y*) with the meaning "x is a physical boundary of the physical structure y". It seems to be that physical boundaries are cognitive items which do not belong to the physical level of reality. One may ask whether a physical boundary of a body B is a kind of "skin", a very thin layer which is a part of B. We do not assume this and consider physical boundaries as particular dependent entities. It seems to be the case that even a thin layer consisting of a surface-arrangement of atoms (i.e., the "height" of this surface equals the diameter of an atom) has no stable, independent existence.

In contrast to spatial and temporal boundaries, physical boundaries cannot coincide. Instead, in order to explain the notion of two physical boundaries touching each other, their spatial locations have to be considered. Two physical structures (or their physical boundaries) are in touch if their occupied space regions have spatial boundaries with coincident parts. One has to take into consideration here that the spatial boundary which is occupied by a physical boundary depends on granularity and context. This dependency may be refined by cognitive aspects. For example, the spatial boundary occupied by a physical boundary may depend on the distance of an observer from the considered objects.

Our notion of physical structure is very general, almost every space-region may be understood as the location of a physical structure. Without an elaborated account of unity, we single out physical objects as physical structures with *natural physical boundaries*. A body is a connected physical object which consists of an amount of solid substrate. An organism is an example of a body. The notion of a natural physical boundary is rather vague and depends on granularity, context and view. We sketch some ideas how this notion could be made more precise. Let us consider a physical structure S which occupies a topoid t and let B the physical boundary of S which occupies the boundary b of t. A part A of the boundary B is considered as natural if there is a physical structure P(A) outside of S such that P(A) and S touch at A (the spatial boundary occupied by A) and such that P(A) and S (or a tangential part of S with boundary A) can be distinguished by a property. Examples of such properties are fluid, solid, gaseous. As an example let us consider a river. A river (at a time point of its existence, i.e., considered as a presential) is a physical structure which consists of fluid substrate and has natural physical boundaries at all places with exception of the region of its river mouth. The solid river bed may be distinguished from the river fluid and the river fluid may be distinguished from the air above the river.

Within our framework certain puzzles can be easily solved. We cite here a passage from [Casati, Varzi, 1994]. In Leonardo's notebooks there is mentioned:

> “What is it … that divides the atmosphere from the water? It is necessary that there should be a common boundary which is neither air nor water but is without substance, because a body interposed between two bodies prevents their contact, and this does not happen in water with air.”

How can two things – the water and the air – be in contact and yet be separated?

Leonardo’s problem can be analysed as follows. There are two physical structures W, A (water and air), W consists of liquid substrate, A consists of gaseous substrate. W and A have natural boundaries because at the “touching area” we may distinguish W and A by the property “fluid” and “gaseous”. These natural boundaries touch because there occupied space-boundaries coincide. The touching phenomenon is captured by the property of the Brentano-space that pure space boundaries may coincide; they may be at the “same place” but, nevertheless, different. What is “interposed” between the two natural boundaries are two coinciding space-boundaries which do not occupy any space.

### 5.2.5 Physical Structures and Time

Physical structures are presentials, so they exist at a certain time-boundary. We express this by means of the basic relation *at*(*s*, *t*) as introduced in section 5.1. We assume that for every time-boundary t there is a physical structure s such that at(s, t).

The relationship at defines an equivalence relation on the category of physical structures. Two physical structures a,b are said to be *temporally co-existent* if there exists a time-point t such that at(a,t) and at(b,t). These equivalence-classes (i.e., the sets of all physical structures existing at a certain time-boundary) are called *complete time-slices.*

A collection of physical structures having at most one member in common with every temporal region is called a *temporal path*. Two physical structures a,b are said to be *sharing a temporal path* P, if a, b are elements of P. Certain (natural) temporal paths are the basis for the understanding of the persistence of persistants.

### 5.2.6 Persistence and the Meaning of Proper Names

It is a speciality for physical structures that proper names are used in natural languages to denote first of all physical structures. Consider an everyday name like “John”. The question arises what John refers to in an ontologically precise understanding. We see three possibilities, i.e., three entities of different categories: (a) John denotes a presential at some point in time, (b) John refers to a persistant, or (c) the name is given to a process which may also be called “John’s life”. Accordingly, each sentence with the term John has to be disambiguated with respect to these variants.

The following connections between these three entities can be stated. Starting with an act of perception of John, we assume that a presential is recognized, call it $\text{John}_{\text{pres}}$. As each presential, $\text{John}_{\text{pres}}$ is tied to a certain time-boundary. If one has seen John several times, with probably varying properties, but still being able to identify him, this forms the basis for a persistant, say $\text{John}_{\text{prstnt}}$. Now one may consider the extension of this persistant (which is a universal), i.e., the class $\text{ext}(\text{John}_{\text{prstnt}}) = \{ j \mid j :: \text{John}_{\text{prstnt}}\}$. Obviously, the entity $\text{John}_{\text{pres}}$ referred to above is a member of this class. Also, one can say that each two members of that class represent “the same John”.

Of course, one cannot follow the inverse path, i.e., consider a class of arbitrary presentials with completely different properties, and claim that there is a persistant with that class as its extension. We stipulate the requirement for persistants that they have to be connected by the formal relation *ontic*(*x*, *y*). This relation is a first attempt to cover several intuitive principles assumed for persistants, and it has to be elaborated in further work. Thus far, ontically connected entities should satisfy at least the conditions of spatio-temporal continuity discussed by [La Podevin, 2000]. Further, we say that a universal U *persists through the history* of John if every element of ext($John_{prstnt}$) instantiates U. Note also that the notion of $John_{prstnt}$ is a similar position as provided in [Simons, 2000], namely that persistants are invariants amid diversity, and that what is true of them is true of their associated class of concrete instances.

Another class which can be derived on the basis of $John_{prstnt}$ is that of all time-boundaries at which "a" John exists: $TB(John_{prstnt}) =_{df} \{ t \mid \exists j (j :: John_{prstnt} \wedge at(j, t) \}$. This class as well as the notion of spatio-temporal continuity leads to the third interpretation of John, namely as a process of a special kind. Such processes are called persistant-processes. In the case of John, the persistant-process $John_{proc}$ is such that each projection of $John_{proc}$ to any suitable time-boundary results in a presential $John_{pres}$ which is an instance of $John_{prstnt}$. Formally, this can be reflected by considering the class of all process boundaries $PRB(John_{proc}) =_{df} \{ j \mid \exists t \, prb(John_{proc}, t, j) \} = ext(John_{prstnt})$ as well as the class of all time-boundaries $PTB(John_{proc}) =_{df} \{ t \mid \exists j \, prb(John_{proc}, t, j) \} = TB(John_{prstnt})$.

Based on $John_{proc}$, one can now also define the lifetime of John. Reasonably, this can be defined as the chronoid to which the persistant-process $John_{proc}$ projects, i.e., if $John_{proc}$ is a persistant-process, $lifetime(John_{proc}, c) =_{df} prt(John_{proc}, c)$. Note that c is the minimal chronoid which covers all time-boundaries in $TB(John_{prstnt})$. We use the functional abbreviation *lf*(*x*) which is defined by the condition $lf(x)= y \leftrightarrow lifetime(x, y)$. Further, we stipulate the axiom that for every persistant x there exists a corresponding persistant-process y, i.e., such that for all presentials holds: z :: x if and only if there is a time-boundary t of lf(y) such that at(z, t).

## 5.3 Properties

There is a kind of entities which allows one to focus on certain aspects of other entities. These entities are called *properties*, understood as characteristics of entities, where the former are existentially dependent on the latter. The formal relation has-property, denoted by *hprop*(*x*, *y*), accounts for such characterizations of one entity by another.

We hold that has-property is a derived ontological relation and that there are many different versions of this relation, which have to be specified separately. In this section we analyse possible has-property relations, which herein we assume to be restricted to properties of individuals. Whether properties should as well be admitted for the characterization of universals is still a matter of debate. Abiding by the separation of ontological and meta-ontological issues, we omit further discussion of properties of universals herein. Some further notions are required in order to state this restriction to individuals more formally.

Properties are important because they allow for the explication of certain aspects of other entities. For instance, if one is interested in a new filing cabinet for one's office, it may be necessary to focus on the size of this cabinet. The size is then one facet which could be of much more interest than others, like the color or the weight. Let us consider a more widespread number of examples:

*Examples*

| | |
|---|---|
| Rhinitis Domain: | the severity of a rhinitis (a severe or a minor rhinitis);<br>the shape of a nose, which may be bulbous, pointy, flattened, etc. |
| Office Domain: | the size or the color of a filing cabinet;<br>its flexibility, referring to a custom-tailored vs. a modular composition |
| Clinical Trials Domain: | the size of a clinical trial (e.g., derived by the number of patients);<br>the number of centers, comprising mono- and multi-center trials;<br>the age of a patient (which may decide on the inclusion or the exclusion in a trial) |
| University Domain: | the size of a university (e.g., derived by the number of students);<br>its reputation which may be excellent, good, established, tarnished, bad, or evil |

These examples further show that properties can be shared among different entities. Filing cabinets can be compared to desks or shelves in size. On the other hand, there may be distinctions between terminologically “the same” property, cf. the size of a desk and that of a university. Nevertheless, a common core notion of size appears acceptable. Altogether, properties provide a means of classification which is orthogonal to sortal universals and classes (cf. [Guarino, Welty, 2000]).

The use of syntactic elements which (roughly) reflect properties in natural as well as representation languages is another hint on the importance of properties. Being aware of the difficulties in assigning parts of speech to ontological categories, nevertheless we consider adjectives and adverbs to be primary means of expressions for properties in natural languages. In artificial languages, there occur syntactic elements like attributes and slots as resemblances of properties.

In order to integrate properties in the GFO, five self-contained categories are introduced: *property bearer*, *property*, *property value*, *quality*, and *quality value*. This core of concepts is extended by notions referring to the observability and measurability: *measurement system*.

### 5.3.1 Property and Property Bearer

The category of property bearer is of relative character. Reconsidering the above example, the filing cabinet is the bearer of the property size. This is formalized by $hprop(x, y)$, where we call x a property bearer and y a property. A property bearer is an individual and a property a universal. Obviously, the filing cabinet can be understood as a presential. The category of property bearer is thus a relative category of individuals of any type involved in the has-property relation. Note that this approach also accounts for properties of processes and of properties themselves. This allows to capture notions like fastness of processes, for instance, as in natural language phrases like “a fast writing” or “a fast healing”, or notions like lightness of colors, as in “a light color”.

Philosophical approaches dealing with properties often contrast them with substances [Butchvarov, 1998; Runggaldier, Kanzian, 1998]. Substances are considered as entities with an independent state of existence, whereas a property is dependent on the substance in the sense that its instances inhere in it. However, this approach lacks the acknowledgement of properties of other types of individuals. The approach pursued herein is rather similar to that taken in [Masolo, Borgo, et al., 2003].

### 5.3.2 Property Value

Let us now consider the following two phrases: “the size of a cabinet” and “a big cabinet”. The first phrase refers to a property of the cabinet, whereas the second speaks about a *value* of this property of the cabinet. Thus we distinguish properties and property values. A property is a certain aspect of some entity x. A property value reflects the relationship between the property of x and the same property as exhibited by another entity y. Like properties, property values are considered to be universals.

Property values usually appear in groups which are called value structures or *measurement systems*. Each of these structures corresponds to some property, i.e., this property may have values of that value structure. More intuitively, one could say that the property may be measured with respect to some measurement system. For instance, sizes may be measured with the values “small” “big” or “very big”, which are the elements of one value structure. This structure and the particular values of the sizes of, e.g., a cabinet and a desk, respectively, allow one to compare their sizes.

The notion of a value structure of a property is similar to a quality dimension in [Gärdenfors, 2000] (note that the term “property value” here resembles Gärdenfors’ notion of “property”, our “property” his “quality dimension”). Further, value structures are related to quality spaces in [Masolo, Borgo, et al., 2003] (which consists of all “quales” (our property values) of some “quality” (our property)). Note, however, that various types of value structures can be found for the same property. Of course, one is tempted to consider all these value structures within one comprehensive or “objective” structure. The latter would cover all values, such that any other structure appears as a selection of values of the objective structure. Instead of this, thus far we consider the approach of having distinct value structures (e.g., based on some measurement instrument), which may afterwards be aligned and composed into a broader structure as the better choice. One reason for this approach is that the precise objective structure is unknown for the most properties (choosing real numbers as isomorphic may often comprise too many values; cf. below). In addition, all measurement instruments are restricted to a certain range of values which can be measured, which amounts to another reason.

Within a value structure, several levels of generality may be distinguished, but preliminarily we understand value structures as sets of values. Often it seems to be the case that a notion of distance can be defined, and that certain layers of value structures are isomorphic to some subset of real numbers, which allows for a mapping of values to pairs of a real number and a unit, as in the case of “10 kg”.

### 5.3.3 Quality and Quality Value

In our considerations about the filing cabinet and its size, we propose to call the filing cabinet the property bearer, the size the property and all possible values of the size the property values of the property size. But one could observe that the size, as it is a universal, can be a property of other entities apart from filing cabinets. Hence the question arises whether the size of the particular cabinet and the size of some other particular entity is the same entity. To answer this question we introduce the distinction of property and quality (as regards these two categories, note the terminological and conceptual affinity with [Masolo, Borgo, et al., 2003]).

Let us now differentiate between two entities in our example: “the size” and “the size of that cabinet”. The size is the property as already introduced and because it is a universal it is independent of the filing cabinet, which is an individual property bearer. But apart from the universal size independent of any property bearer we find the particular size of the particular cabinet, which exists only in the context of this cabinet and therefore depends on it. We call individuals of that kind *qualities*. To say that the property bearer (an individual) has a property (a universal) means that there is a quality (another individual) which is an instance of the property and which is existentially dependent on the property bearer. In the case of the filing cabinet and its size, the “size of that cabinet” is a quality, whereas “size” is a property. The existential dependency of a quality y on a property bearer x is grasped by the formal relation hqual(x, y). Furthermore, subtypes of has-quality will be distinguished below, according to other categories which apply to the property bearer.

Analogously to quality and property, we introduce *quality values* as opposed to property values. For example, big and small may be the values of the property size, whereas a particular big (bigness) or small (smallness) of some cabinet is the value of a quality, namely the size of that cabinet. Quality values are individuals instantiating the corresponding property values. Moreover, the particular quality value x is linked to a quality y by the relationship value(x, y).

A more intuitive example of quality values is supplied by the phrase “She likes the redness of that t-shirt”. The redness of the particular t-shirt is a distinct entity from redness in general. There can be one universal redness or red but a different individual redness with respect to the individual bearer: cf. the redness of the t-shirt, the redness of the car.

### 5.3.4 Classification of Properties

It should be stated explicitly that property values are not considered as specialisations of properties. Properties themselves can be classified and subdivided in various ways. One natural way to classify perceptible properties is by assignment to human senses by means of which they can be perceived. This leads to visible properties (like lengths and color), smells, tastes (e.g. sweetness, bitterness) and so on.

However, there are also more formal classification principles for properties, for instance, according to the categories of the characterized entities. The following subcategories of qualities (and properties) with respect to the categories their bearers belong to are preliminarily distinguished. Note that for each category a different subrelation of has-quality may be introduced, in order to integrate relationships which are fairly established.

- Qualities of physical structures
  (These qualities are connected to physical structures by the formal relation of inherence, denoted by *inh*(*x*, *y*).)
- Qualities of processes
- Qualities of qualities

## 5.4 Occurrents

The category of occurrents centers around the more intuitive notion of *processes*. It captures processes themselves and several other categories which can be derived from processes and share the feature of being extended in time (in various ways). Accordingly, among those entities which are in time, occurrents may be understood as the opposite of presentials.

### 5.4.1 Processes

The category of *processes* captures those entities which develop over time, unfold in time or perdure. Some examples will provide a first intuitive understanding.

*Examples*

| | |
|---|---|
| Rhinitis Domain: | a rhinitis itself, seen as a sequence of different states of inflammation |
| Office Domain: | writing a letter; sitting in front of a computer viewed as a state extended in time; |
| Clinical Trials Domain: | a clinical trial itself; the treatment of a patient; the development of a cancer; |
| University Domain: | a lecture in the sense of an actual event as well as a series of actual events, but opposed to the abstract notion of lecture; an examination |

Accordingly, processes are tied to temporal entities in a different way than physical structures, to wit in terms of the projection relation *prt*(*p*, *c*), which relates some process p to its framing chronoid c. This assumption of projection to chronoids is rather strong, because sometimes, e.g. in the case of a series of lectures seen as a whole, the time entity appears to be a non-connected aggregate of chronoids, called time-region. In this case, however, the "process" can also be derived from processes with an associated chronoid. More precisely, we call these entities *process aggregates* or *generalized processes*. In many cases what is said about processes herein can be easily extended to process aggregates. To complete the example, a lecture series as above is a process aggregate which is formed by single lectures, these themselves being processes. Note further that processes cannot be projected to time-boundaries.

Parts of processes, as well, behave differently with respect to time compared to parts of physical structures. Whereas the latter are found along spatial dimensions, "pure" parts of processes are cut along a single temporal dimension. However, both types of parthood may be combined to speak about spatiotemporal chunks of processes, as will be examined below. As in [Masolo, Borgo, et al., 2003], in contrast to physical structures and their parts, parts of processes cannot exist at a single time-boundary. Rather, parts of processes are processes themselves, i.e., each part of a process starts at some time-boundary and culminates in another time-boundary.

From this the question arises whether there is a corresponding notion which is related to processes as time-boundaries are related to chronoids. Indeed, presentials fill this gap. If a process is projected onto a chronoid in terms of prt(p, c), each boundary b of c refers to a presential e which is called the boundary of the process, denoted by *prb*(*p*, *b*, *e*), which further implies at(e, b). In the general case, this presential will be classified as a *configuration*, i.e., a conglomeration of physical structures, qualities and relators (see section 7).

On the basis of process boundaries, the notion of *participation* in a process p, *partic*(*s*, *p*), is derived, such that every constituent s of the above configuration e participates in p. Analogously to chronoids and temporal boundaries, the boundaries of processes are not considered to be parts of processes, which is already a consequence of rejecting parts of processes which exist at a single time-boundary, like configurations. On the other hand, processes cannot be considered as mere aggregates of their boundaries. Further, based on the coincidence relation between time-boundaries and the derived meeting relation of chronoids, analogous notions can be defined for process boundaries and processes. Two process boundaries coincide iff their corresponding time-boundaries coincide, and two processes meet if and only if their associated chronoids meet (on some level of granularity). Section 10 contains the formal definitions.

Up to this point, it seems that the connection between different process boundaries of a process is not constrained. Equally, one may also consider parts of completely distinct processes which are projected to meeting chronoids as parts of another process[9]. However, in most cases one can assume the coherence of processes, which we understand as obedience to certain underlying principles, e.g. spatiotemporal continuity as well as causal interrelationships. Ontical connectedness as introduced in section 5.2.6 is intended to account for coherence as an initial approach which will have to be extended in the future. Accordingly, all coherent processes are required to have ontically connected boundaries. This allows for another notion of participation which involves persistants (remember that presentials exist solely at a unique time-boundary, whereas persistence is captured in terms of persistants, as a subclass of immanent universals, cf. section 5.2.6). This understanding of participation even seems to be more natural than that described above. For example, if somebody is writing a letter for about half an hour, there is usually an understanding of having "the same" somebody at the beginning and the end of the writing process. This can be interpreted twofold: either (1) this means that in each boundary of the process one can find an instance of one persistant, or, less restrictive, (2) it refers to the fact that there is a part of the process, such that this part satisfies condition (1), having temporally partial participation in mind, like the attendence in half of some conference. The notions of participation are introduced axiomatically in section 10.

Finally, changes (in the sense of an effect or of varying properties) are an important aspect of processes, without which processes could not be realized. Changes can only be realized in terms of ontical connectedness and persistants, in order to know which entities have to be compared with each other to detect a change.

Towards a future extension of this section with a typology of processes, the following works are intended to be considered: [Sowa, 2000], [Sandewall, 1994]. Additionally, we believe that the application of the current ontology will guide the search for a reusable classification of processes.

Now that the basic notions and their interconnections are expounded, several categories can be derived on that basis, which are relevant from an ontological point of view. These are defined in this section, and there will be: *changes*, *discrete* and *continuous processes*, *states*, and *histories*. Further, processes are classified according to the nature of their boundaries and, finally, the relationship between processes and space will be discussed.

---

[9] For example, take the writing of a letter by person A until 1 p.m. and registration of some new student B which starts at 1 p.m. – the „sum" of these parts yields an entity unfolding in time and being projected to a chronoid, i.e., a process.

### 5.4.2 Changes

In contrast to change as an effect, a *change* in the technical sense to be defined here refers to a pair of coincident process boundaries. Accordingly, it comes close to notions like “punctual” or “instantaneous event” as well as “moment” (in a temporal reading). For example, the immatriculation of a student is a change. It comprises two process boundaries, one terminating the process of the application at university, one beginning the process of studying. Another example is that of two process boundaries in the middle of a decrease of an inflammation in the course of a rhinitis. Here, one may not be able to assign a difference of the severity of inflammation to coincident boundaries, but considering one of these boundaries together with another one at the opposite end of a chronoid of arbitrary extension, there will be a difference.

The last two examples illustrate an important distinction in the category of changes: that between *extrinsic* (as in the student example) and *intrinsic changes* (like a continuous decrease of an inflammation). Either notion of change is relative to some collection of pairwise disjoint universals or contradictory conditions between which a transition takes place. Extrinsic changes grasp discontinuous, instantaneous changes, whereas intrinsic changes can be understood to be continuous. With respect to contradictory conditions, locomotions are a prime representative of intrinsic changes. Here, the conditions refer to some change of the distance of the moving entity to some entity or frame of reference.

Herein, we formalize only changes based on universals, for simplicity. Extrinsic changes are represented by $change(e_1, e_2, u_1, u_2, u)$, where $e_1$ and $e_2$ capture the pair of coincident process boundaries[10], and $u_1$ and $u_2$ are disjoint sub-universals of u, such that $e_1$ and $e_2$ instantiate $u_1$ and $u_2$, respectively. Note that this implies instantiation of both $e_1$ and $e_2$ of u, which prevents expressing artificial changes, e.g. a change of a weight of 20kg to a color of red. In order to formalize intrinsic changes, a minimal chronoid universal $\Delta c$ is employed in order to capture the idea of observable differences during certain chronoids, whereas the change itself does not allow the observation of a difference. The predicate $change(e_1, e_2, u_1, u_2, u, \Delta c)$ is intended to formalize this approach. An overall more detailed elaboration possibly capturing theories of vagueness or uncertainty is a future task.

### 5.4.3 Discrete vs. Continuous Processes and States

Based on the notions of extrinsic and intrinsic change, processes can be subdivided according to the nature of changes occurring within a process. First, there are processes all of whose coincident internal boundaries are intrinsic changes. These turn out as purely *continuous processes*, described e.g. in physics by differential equations. Secondly, there are such processes which exhibit extrinsic changes. However, a process just consisting of extrinsic changes does not appear to be very reasonable, because in this case it would be better to employ other universals in order to get a comprehensive understanding of the process. Therefore, extrinsic changes alternate with periods without extrinsic changes (based on the same universals). Those parts of a process without extrinsic changes correspond to the definition of a *state*, which constitutes an own type of process. Note that states are a notion as relative as changes. In summary, two common kinds of processes can be identified: continuous processes based on intrinsic changes and *discrete proc-*

[10] Note that “coincident process boundaries” refers to the fact that the projections of the process boundaries yields a pair of coincident time-boundaries.

*esses* made up of alternating sequences of extrinsic changes and states (cf. p. 214 in [Sowa, 2000] on the distinction of continuous and discrete processes).

### 5.4.4 Histories

Another derived notion of high relevance for modelling is that of histories. A *history* consists of a number of process boundaries, which is best understood in the sense of a universal of certain process boundaries. Of course, a reasonable choice has to be assumed, in order to get a “natural” history. The term reasonable here can be interpreted in a similar fashion as in the case of states, e.g. some universal should be taken into consideration for each element of the history. In any field with periodic measurements of certain properties or periodic determinations of facts, the use of histories is implemented. Obviously, it is not sensible to first measure the temperature of a patient, the next time determining his weight and a third time his blood pressure, but to consider this as a history of patient data. Instead, we assume that any history can be embedded into a process, which then forms a foundation of the history.

### 5.4.5 Simple and Complex Processes

With respect to the naturality of histories and the coherence of processes, another dissection of the category of processes shall be discussed. It is geared to the complexity of the process boundaries in their nature as presentials. Consider some person walking and a clinical trial. In the first case, the process of walking focusses on the person only (and its position in space), whereas the clinical trial is a process with numerous participants and an enormous degree of complexity and interlacement. It is clear that every process is embedded in reality, i.e., the walking is not separated from the world and could be considered with more complexity. The categories of situations and situoids as expounded in section 7 are a first attempt to account for this in a systematic manner. However, often processes refer to specific aspects of their participants such that a division into simple and complex processes appears to be useful.

A process is called *simple* if its process boundaries are simple presentials or even mere qualities of presentials (abstracting from the physical structure these qualities inhere in). Accordingly, simple processes can be split into *quality-processes* or *physical-structure-processes*. Thus far, simple processes are required to exhibit process boundaries all of which instantiate the same persistant or qualities inhering in instances of the same persistant. In contrast to simple processes, *complex processes* involve more than a single presential. The distinction between simple and complex processes captures only a sketchy idea yet, whereas a general theory has to be developed in the future.

### 5.4.6 Relating Processes to Space

The question arises in which way processes relate to space. We assume that this relation can be derived from the presentials which are the process boundaries. Therefore, this question is most easily addressable for physical-structure-processes. In such a process, each boundary comprises exactly one physical structure e(t), where t denotes the corresponding time-boundary. In this case, the convex frame f of the topoid occupied by e(t) can be defined, denoted by $convf(e(t), f)$. In order to assign some topoid to the overall process we consider the convex closure of every frame f which is assigned to some e(t) for any time-boundary t in the duration of the process.

With respect to quality-processes, a step has to be added at the beginning, because qualities do not exhibit a direct relation to space. Therefore, for each boundary of the quality-process one has to determine the physical structure the quality inheres in. The construction for physical-structure-processes can then be applied to these physical structures. The augmentation of the qualities with the corresponding physical structures is called the *inherence closure* of a quality.

For complex processes, which involve a system of physical structures and qualities, both approaches are combined. That means, first the inherence closure of all qualities in each process boundary is derived. Then one can determine the convex closure for each of the physical structures found, and for each time boundary. The final step integrates all topoids determined in this way within a single convex closure, which is then assigned to the complex process as its spatial location.

### 5.4.7 Process Classifications

Above we have presented two ways of classifying processes, first into discrete vs. continuous and secondly into simple and complex processes. However, neither is well suited as a general process classification, because the first case is a relative notion, whereas the second one is very structural in nature and appears useful rather from a technical point of view. Philosophical literature offers some other classifications which shall now be analysed.

[Casati, Varzi, 2002] draws a classical distinction of what they call events ("things that happen") between *activities*, *achievements*, *accomplishments*, and *states*[11]. This classification is summarized in table 1. The classification criteria are specified as follows. An event is homogeneous if the same description applies to its sub-events. Culmination is understood as having a natural finishing point. Instantaneity refers to the duration of the event.

| Type of Event | Homogeneity | Culmination | Instantaneity | Example |
|---|---|---|---|---|
| Activity | homogeneous | never culminates | extended in time | John is walking uphill. |
| Accomplishment | not homogeneous | may culminate | extended in time | John is climbing a mountain. |
| Achievement | not applicable | is a culmination | instantaneous | John reaches to top of the mountain. |
| State | homogeneous | not applicable | not applicable | John knows the mountain. |

**Table 1 : Types of Events compiled according to [Casati, Varzi, 2002]**

Obviously, these types involve more kinds of occurrents than only processes. We start with the following assignments. First, achievements appear to be extrinsic changes, as they are assumed to happen instantaneously. Choosing extrinsic changes, as opposed to intrinsic, is based on the notion of culmination which seems to refer to a realizable difference. States in the sense of [Casati, Varzi, 2002] seem to refer to the realm of relations and facts, since there are no changes (in an intuitive sense) involved.

[11] Note here that this is a different notion of state. A substantiation of this is given below.

What remains are achievements and accomplishments, which are at least extended in time like processes. However, we doubt that these are an adequate classification of processes due to relying on the notion of homogeneity. Homogeneity is not a property of a process individual, but it is a property of some process universal, e.g. walking. Neglecting granularity aspects, one can agree that all temporal parts of an individual walking are also instances of walking. However, this is not the property of the individual. For instance, we may extend the description to "John walks from A to B.", which still refers to a walking, but more precisely to a walking from A to B. The latter is no longer homogeneous, but it has the same instance.

Culmination allows for a similar argumentation. It seems to be based on the question of what can be derived at the end of the process. A culminating event is associated with an end point. This does not mean, however, that a non-culminating event does not have an end point. Each walking of John finds an end and could thus also be classified as an accomplishment of the form John walked to X.

For the above reasons we refrain from accepting the distinction between achievements and accomplishments as a classification for process individuals, although we acknowledge these terms as referring to process universals. Note that spiny questions of the identity of processes touch the issues just discussed. Nevertheless, herein we will not address such issues as they are not in the focus of this work.

## 5.5 Mental and Social Entities

Up to this point, the level approach as presented in, e.g. [Poli, 2001b; 2002], and adopted for GOL in section 3.3 has not been further expounded. This section is a small, indicative step in this direction. Without special emphasis, some ontological categories described above refer to the physical stratum only. For instance, this applies to the individuation principle based on space and time and the assumption that physical structures occupy space.

Basically, some examples of entities in the mental and the social realm can be given. We are aware of the fact that there are several deficiencies in the ontology provided so far, comprising the lack of theories of intentionality and denotation, for example. Nevertheless, most of the basic ontological distinctions are useful for mental and social entities as well. The following collection of cases will exemplify our understanding of mental and social entities, their assignment to basic categories and initial points for future extensions.

Let us consider some entities of the mental realm.

| | |
|---|---|
| Mental Structures: | an idea; a hypothesis; fictive entities (like Sherlock Holmes) |
| Mental Qualities: | a characteristic (behaviour) of some person (e.g., diligence with values from diligent to lazy) |
| Mental Occurrents: | a decision; a dream |

Admittedly, the relationship between cognitive and fictive entities is not completely clear, in particular as interference with social aspects may occur (cf. the fact that Sherlock Homes is famous).

The level of social entities is much more pervasive herein, in particular, as two of the four example domains have a highly social character: the university domain and the clinical trial domain.

| | |
|---|---|
| Social Structures: | a university, a faculty, a student;<br>a coordination center for clinical trials, a documentalist, a physician |
| Social Properties: | an academic degree, a reputation;<br>eligibility for support, social state (poor … wealthy) |
| Social Occurrents: | a lecture, an examination, an immatriculation, a study;<br>a clinical trial, an anamnesis (in the sense of recording the medical history) |

# 6 Relations and Facts

To put it in simple words, *relations* are entities which glue together the things of the real world whereas *facts* are constituted by several related entities together with their relation. Every relation has a finite number of *relata* or *arguments* which are connected or related. The number of a relation's arguments is called its *arity*. We admit the possibility of *anadic* relations, i.e., relations with an indefinite number of arguments. Further, the relata of a relation can play the same or different roles in the context of the relation.

*Examples*

| | |
|---|---|
| Rhinitis Domain: | a nose being part-of a head; an inflammation being more severe than another |
| Office Domain: | a file being to the left of another one; being related by a discussion |
| Clinical Trials Domain: | being a patient of some physician; being a participant of a trial; |
| University Domain: | being a student of a university; being related by a lecture; |

## 6.1 Relations, Relators and Relational Roles

### 6.1.1 Basic Notions

Let us first consider the connection between a relation and its arguments (referring to facts on an intuitive basis). At this point, a particular fact seems to involve a relation and particular arguments. John's being a patient of hospital A is one fact, whereas the same John's being a patient of hospital B amounts to a different fact. Different particular arguments are involved in these facts, but the same relationship appears, namely "being a patient of". For this reason we assume that relations exhibit a universal character.

As a consequence, we have to answer the question what kind of entities relations are predicated of. Put differently, what are the instances of a relation? In contrast to the extensional definition of relations in a mathematical reading, we do not consider the mere collection of the arguments with respect to a single fact as an instance of a relation. For example, the pair (John, hospital A) is not an instance of the relation "being a patient of". Instead, we assume that there are concrete entities with the power of connecting other entities (of any kind). These connecting entities are called *relators*, and they are the instances of relations.

Relators themselves offer an "internal" structure which allows one to distinguish the differences in the way the arguments of a relation participate in a fact. Returning the example, John is involved differently in the fact of being a patient of hospital A as compared to the hospital. Exchanging John and the hospital would result in a strange sentence like "the hospital A is a patient of John". We say that John and the hospital play different roles in that relationship. Formally, this leads us to the introduction of a further type of entity: *relational roles*[12]. A relator can be decomposed into relational roles, such that each role is a mediator between exactly one argument and the relator.

[12] For convenience, „role" is used as an abbreviation for relational role in the remainder of this section.

Now the link between an argument and a relator can be completed. The relationship between relators and roles is called *role-of*. As indicated in [Loebe, 2003], role-of might be understood as a subtype of an abstract part-of relationship (namely between roles and relators), but we will not adopt this until a sound standing comparison of the role-of and part-of relations is available. Further, roles have to be connected with the relata of the relator. This purpose is served by the basic relation *fills-role*. It is subsumed by the basic relation *dependent-on*, because roles are a specific kind of dependent entities: they are dependent on their filler (which is the relatum) and on antagonistic roles (such that the totality of involved roles constitutes the relator).

### 6.1.2 Classifications of Relations

One way of classifying relations is with regard to the types of their relata. There are *intra-categorial* relations, e.g. between classes, between individuals, and between universals, but there are also *inter-categorial* relations, for instance between universals and individuals, or between presentials and processes. However, this will not be the major classification of relations, as it can be derived on the basis of the categories. Thus we turn to another distinction of major importance.

We divide relations into two categories, called *material* and *formal relations*, respectively. The relata of a material relation are mediated by (material) relators. As relators in general, material relators are concrete entities, but it is an open question whether they can be seen as individuals in the sense as described in section 3.2. But, by introducing a general notion of individual we may stipulate that every relator, formal or material, is an individual. In the next version of this document we will introduce a more general notion of an individual (cf. [Gracia, 1988]). Then the question arises whether there are individuals which are independent from time and space.

Material relators are *founded* in other entities; contracts, conversations, and treatments, for example, are individuals generating relators which connect individual persons or organizations. The notion of being founded captures the idea that other entities than the relata "create" the relator. For instance, processes will often have this effect. One has to distinguish thoroughly between the relator itself and its foundation. A conversation is the foundation for the relator of "being connected by a conversation". Note that we assume that at least one of the arguments of a material relator is an individual.

In contrast to material relations, *formal relations* hold between two or more entities directly – without any further intervening individuals for a foundation. Examples of formal relations are: greater-than, part-of, different-from, and dependent-on. This type of relations also includes the basic relations which are introduced throughout this work (see section 6.3 for an overview). Formal relations are considered – akin to material relations – as a kind of immanent universals. The instances of formal relations are called formal relators which are composed of formal roles.

Apart from the distinction of material and formal relations, there is a kindred term in computer science, namely *extensional relation*. Actually, however, extensional relations are sets of tuples. We do not consider them as relations in the sense as introduced above. Instead, extensional relations are a common set-theoretical reflection of relations. Consequently, they are subsumed by the notion of the extension of a universal, since relations are considered as universals.

## 6.2 Facts, Propositions and Infons

### 6.2.1 Basic Notions

With relations, relators and roles all components of facts are available, such that a more formal approach can be established. Since relations are entities connecting others, it is useful to consider collections of entities and their relators. The simplest combinations of relators and relata are *facts*. Facts are considered as parts of the world, as entities sui generis, for example "John's being an instance of the universal Human" or "the book B's localization next to the book C" refer to facts. Note that the existence of facts is not uncontroversial in the philosophical literature. Approaches span from the denial of facts on the one hand to their acknowledgement as the most primitive kind of entity on the other (cf. [Runggaldier, Kanzian, 1998], p. 198 ff.).

Further, facts are frequently discussed in connection with other abstract notions like propositions (cf. [Loux, 1998], chapter 4), which are not covered in depth in this version of the document. However, what can already be said about propositions is that they make claims about the existence or non-existence of facts. Therefore, truth-values are assigned to propositions and they can be logically combined. Neither is the case for facts. That means we assume that there are no logical combinations of facts, in particular there are no negative facts. In analogy to atomic formulas in logic, a special type of propositions is introduced which reflects a single fact and which is called an *infon*, similar to the notion of infons in [Barwise, 1989; Devlin, 1991]. We write $\langle\langle R: a_1, \ldots, a_n \rangle\rangle$ for the fact that a relator, i.e., an instance, of the relation R connects the entities $a_1, \ldots, a_n$. Preliminarily, we use $\langle R: a_1, \ldots, a_n \rangle$ for the corresponding infon about the same situation.

To make the difference between facts and infons clear let us consider the above examples. The fact of "John's being an instance of the universal Human" is expressed (denoted) by the symbolic structure ⟨⟨Inst: John, Human⟩⟩. In contrast, the symbolic structure ⟨Inst: John, Human⟩ denotes an infon (more common notations include Inst(John, Human) or John :: Human). The difference is that the the latter is a claim about the world which has an assigned truth-value and which can be logically combined with other propositions. The former simply denotes a part of the world.

### 6.2.2 Representing Facts

To speak about facts and to communicate knowledge and information about them we need a representation of facts. For this purpose the notion of *factual pictures* is introduced, which have the form ⟨⟨Inst: John, Human; $\alpha$⟩⟩. In contrast to facts, factual pictures are equipped with an injective *assignment function* $\alpha$ which assigns to every symbol in the factual picture an object of the world or of the universe of some model-theoretic structure which mirrors some situation (cf. also sect. 13). Like facts, factual pictures do not have a truth-value. Similar to factual pictures, an infon may be understood to some extent as a representation of a fact, but with the additional characteristic of being a truth-bearer, where the truth-value of an infon may depend on the context. Both, infons and factual pictures are abstract entities which exist in an agent's mind. A deeper elaboration of the interconnections of facts, factual pictures, infons, and agents in terms of an analysis of the denotation relation is to be developed in the future (cf. sect. 6.3.9). For the present version we discuss a refined method of representing facts, assuming that facts (instead of propositions) are represented by common formalisms such as first-order logic.

The standard way of representing facts in a logic is as in "next-to(b, c)", which employs a predicate representing the relation and names the arguments in a certain order. In the style of [Loebe, 2003], (sect. 5.1 therein), we introduce a more detailed way of representing facts, such that the standard mode appears as a simplified version with certain assumptions. The general and detailed pattern to denote a fact is based on a relation R, the roles of the relation, $Q_1, \ldots, Q_n$, and for each role $Q_i$ a number $m_i$ ($1 \leq i \leq n$) of corresponding relata. Then

$$\langle\langle R : Q_1(e_1^1, \ldots, e_{m_1}^1); Q_2(e_1^2, \ldots, e_{m_2}^2); \ldots; Q_n(e_1^n, \ldots, e_{m_n}^n)\rangle\rangle$$

describes the fact. This corresponds to the following standard representation, which is also used in most cases herein. Using prefix notation, the above fact reduces to

$$R(e_1^1, \ldots, e_{m_1}^1, e_1^2, \ldots, e_{m_2}^2, \ldots, e_1^n, \ldots, e_{m_n}^n)$$

or, according to the representation introduced above, we get

$$\langle\langle R : e_1^1, \ldots, e_{m_1}^1, e_1^2, \ldots, e_{m_2}^2, \ldots, e_1^n, \ldots, e_{m_n}^n\rangle\rangle$$

In which way are these syntactic constructs to be interpreted? By denoting the relation R, the fact refers to some relator r which instantiates R and exhibits roles according to the role universals $Q_i$. Accordingly, a detailed version describes the following assumptions (cf. [Loebe, 2003], sections 5.1 and 3.3.3 for an extended characterisation):

(a) $\exists r\ (r :: R)$

(b) Let $1 \leq i \leq n$ and for each i $1 \leq k_i \leq m_i$. Each e = $e_{k_i}^i$ satisfies the condition
$\exists q\ (q :: Q_i \wedge \text{role-of}(q, r) \wedge \text{fills-role}(e, q))$

(c) all $Q_i$ are pairwise disjoint

This decomposition of *every* fact into its relata and a relator which relates these relata is problematic, because it requires new facts, for instance describing the decomposition of the relator into roles. According to the second condition above further formal facts are introduced explaining this decomposition, which leads to an infinite regress. This is a well-known issue in philosophy, where Bradley's regress of instantiation is very similar (cf. [Swoyer, 2000], sect. 7.8). A possible loophole which is often described is to reject considering the relation of instantiation (or in our case, role-of and fills-role) as a relation, or at least as a relation of a "different kind". However, the problem still arises if one tries to accommodate this different kind of relations in the same ontology, because there must then be entities which connect entities of that category with those of other categories. Therefore we tentatively accept the infinite regress, and we expect that it is no more problematic than the assumption of an infinity of spatial parts of an entity or the existence of an infinity of classes based on some finite set of entities (cf. the notion of the support of classes below). The regress is slightly more complicated in our case since it involves three formal relationships: instantiation, role-of, and fills-role. This is due to the decomposition of instantiation itself into formal roles *instance* and *universal*.

Regarding the standard representation of facts, note that the interpretation of the detailed notation does not pay attention to the order of the relata, because their role universals are explicitly expressed. In the simplified version, there is a lack of precision with regard to this, because the role universals are left implicit. This is not problematic in the case of distinct role universals with only one instance per relator (e.g., for many binary relations), where one has to assume a correspondence between the position of a relatum and the type of the role it fills. However, if several entities fill roles of the same type, this becomes problematic (cf. [Loebe, 2003], especially sect. 3.4 – 3.6 therein). Therefore, the role universal which corresponds to each place in a relation should be declared explicitly when a relation is introduced.

### 6.2.3 Classifications of Facts

With respect to the kinds of entities facts are about, it should again be stressed that these are not necessarily individuals. For example, the fact "Mary is speaking about humanity" can be represented as speaking(Mary, humanity), referring to a relator of type "speaking" which connects Mary with the universal humanity. On the basis of the relator and the types of the arguments, several kinds of facts can be distinguished.

Firstly, facts may be classified into *concrete* and *abstract*. A fact is said to be concrete if at least one of the relata is a concrete entity, it is said to be abstract if none of the relata is concrete. Another distinction is between *formal* and *material*, which is derived from the relator of a fact. A fact is said to be formal if the connecting relator is formal, it is called material if the connecting relator is material. We assume that every material fact is concrete, i.e., it has at least one concrete relatum. Hence, material facts cannot be abstract, whereas this is possible for formal facts. On the other hand, there are formal facts which are concrete.

Concrete and abstract facts may be further classified. We outline a refined classification which pertains to concrete facts which is important for the category of situations and situoids (treated in section 7). We restrict to the case that one of the relata of the fact is an individual; such a fact is called a *presential fact* if every of its individual relata are presentials which exist at the same time-boundary. Facts which are not presential facts can be classified in many different sub-types. A *generalized presential fact* satisfies the condition that every individual is a presential, but it is not assumed that all these relata exist at the same time-boundary. Moreover, the relata may be processes only, or may be of mixed type, e.g. presentials and processes. The development of a practically relevant classification remains a future task.

### 6.2.4 Factual Universals

Besides concrete facts, universals of facts need to be grasped. For instance, sentences of the form "A man's kissing of a woman" or "John's kissing of Mary" can be interpreted in a universal sense. For each relation R there is the set of its facts, denoted by *facts*(*R*), which is defined by the instances of R (being relators) and their corresponding arguments. Further, we assume the axiom that for each relation R there exists a *factual universal F*(*R*) whose extension equals the set *facts*(*R*). Take, for example, the relation K whose instances are individual kiss-relators. Then we may form a factual universal F(K) having the meaning "A person x's kissing of a person y", whose instances are all facts of the form ⟨⟨K: Kisser(x); Kissee(y)⟩⟩, where the instances of K relate individual persons x, y (x and y are variable terms). There are sub-universals F(K, J, M) of F(K), say, with the meaning "John's kissing of Mary", whose instances are all facts of the form ⟨⟨K: KisserJohn(x); KisseeMary(y)⟩⟩ where KisserJohn constrains x to those entities which fill a Kisser role as above and which are themselves an instance of the persistant John (analogously for KisserMary). Thus, natural-language sentences of the form "A man kisses a woman" can be interpreted in terms of (sub-)universals of factual universals.

## 6.3 Formal Relations of the GFO

Sections 5 to 7 present several categories of entities, reticently accompanied by formal relations which glue entities of these categories together. Some of these formal relations are basic relations which cannot be defined explicitly, but which are characterized axiomatically in section 10 (to some extent). For a relation-centered access to the GFO, we briefly summarize important representatives of formal relations in the GFO in the following subsections.

| **Relation** | **Prefix Reading with Roles** | **Section** |
|---|---|---|
| Membership | ∈(Element, Class) | 6.3.1 |
| Instantiation | ::(Instance, Universal) | 6.3.2 |
| Has-Quality | hqual(Bearer, Quality) | 6.3.3 |
| Inherence | inh(Quality, Bearer) | 6.3.3 |
| Value-Of | value(Value, Quality) | 6.3.3 |
| Parthood | part(Part, Whole) | 6.3.4 |
| Participation | partic(Participant, Participatum) | 6.3.4 |
| Projection | prt(Projector, Projectee) | 6.3.5 |
| Occupation | occ(Occupator, Occupant) | 6.3.5 |
| Coincidence | coinc(Coincidant, Coincidant) | 6.3.5 |
| Association | assoc(Associative, Associant) | 6.3.6 |
| Ontical Connectedness | ontic(Connectee, Connectee) | 6.3.7 |
| Existential Dependence | depend(Dependent,Depender) | 6.3.8 |

**Table 2 : Overview of Selected Formal Relations in GFO**

### 6.3.1 Class and Set-theoretical Relations

The *membership* relation is the basic relation of set theory and (mathematical) class theory. Usually, the notation $\in$ is used for type-free systems (ZF, for example), but it may be adapted for typed languages. $x \in y$ implies that either x and y are both classes, or x is a so-called *class-urelement* and y is a class. The *subclass* relationship $\subseteq$ is defined in terms of membership: $x \subseteq y =_{df} \forall z\, (z \in x \rightarrow z \in y)$.

As classes can be nested, it is interesting to consider all class-urelements which occur in a class. First, there is the least flattened class y = trans(x), which extends the nested class on the first level of nesting with all class-urelements contained in any depth of nesting. That means, y satisfies the conditions $x \subseteq y$, and for every $z \in y$, it holds $z \subseteq y$. Then the class supp(x) = {a | a is a class-urelement and $a \in$ trans(y)}, called the *support* of x, contains all class-urelements of x and only them. A class x is said to be pure if supp(x) = ∅.

For typed systems, note that the elements of a class respect the type of the class, and more precisely, also the membership-symbol $\in$ should be indexed by the associated types. Assume X is a class of type $[\tau_1, \ldots, \tau_n]$, and $(Y_1, \ldots, Y_n) \in X$. This implies that the member components $Y_1, \ldots, Y_n$ are of types $\tau_1, \ldots, \tau_n$, respectively.

### 6.3.2 Instantiation

In a sense, *instantiation* is the intensional counterpart of the membership relation, as it does not satisfy the *principle of extensionality*. The symbol :: denotes instantiation. In the full type system of RGOL the second argument is always a category, the first argument can be (almost) any entity. If the second argument is a primitive category then the first has to be an individual. Concrete entities – in general – can be understood as urelements with respect to instantiation. Since we assume categories of arbitrary (finite) type, there can be arbitrary long (finite) chains of iterations of the instantiation relation. Since classes have no instances (they have elements) they can be understood as another kind of urlements w.r.t. instantiation. On the other hand, categories do not have elements, but instances, hence categories are urlements with repect to the membership relation. If x :: u, and u is a primitive category then u expresses a certain time- and space-independent pattern of features and x is an individual in which this pattern of features is realized.

Similar as for classes it might be interesting to consider all concrete entities which are related to a category (of arbitrary type). To make this precise we introduce the *concrete support* of a category a, denoted by *concsupport*(*a*). The transitive closure of *a*, denoted by trans(a), is the smallest class x containing a as element and being closed with respect to the following condition: if $z \in x$ then $\{b \mid b :: z\} \subseteq x$. The concrete support of the category a is defined by concsupp(a) $=_{df}$ trans(a) $\cap$ {e : CEnt(e)}. Since our notion of category is very general, there are different cases of categories to be distinguished. A category which is based on classes only has always an empty concrete support, even if the classes being instances of the category have a non-empty support. The concrete support of a primitive category is always a subclass of the class of concrete entities. Of course, the concrete support of a primitive category may be empty in case this category is contradictory, for example.

### 6.3.3 Property Relations

Further, several relations connect properties (or qualities, which are their instances), their values and their bearers as introduced in section 5.3. First, there are the general relations has-property, *hprop*(*x*, *y*), and has-quality, *hqual*(*x*, *y*), which relate a property bearer x and one of its properties/qualities y. However, there are specializations for certain types of arguments. The best known of such specializations is the relation of *inherence*, *inh*(*x*, *y*), as a sub-relation of has-quality. The phrase “inherence in a subject” can be understood as the translation of the Latin expression “in subjecto esse”, as opposed to “de subjecto dici”, which may be translated as “predicated of a subject”. Sometimes inherence is called ontic predication.

The extension space of a physical structure is a special kind of quality with respect to space. It reflects the capability to occupy space. *extsp*(*x*, *y*) has the meaning: y is the extension space of the physical structure x. The relation extsp is subsumed by inherence.

The second kind of relations connects a property/quality with some value of a measurement system. In the denotation *value*(*x*, *y*), x refers to the property/quality and y to the value.

### 6.3.4 Parthood and Its Neighbors

Part-of is a basic relation between certain kinds of entities. We assume that only concrete entities (i.e., entities of space and time or individuals) can have parts, which excludes classes and categories.

### 6.3.4.1 Abstract and Specialized Part-Of

One can consider a very abstract notion of *part-of*, *p*(*x*, *y*), which is axiomatized in section 10.1. However, this theory has to be specialized, modified, and extended correspondingly. Thus far, we distinguish mainly following types: *spart*(*x*, *y*)$=_{df}$ “x is a proper spatial part of y”, where x and y are space entites; *tpart*(*x*, *y*) $=_{df}$ “x is a proper temporal part of y”, where x and y are time entities; *phpart*(*x*, *y*) $=_{df}$ “x is a physical part of y”, where x and y are physical structures; *procpart*(*x*, *y*) $=_{df}$ “x is a processual part of y”, where x and y are processes, and, finally *cpart*(*x*, *y*) $=_{df}$ “x is a proper constituent part of y”. spart applies to spatial regions, tpart refers to time regions and chronoids, whereas cpart represents a relationship between situoids (or situations) and their constituents. The constituents of a situoid s include, among other entities, the pertinent physical structures (which participate in s) and the qualities which inhere in them. Further, facts and configurations are constituents of situoids. Note, that not every part of a constituent of a situoid is contained in it. Every notion of part-of allows for a non-reflexive version of the relationship. These are denoted by adding a “p” predicate notation, e.g. ppart(x, y) or tppart(x, y) (expressing “proper part”).

### 6.3.4.2 Relativized Part-of

Particularly one axiom of the part-of relation has been the matter of many debates, the axiom of transitivity. For instance, this faces a problem if we consider the facts that a hand is a part of a human and a human is part of an orchestra. Transitivity now allows to deduce that the hand is part of the orchestra – which is rather counter-intuitive. Remembering the level theory as introduced in section 3.3, we expect that an elaborated version of it will provide a means to deal with this problem. Our interim solution is a *relativized part-of* relationship. The ternary part-of relation *part*(*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 the sense of part(x, y, u), then x and y are instances of universals associated with the domain u and p(x, y). But more is involved, since the notions of granularity and point of view are at issue. We propose the following axiom: for every domain u there are universals $u_1$, ..., $u_n$ such that part(x, y, u) implies that x, y are instances of one of the $u_i$’s and every instance of each of the $u_i$’s is part of an instance of some other $u_k$.

Consider the following example, taken from the domain of biology. Let $u_T$ be the biological subdomain of trees, i.e., the central organisms are trees. Then: part(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 set of universals $\{u_1, ..., u_n\}$ by which the biologically relevant parts of trees are demarcated. All such parts of trees are either instances of some $u_i$, $1 \leq i \leq n$, or they can be decomposed into a finite number of parts, each of which satisfies this condition. Examples of relevant $u_i$ would be branch of a tree, leaf of a tree, trunk of a tree, root of a tree, and so on.

### 6.3.4.3 Participation

*Participation*, denoted by *partic*(*x*, *y*), relates presentials and persistants to processes. Participants of a process form an orthogonal axis of division for processes than temporal parts. The relationship is introduced in section 5.4.1. It can be defined in terms of the projection relation prb.

#### 6.3.4.4 Boundary-of

Boundaries are not parts, but they are a similar category. The *boundary-of* relationship connects entities of various categories, namely (a) time-boundaries and chronoids, (b) spatial boundaries and space regions, (c) presentials and processes, and (d) physical boundaries and physical structures. We have not introduced a general relationship, but particular boundary-relations for each of these cases. Case (a) relies on the notions of left and right boundary-of, *lb*(*x*, *y*) and *rb*(*x*, *y*) respectively. In case (b), *bd*(*x*, *y*) denotes the fact that x is a spatial boundary of y. Case (c) is discussed in the next section, whereas the fourth case is not formalized thus far.

#### 6.3.4.5 Role-of

The *role-of* relationship was introduced above as a close relative of part-of (at least). It relates roles x and relators y, denoted by *role-of*(*x*, *y*).

### 6.3.5 Relating to Time and Space

In accordance with section 5, all individuals are related to time and space. We do not introduce an abstract relation between individuals and time or space, respectively, as time and space are clearly separated categories. In this case we directly refer to more specialized relations.

#### 6.3.5.1 Projection

*Projection* embeds individuals to time. We distinguish several cases, denoted by *prt*(*x*, *c*), *at*(*y*, *t*), *prb*(*x*, *t*, *y)*. In each of these, x is a process, y is a presential, c is a chronoid, and t is a time-boundary. The binary relations assign to presentials and processes a temporal entity. prb(x,t,y) is the projection of a process x to its boundary u, which is determined by the time-boundary t. Note that prb can be used to define the relations at and partic, cf. the definitions in section 10.6.

#### 6.3.5.2 Occupation and Location

The binary relation of *occupation*, *occ*(*x*, *y*), describes a fundamental relation between physical structures and topoids. Occupation is a functional relation because it relates an individual to the minimal topoid in which a physical structure is located. *Location* is a less detailed notion, which can be derived in terms of occupation and spatial part-of. An x is located in a region y, *loc*(*x*, *y*), iff the topoid z occupied by x is a spatial part of y.

#### 6.3.5.3 Framing

Every situoid, for example the fall of a book from a desk, consumes an amount of time and occupies a certain space. The binary relations of *framing*, *tframe*(*s*, *c*), *sframe(s*, *x*) glues chronoids c or topoids x to situoids s. We presume that every situoid is framed by exactly one chronoid and one topoid. The relation tframe(s, z)/sframe(s, z) is to be read: “the chronoid/topoid z frames the situoid s”.

#### 6.3.5.4 Congruence, Coincidence and Adjacency

Space and time entities with an extension allow for the notion of *congruence*, e.g., two topoids are congruent if they share exactly the same size and shape. The relation of congruence is mentioned in section 4.2.

*Coincidence* is a relationship between space and time-boundaries. Intuitively, two such boundaries are coincident if and only if they occupy “the same” space (or time-boundary), but they are still different entities (cf. sect. 4). Obviously, congruence of extended boundaries like surfaces is entailed by their coincidence.

Further, the notion of coincidence allows for the definition of *adjacency*. In the case of space-time-entities, these are adjacent as soon as there are coincident parts of their boundaries. In contrast, physical structures and processes cannot have coincident boundaries. Nevertheless, they are adjacent if the projections of their boundaries are adjacent.

### 6.3.6 Association

The relation *assoc*(*s*, *u*) has the meaning “The universal u is associated with the situoid s”. These universals determine which material relations and individuals occur as constituents within a given situoid. Thus association informs about the granularities and viewpoints a situoid 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 types of individuals (branches are included, electrons are not). The association relation is related to a cognitive procedure which transforms merely physical structures into situations. Situations/situoids are parts of the world which can be “comprehended as a whole”. On the purely physical level these parts can be understood – we believe – as superimposing fields (gravitational, electromagnetic, ect.) which constitute a certain distribution of energy and matter. On the mental/psychological level this distribution is percepted as a physical structure. A physical structure – as we have introduced it – is a pre-version of a situation. On this level of perception already certain structures may be percepted: physical boundaries, colors, and the like. The level of comprehension, of understanding this part of the world as a situation needs more than only the elementary perceptual structures. Comprehension presupposes the availability of concepts, and the formation and the use of concepts seems to be a component of the mind’s cognitive process. The association relation is related to this ability of the mind to grasp physical structures of the world as situations.

### 6.3.7 Ontical Connectedness

Presentials are connected by spatio-temporal and causal relationhips which give rise to persistants. The relation *ontic*(*x*, *y*) connects presentials x and y by an integrated system of such relationships. It is assumed that x, y are processes or presentials. We believe that there are different relations of this kind. One interesting case of ontological connectedness is *substrate-connectedness*, two physical structures x and y are substrate-connected if they consist of the same amount of substrate. For example, the statue st made of clay considered at a certain time-boundary is substrate-connected to the physical structure which results from a crash which destroys st.

### 6.3.8 Existential Dependence

For many types of entities, their instances *existentially depend* on other entities. For instance, a time-boundary depends on the chronoid it is a boundary of, or the quality which inheres in a physical structure depends on that structure. Various types of dependency relations are discussed in the philosophical literature, e.g., chapter 9 in [Johansson, 1989].

Herein, we assume the following relations to be subsumed by the notion of existential dependency (subroles of the role "dependent" are given in parentheses): has-quality (quality), partic (participant), bd (boundary), fills-role (role).

### 6.3.9 Future Extensions: Causality and Denotation

Note that further relations are to be introduced in the future. Among those of the next version, there are causality and denotation for which there is an urgent need.

*Causality* may help to ex-plain the connection between presentials, persistants and the relation of ontical connectedness. Our aim is to account at least for a binary causation relation with processes as relata. The notion of coincident boundaries might be useful for the temporal connection of these processes. Apart from (concrete) "causation", a second relation of "causality" (dealing with abstracta) might be required to model law-like expressions of higher generality.

*Denotation* will be necessary to account for many entities in the domain of clinical trials because it heavily relies on documents and documentational aspects[13].

[13] Remember that the domain of clinical trials is one of the primary application domains of the Onto-Med.

# 7 Situoids, Situations, and Configurations

In this section we survey some basic notions about the most complex entities of the world, about situations and situoids.

## 7.1 Situations and Configurations

Physical structures, qualities, and (formal or material) relators (see sect. 6.1.2) presuppose one another, and constitute complex units or wholes. The simplest units of this kind are, obviously, facts. A general configuration is an aggregate of facts. We restrict in this section to a special class of facts and ask whether an aggregate of facts can be integrated into a whole, or, put differently, whether a collection of facts counts as a whole. We consider a collection of presential (concrete) facts which exist at the same time-boundary. Such collections may be considered themselves as presentials, and we call them *configurations*.

As a restriction, we impose the condition on configurations that at least one physical object should be contained in it. Physical objects are entities having a natural boundary, and on this basis configurations may be classified into *simple* and *non-simple*. A simple configuration is a unit which is composed of one physical object and only qualities inhering in that physical object. A configuration is said to be non-simple if it is made up of more than one physical object and (formal or material) relators 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, relations and categories associated with the situation. Hence, situations satisfy a condition of unity and comprehensibility. This implies that situations are related to minds and that the psychological stratum is involved in them. Situations present the most complex presentials of the world. In the realm of presentials they have the highest degree of independence.

It seems to be impossible to get a complete representation of a situation S, but we could extract information about S by describing which kind of facts are constituent parts of S. An infon $I = \langle R: a_1, \dots, a_n \rangle$ is supported by S, denoted by $S \vDash I$, if the factual picture pict(I) = $\langle\langle R: a_1, \dots, a_n \rangle\rangle$ corresponds to some fact of S, i.e., if there is a fact f being a part of S, such that corresp(f, pict(I)). The infon $I = \langle R: a_1, \dots, a_n \rangle$ is not supported by S if the factual picture pict(I) does not correspond to any fact being a part of S. Let be Facts(S) the set of facts being parts of the situation S. Let S and T be situations at the same time-point. Then, the relation $S \subseteq T$ ist defined by the condition $\text{Facts}(S) \subseteq \text{Facts}(T)$. To every situation S a number of primitive universals $U_1, \dots, U_m$, and relational universals $R_1, \dots, R_n$ is associated . The individuals Ind(S) which are contained in S form a subclass of the class $\text{Ext}(U_1) \cup \dots \cup \text{Ext}(U_m)$ and the facts Facts(S) contained in S form a subclass of $\text{WorldFacts}(U_1, \dots, U_m, R_1, \dots, R_n)$ which denotes the class of all facts which exist in the world at the same time-point and which pertain to the universals $U_1, \dots, U_m, R_1, \dots, R_n$. Let $\text{assoc}(S) = \{U_1, \dots, U_m, R_1, \dots, R_n\}$. If $S \subseteq T$ then $\text{assoc}(S) \subseteq \text{assoc}(T)$ and $\text{Ind}(S) \subseteq \text{Ind}(T)$. We may ask whether there is a largest situation (w.r.t. $\subseteq$ ) at a certain time-point. We assume as a basic axiom that largest situations (at a time-point) do not exist. i.e., the whole world at a time-point is not considered as a situation. This conforms with our intuition that the whole world cannot be comprehended as a whole.

We considered the simplest type of situations, the complexity increases if we assume that the situation participates in different strata (which is usually the case).

## 7.2 Situoids and Configuroids

According to the basic assumptions of GFO, presentials have no independent existence, they depend on processes. Since configurations are presentials, too, they depend on processes. We call such processes *configuroids*. They are in the simplest case – in a sense – integrated wholes made up of physical-structure-processes and quality-processes. We claim that physical-structure-processes and quality-processes presuppose each other. Surely, a quality-process depends on a physical-structure-process, on the other hand, we may assume that a physical-structure-process needs an extension which includes a quality-process.

Finally, there is a category of processes whose boundaries are situations and which satisfy certain principles of coherence, comprehensibility, 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 individuals John and Mary and a relator "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 *assoc*(*s*, *u*) expresses that the universal u is associated to the situoid s.

How are situoids related to time and space? Every situoid is framed by a chronoid and a topoid. We use here two relations *tframe*(*s*, *x*), and *sframe(s*, *z*), where x is the chronoid framing the situation s and z is the topoid framing s. Note, that the relation tframe(s, x) is equivalent with prt(s, x) since a situoid is a process; the relations prs(s, x) and sframe(s, x) are different, though, but as such that the following relation is satisfied: prs(s, x) $\wedge$ sframe(s, y) $\rightarrow$ spart(x, y).

Every temporal part of a situoid is a process. The temporal parts of a situoid s are determined by the full projection of s onto a part of the framing chronoid c of s. This full projection relation is denoted by prt(a, c, b), where a is a situoid, c is a part of the framing chronoid of a and b is the situoid which results from this projection. Boundaries (including inner boundaries) of situoids are projections to time-boundaries. We assume that projections of situoids to time-boundaries, which are denoted by prb(a, t, b), are presentials which are called situations. In every situation a physical structure is contained, and we say that a presential e is a constituent of a situation S iff there is a time-boundary t of S such that the projection of S onto t is a situation containing e. A presential e is a constituent of a situoid S if there is a time-boundary t such that e occurs in the situation determined by prb(S, t, b).

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

(a) P is a process,

(b) P and S are framed by the same chronoid,

(c) every boundary of P contains a physical structure,

(d) Let p, q be arbitrary time-boundaries of the framing chronoid of S, such that p is before q, and let prb(P, p, e) and prb(S, q, f). Then: if m is a physical structure which is contained in the P-boundary e and n is a physical structure which is contained in the S-boundary f, and m, n are ontically connected, ontic(m, n), then n is contained in the corresponding P-boundary g, where prb(P, q, g).

The notion of a *quality-layer* of a situoid could be introduced in a 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 *structural extension* of S if S is a structural layer of T. Both kinds of extensions can be combined to the more general notion of a *structural-temporal extension.* The whole reality can – in a sense – be understood as a web of situoids which are connected by structural-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 structural extension. As an example consider a fixed single physical structure P which occurs in situation S. Every extension of S is determined by adding further qualities or relators to S to the intrinsic properties of P. A quality-bundle which is unified by the physical structure P is called saturated if no extension of S adds new qualities. It is an open question whether there is an extension T of S such that every physical structure P in T unifies with a saturated bundle of qualities?

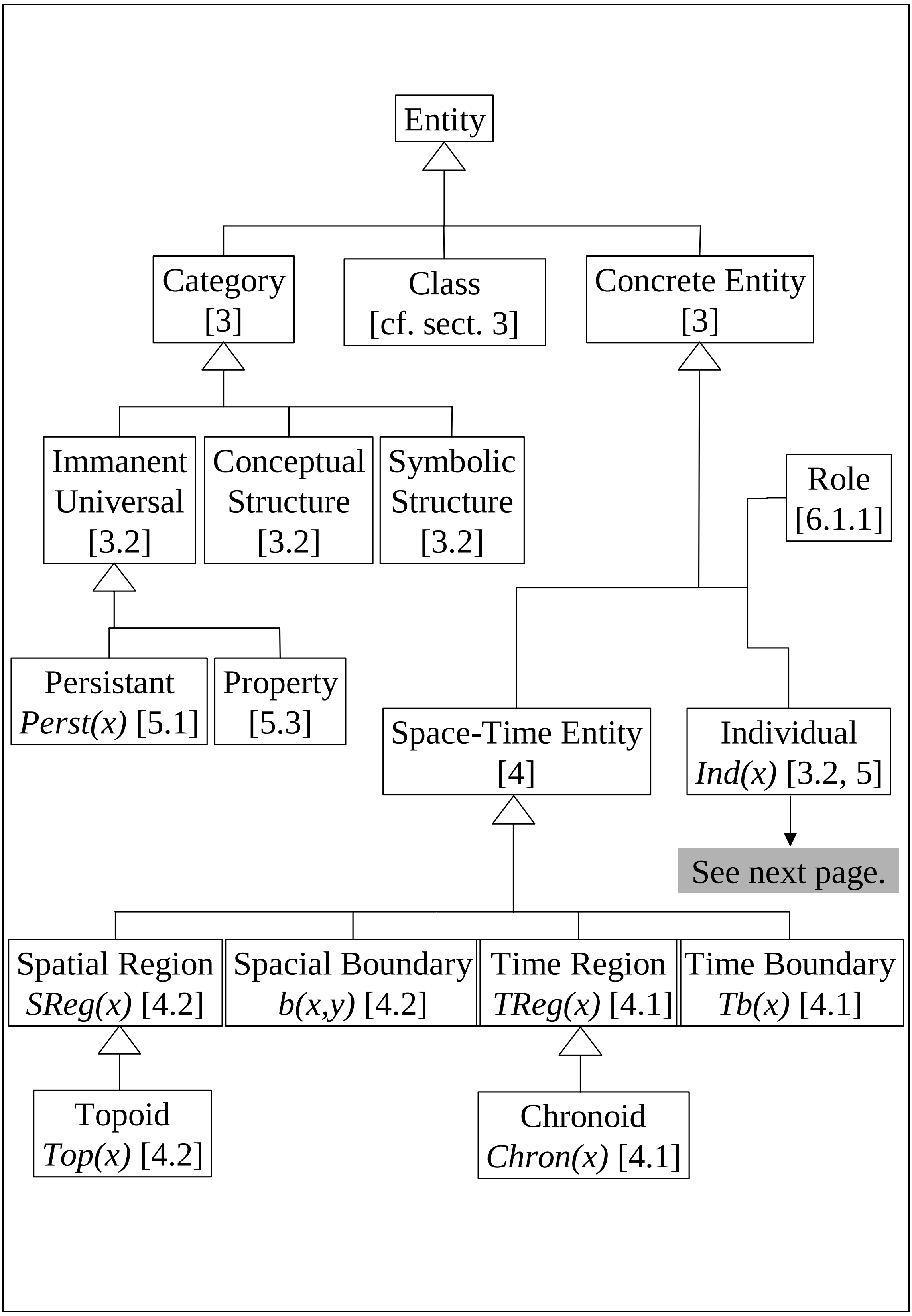
A *configuroid* c in the situoid S is defined as the projection of a structural layer of S onto a chronoid which is a part of the time-frame of S. In particular, every structural layer of S is itself a configuroid of S. Obviously every configuroid is a process. But not every process is a configuroid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

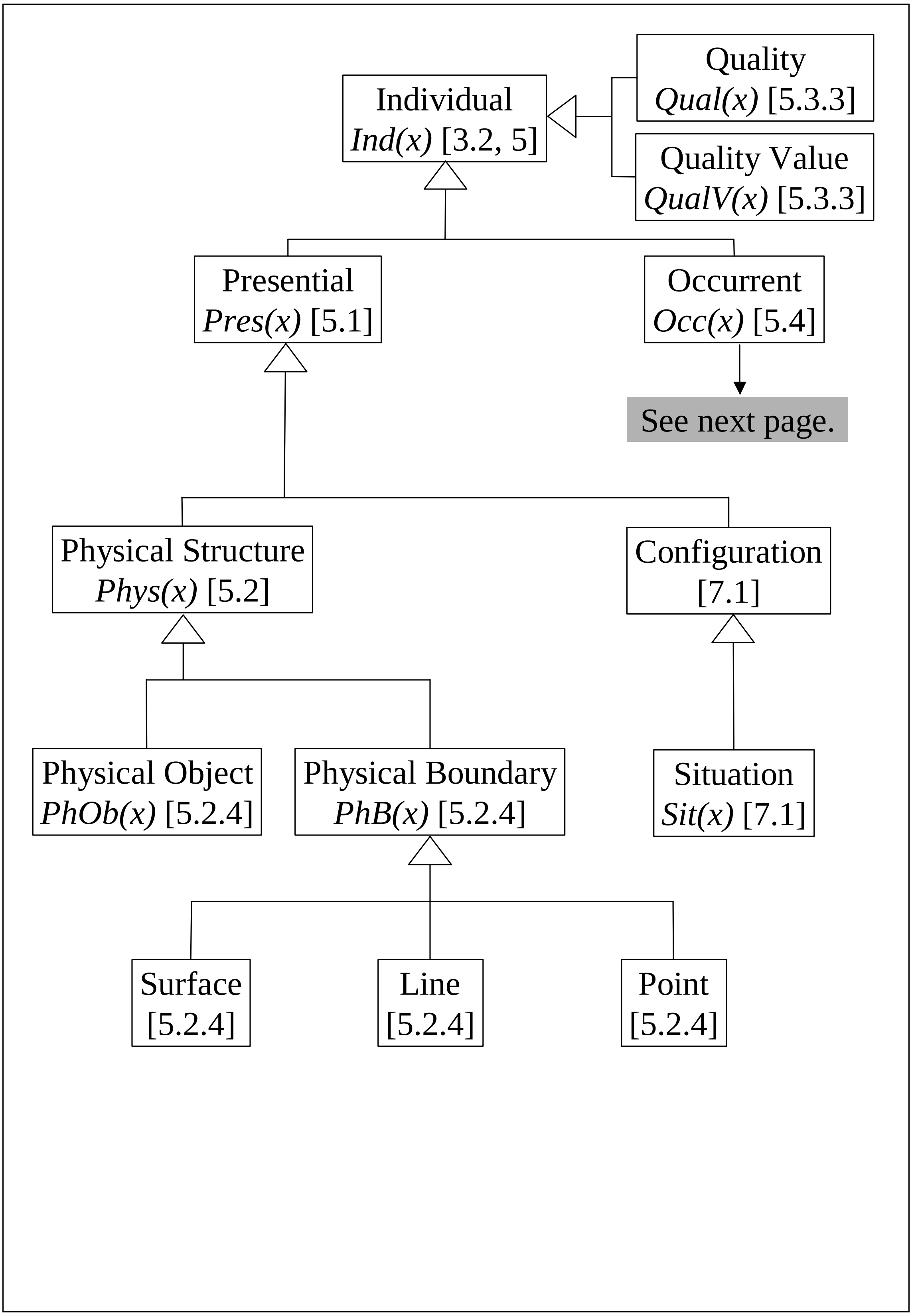
We postulate as a basic axiom that every occurrent is – roughly speaking – a "portion" of a situoid, and we say that every occurrent is embedded in a situoid. Furthermore, we defend the position that processes should be analysed and classified in the framework of situoids. Also, situoids may be used 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 an occurrent.

Similar as for situations we may consider the question of which kinds of facts (or infons) are supported by a situoid. The setting here is much more complicated than for situations. Which kinds of facts $\langle\langle R: a_1, \ldots, a_n\rangle\rangle$ may be parts of a situoid S? For every boundary B of S, being a situation, there are the (presential) facts supported by B. But then there may be facts in S which relate presentials at different time-points, and facts which relate processes to presentials, and processes to processes, etc. Which kind of entities are related to S? Again universals, individuals, relations, but also persistants, presentials. A presential p, for example, belongs to S, if p is a constituent part of a boundary B of S. But also layers (certain connected processes) belong to S, and also parts of the framing chronoids and the framing topoid, etc.

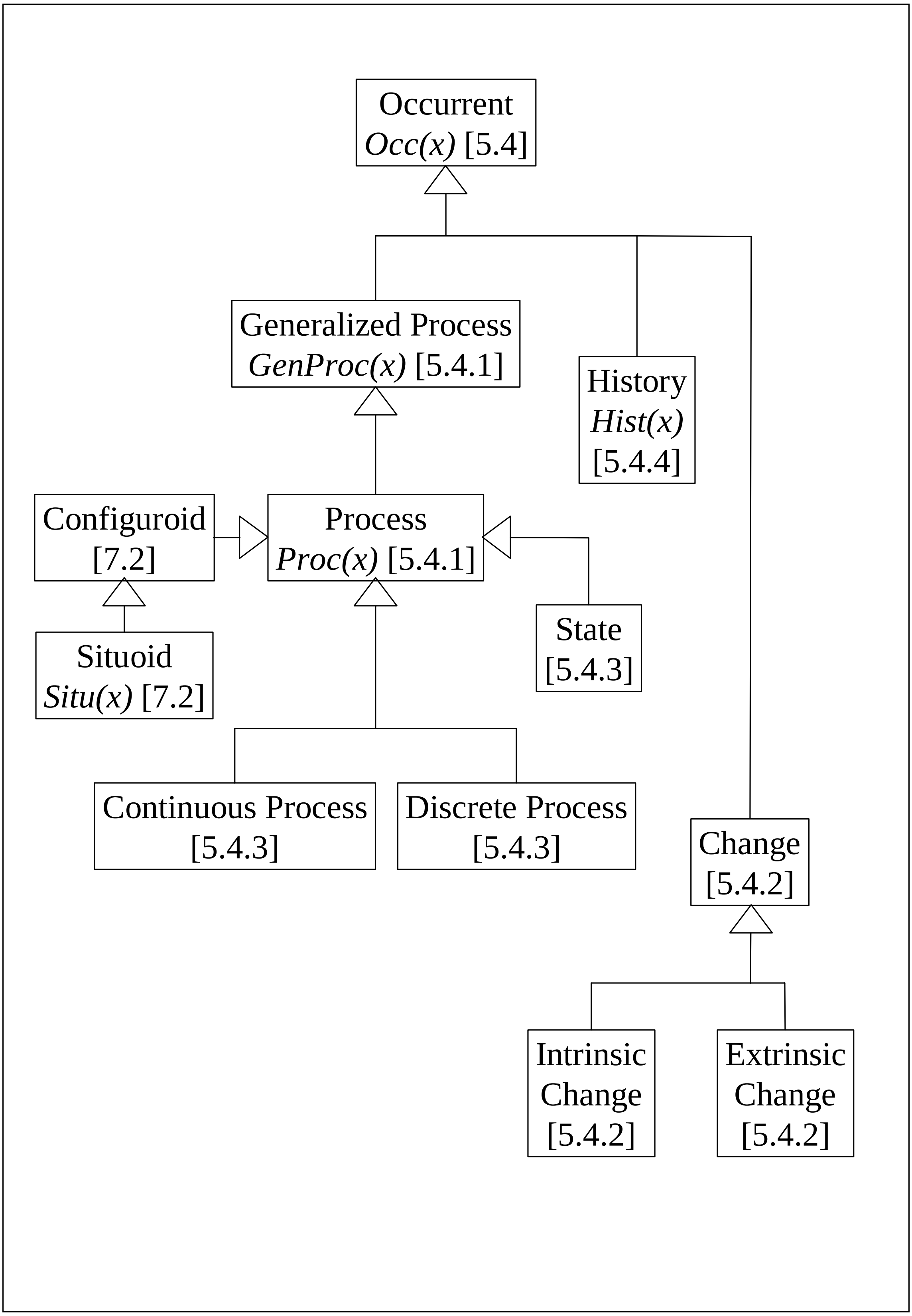
As a final note regarding situoids, configurations, and their relatives, there are a number of useful, derivable categories. For instance, one can now define situational histories as such histories all of whose boundaries are situations. In general, the theory of these entities is considered a promising field for future research.

## Appendix A: GFO Category and Relation Hierarchies

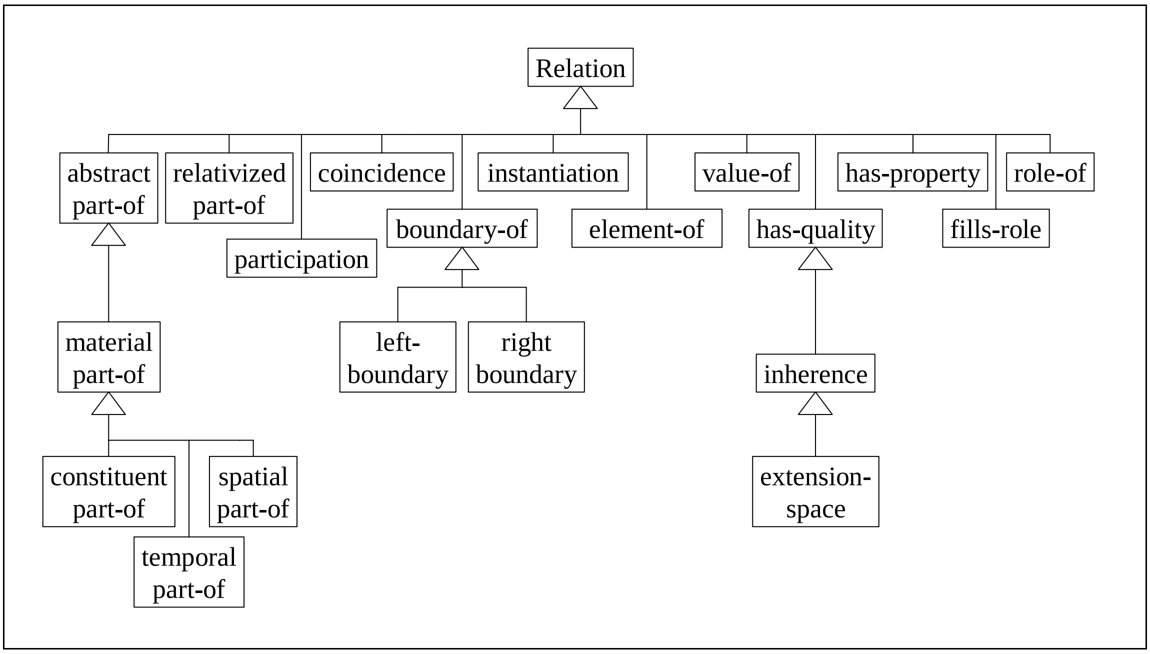




Individual
*Ind(x)* [3.2, 5]
Quality
*Qual(x)* [5.3.3]
Quality Value
*QualV(x)* [5.3.3]
Presential
*Pres(x)* [5.1]
Occurrent
*Occ(x)* [5.4]
See next page.
Physical Structure
*Phys(x)* [5.2]
Configuration
[7.1]
Physical Object
*PhOb(x)* [5.2.4]
Physical Boundary
*PhB(x)* [5.2.4]
Situation
*Sit(x)* [7.1]
Surface
[5.2.4]
Line
[5.2.4]
Point
[5.2.4]


Occurrent
*Occ(x)* [5.4]
Generalized Process
*GenProc(x)* [5.4.1]
History
*Hist(x)*
[5.4.4]
Configuroid
[7.2]
Process
*Proc(x)* [5.4.1]
Situoid
*Situ(x)* [7.2]
State
[5.4.3]
Continuous Process
[5.4.3]
Discrete Process
[5.4.3]
Change
[5.4.2]
Intrinsic
Change
[5.4.2]
Extrinsic
Change
[5.4.2]

## GFO Relation Hierarchy



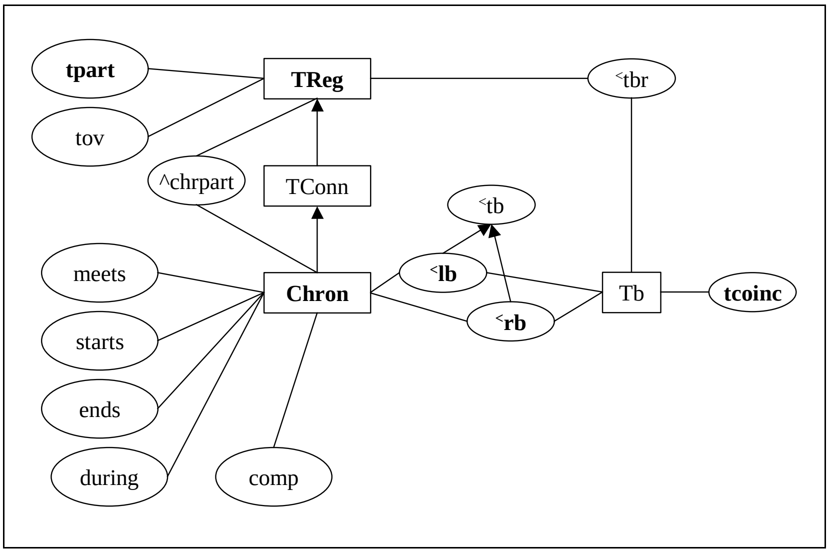
# Appendix B: Diagrammatic Schemes

This appendix contains a diagrammatic representation of the interrelationships of the main GFO notions. The diagrams are organized in rough correspondence with the structure of chapters 4 to 7. The following notation is employed:

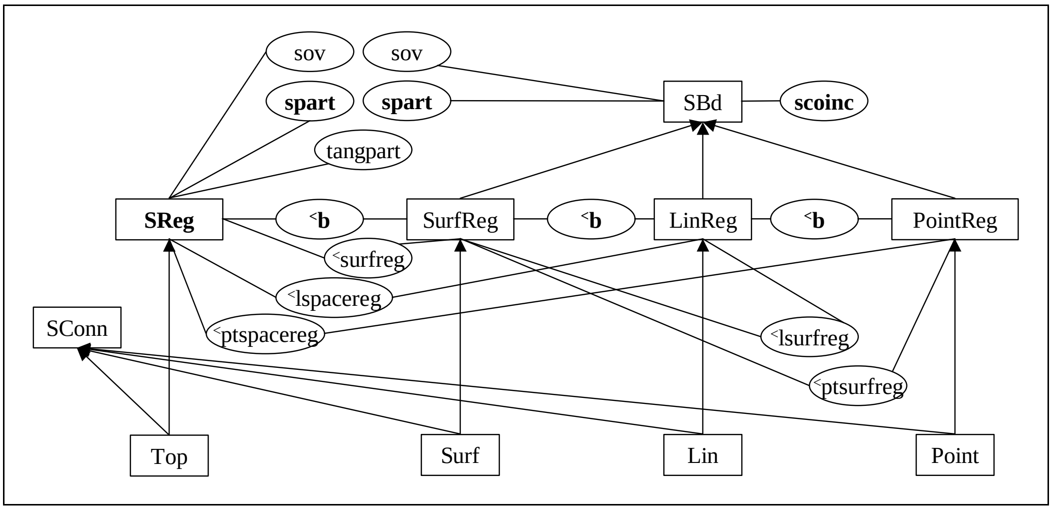
| Notation | Description |
|---|---|
| Chron | *Category*. Most of the categories are labeled with abbreviations as used in the axioms of chapter 10. Bold letters indicate primitive categories regarding that chapter. |
| Chron — <lb — Tb<br>meets — Chron<br>ContProc - - - - IntrCh | *Relation* between categories.<br>The arrows (^, <, >, v) indicate the direction of reading and thus the order of the arguments. The example on the left is to be read "Tb is a left boundary of Chron"<br>The number of arcs corresponds to the arity of the relation, exceptions are self-referring binary relations of a category. For simplicity only one arc is shown, e.g. "meet(Chron, Chron)"<br>Certain more complex, unnamed relationships are indicated by a dashed line. |
| TReg ← Chron<br><tb ← <lb | Specialization (i.e., subsumption defined by logical implication) of categories/relations. |

**Table 3 : Notation of the Diagrams.**

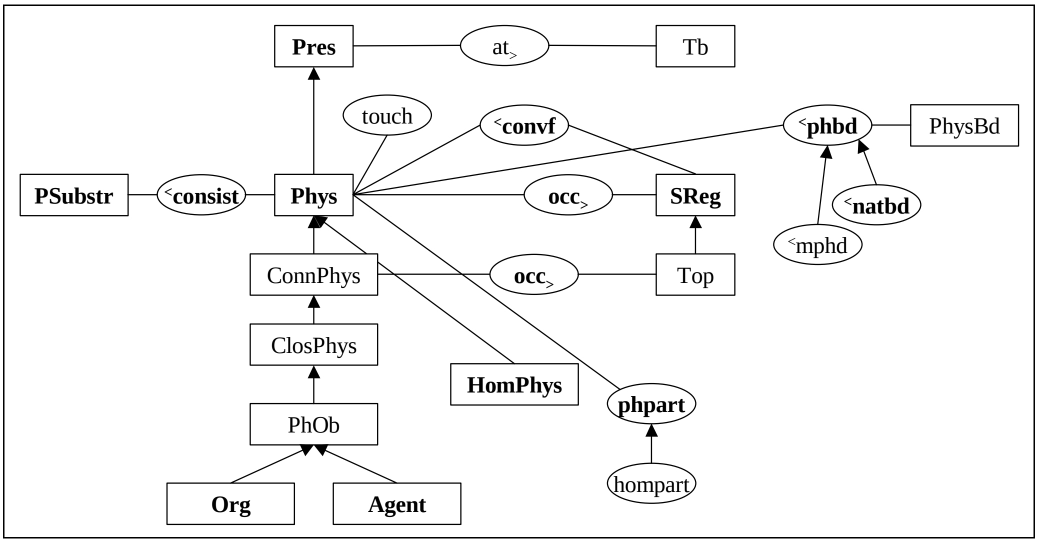
### Time (sect. 4.1 [...])



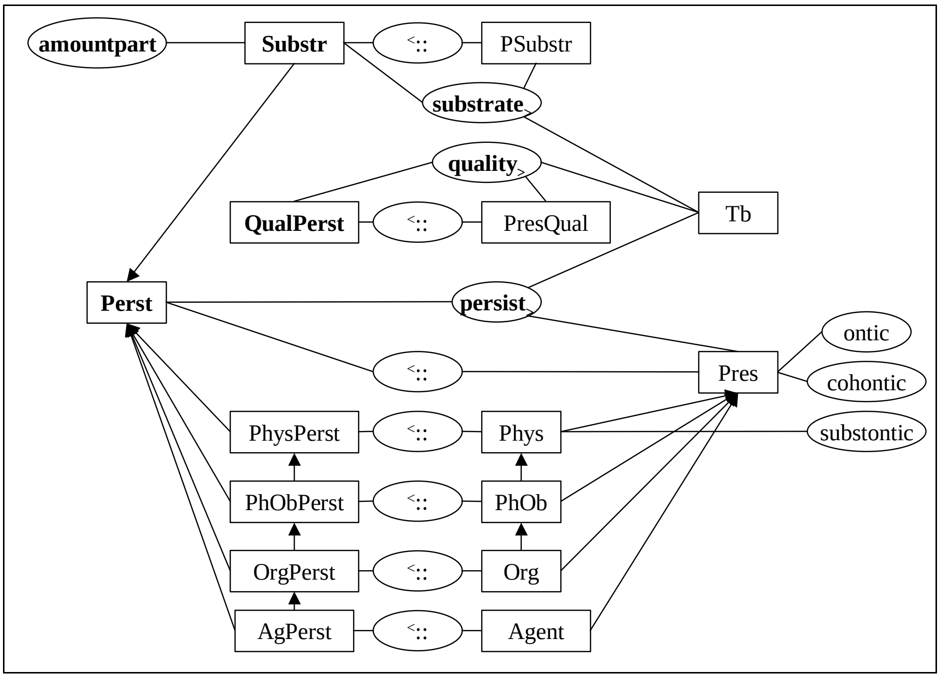
## Space (sect. 4.2 [...])



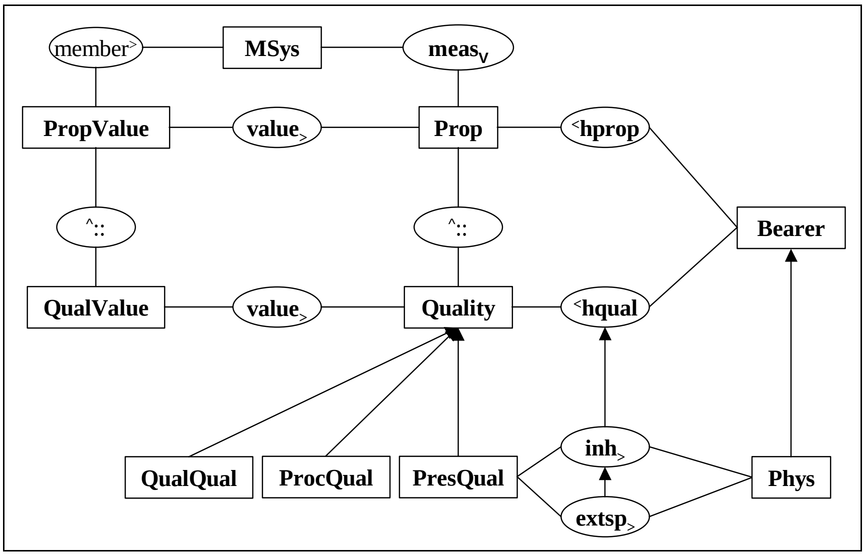

## Presentials and Physical Structures (sect. 5.1, 5.2 [...])



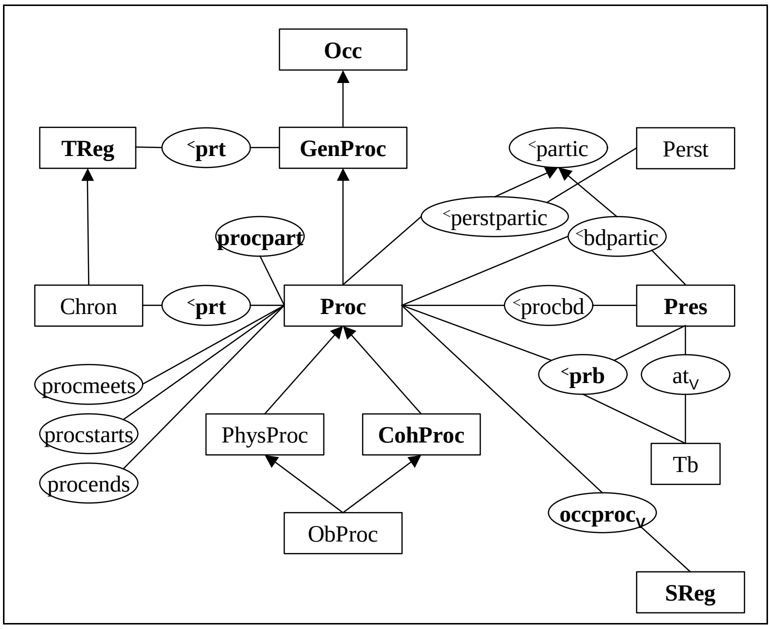
## Persistants (sect. 5.1 [...])



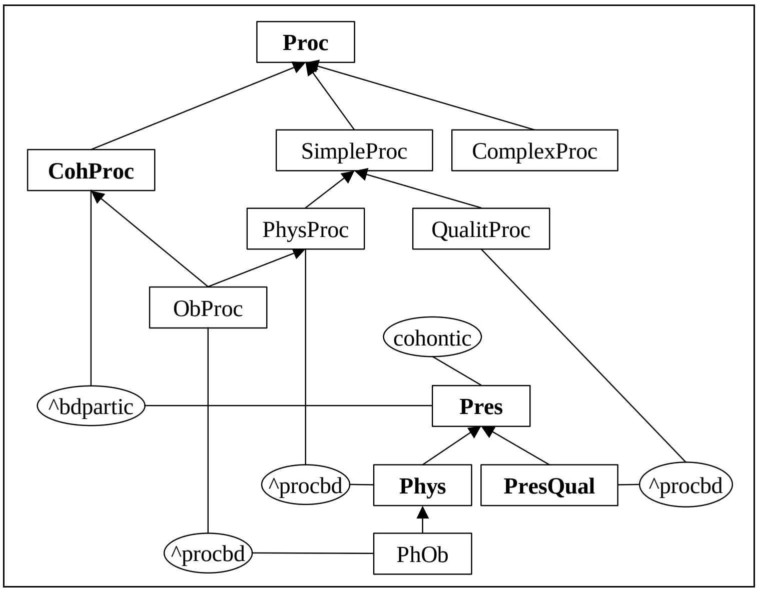

## Properties (sect. 5.3 [...])



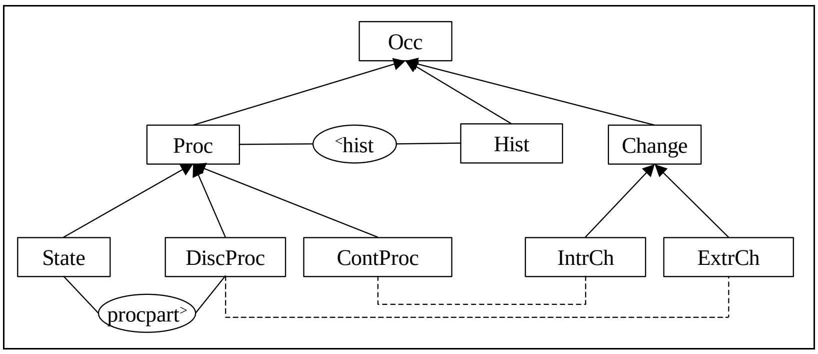
## Occurrents (sect. 5.4 [...])



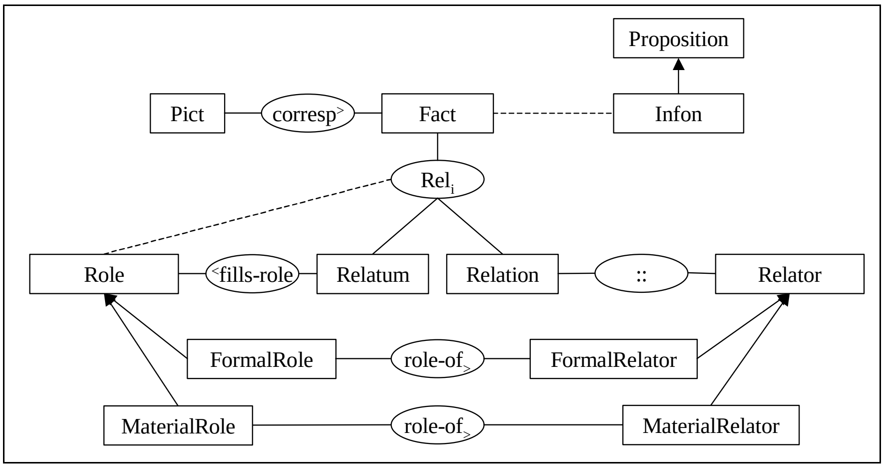

## Simple and Complex Processes (sect. 5.4 [...])



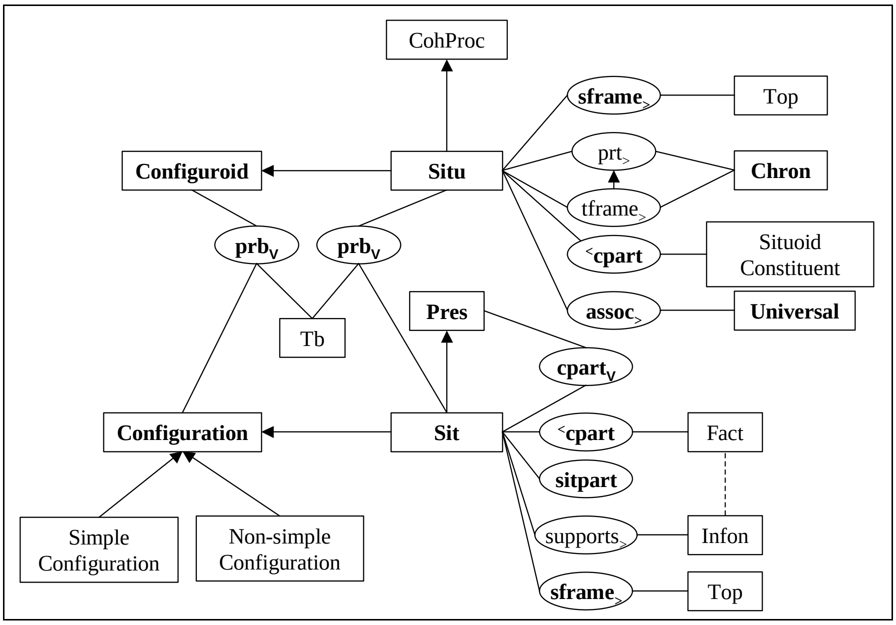

## Classification of Occurrents (sect. 5.4 [...])



## Relations and Facts (sect. 6, 7.1 [...])




## Situations and Situoids (sect. 7 [...])



## Bibliography


**Albertazzi, L. 2002.** *Unfolding Perceptual Continua*. Advances in Consciousness Research, Vol. 41. Amsterdam: John Benjamins.

**Alferes, J. J., Pereira, L. M. 1996.** *Reasoning with Logic Programming*. Lecture Notes in Artificial Intelligence, Vol. 1111. Berlin: Springer.

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

**Armstrong, D. M. 1999.** *A World of States of Affairs*. Cambridge Studies in Philosophy. Cambridge: University Press.

**Baader, F., Calvanese, D., McGuinness, D., Nardi, D., Patel-Schneider, P. (eds.) 2003.** *The Description Logic Handbook: Theory, Implementation and Applications*. Cambridge (UK): Cambridge University Press.

**Barwise, J. 1989.** *The Situation in Logic*. CSLI Lecture Notes, Vol. 17. Stanford (California): CSLI Publications.

**Barwise, J., Perry, J. 1983.** *Situations and Attitudes*. Bradford Books. Cambridge (Massachusetts): MIT Press.

**Bonitz, H., Rolfes, E., Seidl, H., Zekl, H. G. 1995.** *Aristoteles. Philosophische Schriften*. Hamburg: Felix-Meiner Verlag.

**Booch, G., Jacobson, I., Rumbaugh, J. 1999.** *The Unified Modeling Language User Guide*. The Addison-Wesley Object Technology Series. Reading (Massachusetts): Addison-Wesley.

**Brachman, R. J., Schmolze, J. G. 1985.** An Overview of the KL-ONE Knowledge Representation System. *Cognitive Science* 9(2):171-216.

**Braunwald, E., Isselbacher, K. J., Petersdorf, R. G., Wilson, J. D., Martin, J. B., Fauci, A. S. (eds.) 1987.** *Harrison's Principles of Internal Medicine*. 11. ed. New York: McGraw-Hill Book Company.

**Brentano 1976.** *Philosophische Untersuchungen zu Raum, Zeit und Kontinuum*. Hamburg: Felix-Meiner Verlag.

**Butchvarov, P. 1998.** Substance. In: Audi, R. (ed.) *The Cambridge Dictionary of Philosophy*. 6. ed. Cambridge (UK): Cambridge University Press.

**Casati, R., Varzi, A. 1994.** *Holes and other Superficialities*. Cambridge (Massachusetts): MIT Press.

**Casati, R., Varzi, A. 2002.** Events [Internet]. In: Zalta, E. N. (ed.) *The Stanford Encyclopedia of Philosophy*. Fall 2002. ed. Metaphysics Research Lab, Center for the Study of Language and Information, Stanford University. Cited 02.12.2003.

**Chalupsky, H. 2000.** OntoMorph: A Translation System for Symbolic Knowledge. In: Cohn, A. G., Giunchiglia, F., Selman, B. (eds.) *Proceedings of the 7th International Conference on Knowledge Representation and Reasoning (KR2000)*. Breckenridge, Colorado, USA, p. 471-482. Morgan Kaufmann.

**Chang, C. C., Keisler, H. J. 1990.** *Model Theory*. 3. ed. Studies in Logic and the Foundations of Mathematics, Vol. 73. Amsterdam: Elsevier.

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

**Chisholm, R. M. 1989.** Boundaries. In: Chisholm, R. M. (ed.) *On Metaphysics*. Minneapolis: University of Minnesota Press.

**Cocchiarella, N. B. 1991.** Formal Ontology. In: Burkhardt, H., Smith, B. (eds.) *Handbook of Metaphysics and Ontology*. p. 640-647. Munich: Philosophia Verlag.

**Corcho, O., Fernández-Lopéz, M., Gómez-Pérez, A. 2003.** Methodologies, tools and languages for building ontologies. Where is their meeting point? *Data and Knowledge Engineering* 46(1):41-64.

**da Costa, N. C. A. 1974.** On the Theory of Inconsistent Formal Systems. *Notre Dame Journal of Formal Logic* 15:497-510.

**de Keizer, N. F., Abu-Hanna, A., Zwetsloot-Schonk, J. H. M. 2000.** Understanding terminological systems. I: Terminology and typology. *Methods of Information in Medicine* 39(1):16-21.

**Degen, W., Heller, B., Herre, H. 2001a.** Contributions to the Ontological Foundation of Knowledge Modelling. Report No. 2/2001. University of Leipzig, Department of Computer Science. ISSN 1430-3701.

**Degen, W., Heller, B., Herre, H. 2002.** GOL: A Framework for Building and Representing Ontologies. In: Heller, B., Herre, H., Smith, B. (eds.) *Ontological Spring: A Reader in Formal and Applied Ontology. IFOMIS-Report No. 1*. p. 182-203. Institute for Formal Ontology and Medical Information Science, University of Leipzig.

**Degen, W., Heller, B., Herre, H., Smith, B. 2001b.** GOL: A General Ontological Language. In: Welty, C., Smith, B. (eds.) *Proceedings of the International Conference on Formal Ontology in Information Systems*. (FOIS 2001), Oct. 17-19, Ogunquit, Main, p. 34-46. ACM/SIGART. New York: ACM Press.

**Devlin, K. 1991.** Logic and Information. Cambridge (UK): Cambridge University Press.

**Dori, D. 2002.** *Object-Process Methodology: A Holistic Systems Paradigm*. Berlin: Springer.

**Doyle, J., Patil, R. S. 1991.** Two Theses of knowledge representation: language restriction, taxonomic classification, and the utility of representation services. *Artificial Intelligence* 48:261-297.

**Fellbaum, C. (ed.) 1998.** *WordNet: An Electronic Lexical Database. Language, Speech and Communication Series*. Language, Speech, and Communication. Cambridge (Mass.): MIT Press.

**Fensel, D. 2001.** *Ontologies: a Silver Bullet for Knowledge Management and Electronic Commerce*. Berlin/Heidelberg/New York: Springer. Available from: dieter@cs.vu.nl

**Fensel, D., Hendler, J., Lieberman, H., Wahlster, W. (eds.) 2003.** *Spinning the Semantic Web*. Cambridge: MIT Press.

**Flouris, G., Plexousakis, D., Antoniou, G. 2003.** On a Unifying Framework for Comparing Knowledge Representation Schemes. In: Bry, F., Lutz, C., Sattler, U., Schoop, M. (eds.) *Proceedings of the 10th International Workshop on Knowledge Representation meets Databases (KRDB 2003)*. Hamburg, Germany, September 15-16. CEUR Workshop Proceedings, Vol. 79. Technical University of Aachen (RWTH). Cited 15.04.2004.

**Gangemi, A., Navigli, R., Velardi, P. 2003.** The OntoWordNet Project: extension and axiomatization of conceptual relations in WordNet. *Proceedings of the International Conference on Ontologies, Databases and Applications of Semantics (ODBASE 2003)*. Catania, Italy, Nov 3-7. p. 820-838. 2888 ed. Lecture Notes in Computer Science.

**Gärdenfors, P. 2000.** *Conceptual Spaces: The Geometry of Thought*. A Bradford Book. Cambridge (Massachusetts): MIT Press.

**Genesereth, M. R., Fikes, R. 1992.** Knowledge Interchange Format, Version 3.0, Reference Manual. Logic Group Report No. 92-1. Stanford: Computer Science Department, Stanford University.

**Goltz, H.-J., Herre, H. 1990.** *Grundlagen der logischen Programmierung*. Informatik - Kybernetik - Rechentechnik, Vol. 34. Berlin: Akademie Verlag.

**Gracia, J. J. E. 1988.** *Individuality: An Essay on the Foundations of Metaphysics*. SUNY Series in Philosophy. Albany: State University of New York Press.

**Gracia, J. J. E. 1996.** *Texts: Ontological Status, Identity, Author, Audience*. SUNY Series in Philosophy. Albany: State University of New York Press.

**Gracia, J. J. E. 1999.** *Metaphysics and Its Tasks: The Search for the Categorial Foundation of Knowledge*. SUNY Series in Philosophy. Albany: State University of New York Press.

**Gruber, T. R. 1993.** A Translation Approach to Portable Ontology Specifications. *Knowledge Acquisition* 5(2):199-220.

**Gruber, T. R. 1995.** Toward Principles for the Design of Ontologies Used for Knowledge Sharing. *International Journal of Human and Computer Studies* 43(5/6):907-928.

**Guarino, N. 1998a.** Formal Ontology and Information Systems. In: Guarino, N. (ed.) *1st International Conference (FOIS-98)*. Trento, Italy, June 6-8. p. 3-15. Amsterdam: IOS Press.

**Guarino, N. 1998b.** Some Ontological Principles for Designing Upper Level Lexical Resources. In: Rubio, A., Gallardo, N., Castro, R., Tejada, A. (eds.) *First International Conference on Lexical Resources and Evaluation (LREC'98)*. Granada, Spain, May 28-30. Berlin: Springer.

**Guarino, N., Welty, C. 2000.** A Formal Ontology of Properties. In: Dieng, R., Corby, O. (eds.) *Knowledge Engineering and Knowledge Management. Methods, Models, and Tools: Proceedings of the 12th International Conference on Knowledge Engineering and Knowledge Management (EKAW2000)*. Juan-les-Pins, France, October 2-6. p. 97-112. Lecture Notes in Computer Science, Vol. 1937. Berlin: Springer.

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

**Hayes, P. J. 1995.** A Catalog of Temporal Theories. Technical Report No. UIUC-BI-AI-96-01. University of Illinois.

**Heller, B., Herre, H. 2003.** Formal Ontology and Principles of GOL. Onto-Med Report No. 1/2003. Research Group Ontologies in Medicine, University of Leipzig. ISSN 1611-7352.

**Heller, B., Herre, H. 2004.** Ontological Categories in GOL. *Axiomathes* 14(1):57-76.

**Heller, B., Herre, H., Loebe, F. 2004.** Ontological Reductions Based on Top-Level Ontologies [forthcoming 2004].

**Herre, H., Jaspers, J., Wagner, G. 1999.** Partial Logics with two kinds of negation as a foundation for knowledge-based reasoning. In: Gabbay, D. M., Wansing, H. (eds.) *What is negation?* p. 121-159. Applied Logic Series, Vol. 13. New York: Kluwer Academic Publishers.

**Johansson, I. 1989.** *Ontological Investigations: An Inquiry into the Categories of Nature, Man and Society*. London: Routledge.

**Kalfoglou, Y., Schorlemmer, M. 2003.** Ontology mapping: the state of the art. *The Knowledge Engineering Review* 18(1):1-31.

**Klein, M. 2001.** Combining and relating ontologies: an analysis of problems and solutions. *Workshop on Ontologies and Information Sharing, IJCAI'01*. Seattle, USA. Cited 23.03.2004. Available from: http://www.cs.vu.nl/~mcaklein/papers/IJCAI01-ws.pdf

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

**Lewis, D. K. 1991.** *Parts of Classes*. Oxford (Massachusetts): Blackwell.

**Loebe, F. 2003.** An Analysis of Roles: Towards Ontology-Based Modelling [Master's Thesis]. Onto-Med Report No. 6. Aug 2003. Onto-Med Research Group, University of Leipzig.

**Loux, M. 1998.** *Metaphysics: A Contemporary Introduction*. New York: Routledge.

**Masolo, C., Borgo, S., Gangemi, A., Guarino, N., Oltramari, A. 2003.** WonderWeb Deliverable D18. Ontology Library (final). Version 1.0. 31.12.2003. Trento (Italy): Laboratory For Applied Ontology, ISTC-CNR.

**Masolo, C., Borgo, S., Gangemi, A., Guarino, N., Oltramari, A., Schneider, L. 2002.** Wonderweb Deliverable D17. Preliminary Report. Version 2.0. 15.08.2002. Padova [Italy]: ISTC-CNR.

**McGuinness, D. L., Fikes, R., Rice, J., Wilder, S. 2000.** An Environment for Merging and Testing Large Ontologies. In: Cohn, A. G., Giunchiglia, F., Selman, B. (eds.) *Principles of Knowledge Representation and Reasoning: Proceedings of the 7th International Conference on Knowledge Representation and Reasoning (KR2000).* Breckenridge, Colorado, USA, April 11-15. p. 483-493. San Francisco: Morgan Kaufmann.

**Musen, M. 1992.** Dimensions of Knowledge Sharing and Reuse. *Computer and Biomedical Research* 25(5):435-467.

**Musen, M. A., Noy, N. F. 2003.** The PROMPT suite: interactive tools for ontology merging and mapping. *International Journal of Human-Computer Studies* 59(6):983-1024.

**Niles, I., Pease, A. 2001.** Towards a Standard Upper Ontology. In: Welty, C., Smith, B. (eds.) *Formal Ontology in Information Systems: Collected Papers from the Second International Conference*. New York, Oct. p. 2-9. ACM Press.

**Pease, A., Niles, I. 2002.** IEEE Standard Upper Ontology: A Progress Report. *The Knowledge Engineering Review* 17(1):65-70.

**Poli, R. 2001a.** ALWIS: Ontology for Knowledge Engineers [PhD Thesis]. Zeno, the Leiden-Utrecht Research Institute of Philosophy, University of Utrecht.

**Poli, R. 2001b.** The Basic Problem of the Theory of Levels of Reality. *Axiomathes* 12(3-4):261-283.

**Poli, R. 2002.** Ontological Methodology. *International Journal of Human-Computer Studies* 56(6):639–664.

**Priest, G. 1991.** Minimally Inconsistent LP. *Studia Logica* 50(2):321-331.

**Pschyrembel, W., Dornblüth, O. (eds.) 2002.** *Pschyrembel Klinisches Wörterbuch* [CD-ROM Version]. 259. ed. Berlin: Walter de Gruyter.

**Rahm, E., Bernstein, P. A. 2001.** A survey of approaches to automatic schema matching. *The Very Large Databases Journal* 10(4):334-350.

**Ritter, L. 2002.** *Mereology*. Frankfurt (Main): Vittorio Klostermann.

**Rumbaugh, J., Jacobson, I., Booch, G. 1999.** *The Unified Modeling Language Reference Manual*. The Addison-Wesley Object Technology Series. Reading (Massachusetts): Addison-Wesley.

**Runggaldier, E., Kanzian, C. 1998.** *Grundprobleme der Analytischen Ontologie*. Uni-Taschenbücher, Vol. 2059. Munich: Ferdinand Schöningh.

**Russel, S., Norvig, P. 1995.** *Artificial Intelligence: A Modern Approach*. New York: Prentice Hall, Englewood Cliffs.

**Sandewall, E. 1994.** *Features and Fluents*. Oxford: Clarendon Press.

**Scheidler, A. 2004.** A Prove of the Interpretability of the GOL Theory of Time in the Interval-based Theory of Allen-Hayes. [Unpublished Manuscript].

**Seifert, J. 1996.** *Sein und Wesen*. Heidelberg (Germany): Universitätsverlag C. Winter.

**Simons, P. 1987.** *Parts - A Study in Ontology*. Oxford (UK): Clarendon Press.

**Simons, P. M. 2000.** How to exist at a time when you have no temporal parts. *The Monist* 83:419-436.

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

**Sowa, J. F. 1984.** *Conceptual Structures: Information Processing in Mind and Machine*. Reading (Massachusetts): Addison-Wesley.

**Sowa, J. F. 2000.** *Knowlegde Representation - Logical, Philosophical and Computational Foundations*. Pacific Crove, CA: Brooks/Cole.

**Stumme, G., Maedche, A. 2001.** FCA-MERGE: Bottom-Up Merging of Ontologies. In: Nebel, B. (ed.) *Proceedings of the Seventeenth International Joint Conference on Artificial Intelligence (IJCAI 2001)*. Seattle, Washington, USA, Aug, 4-10. p. 225-234. San Francisco: Morgan Kaufmann.

**SUO 2004.** IEEE P1600.1 Standard Upper Ontology Working Group (SUO WG) [homepage]. Cited 20.04.2004. Available from: http://suo.ieee.org

**Swoyer, C. 2000.** Properties. In: Zalta, E. N. (ed.) *The Stanford Encyclopedia of Philosophy*. Winter 2000. ed. Stanford University, Center for the Study of Language and Information. Cited 23.04.2004.

**Szabo, M. E. (ed.) 1969.** *The Collected Works of Gerhard Gentzen*. Amsterdam: North-Holland Publishing Company.

**Szczerba, L. W. 1977.** Interpretability of elementary theories. In: Butts, R. E., Hintikka, J. (eds.) *Logic, Foundations of Mathematics and Computability Theory*. p. 129-145. The Western Ontario Series in Philosophy of Science, Vol. 9. Dordrecht: D. Reidel.

**Tarski, A. 1944.** The Semantic Conception of Truth and the Foundation of Semantics. *Philosophy and Phenomenological Research* 4:341-375.

**Tarski, A. 1949.** Arithmetical classes and types of mathematical systems. *Bulletin of the American Mathematical Society* 55:63-64.

**Varzi, A. 1996.** Parts, Wholes and Part-Whole Relations: The Prospects of Mereotopology. *Data and Knowledge Engineering* 20(3):259-286.

**Varzi, A. 1997.** Boundaries, Continuity and Contact. *Nous* 31:26-58.

**von Wachter, D. 2000.** *Dinge und Eigenschaften: Versuch zur Ontologie*. Neue Ontologische Forschung, Vol. 1. Dettelbach (Germany): J. H. Röll.

**W3C 2004.** OWL Specifications [Internet]. World Wide Web Consortium (W3C). Cited 23.03.2004. Available from: http://www.w3.org/2001/sw/WebOnt/

**Wittgenstein, L. 1922.** *Tractatus Logico-Philosophicus* [transl. by Ogden, C. K.]. London: Routledge & Kegan Paul.