Formal Ontology and Principles and Prospects of Knowledge Organisation: An Axiomatic Approach

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Zusammenfassung/Summary

Research in ontology has in recent years become widespread in the field of information systems, in various areas of sciences, in business, in economy, and in industry. The importance of ontologies is increasingly recognized in fields diverse as in e-commerce, semantic web, enterprise, information integration, information science, qualitative modeling of physical systems, natural language processing, knowledge engineering, and databases. Ontologies provide formal specifications and harmonized definitions of concepts used to represent knowledge of specific domains. An ontology supplies a unifying framework for communication, it establishes the basis for knowledge representation and contributes to theory formation about a specific domain.

In the present paper we endeavor an outlook onto the future of knowledge organization in multi-lingual, cross-scale repository integration and navigation and as the central part of this paper present and discuss principles of representation and organization of knowledge that grew out of the use of formal ontology. The core of the discussed ontological framework is a top level ontology, called GFO (General Formal Ontology), which is being developed at the University of Leipzig. After discussing the meaning of the current information crisis, an ontological framework is presented and principles are discussed which could be used to contribute to a solution of this crisis. These principles make use of the onto-axiomatic method, of graduated conceptualizations, of levels of reality, and of levels of information abstraction.

Suchbegriffe/Key words

Ontology, Knowledge Representation, Axiomatic Method, Knowledge Organization
Ontologie, Wissensrepräsentation, Axiomatische Methode, Wissensorganisation.

1. Introduction

In this paper we present and discuss principles of organization and representation of knowledge which are grounded on formal ontology and the axiomatic method. We use the term *formal ontology* to name an area of research which is becoming a science similar to formal logic. *Formal ontology* is concerned with the systematic development of axiomatic theories describing forms, modes, and views of being of the world at different levels of abstraction and granularity. Formal ontology integrates aspects of philosophy, formal logic, artificial intelligence (computer science), and cognitive science.

Knowledge Organization in Library and Information Sciences (LIS) is focused on the classification of knowledge fields and of concept formation, Hjorland, 2008, 2009. A classification schema in LIS consists of a set of concepts and relations connecting them; though, neither the concepts nor the relations are made explicit by introduction of formal axioms. The focus and purpose of formal ontology differs from this approach because an ontology is presented by a system of axioms which can be used to draw conclusions, to generate hypotheses, to interpret data by annotations, and to solve problems in the corresponding domain by computer-based methods. On the other hand, ontologies are included in the layer of knowledge organization systems, addressed in Gnoli, 2011 2008; hence, both disciplines overlap.

A core topic of both KO and formal ontology is the creation of conceptualizations which consists of systems of concepts and connecting relations. According to Gruber 1993, who introduced the term *ontology* in computer science, an ontology is a formal specification of a conceptualization. The interrelation between both fields is discussed in Dahlberg 2008, where a theoretical basis for the Information Coding Classification is established (Dahlberg 1978, 1982). This theory includes an integrative level theory, an approach of ontical areas, and the application of a feature of system theory.

A basic task of formal ontology consists of an analysis of systems of terms, denoting concepts, and in translating them into formal theories, which are the basis for various applications. In LIS several sorts of information artifacts are developed, like coding systems, keyword sets, controlled vocabularies, and classifications, Keizer 2000. These systems exhibit an important basis for ontological investigations; they can be integrated in the field of formal ontology, Herre 2010a. There is another problem in the field of KO which is closely related to formal ontology: The establishment of a system of most general categories. This is a task of top level ontologies, and there are various alternatives for such systems, as discussed in Herre, 2010b.

Another core topic of KO is the establishment of concepts theories, see Hjorland, 2009. In Dahlberg, 2008, four kinds of relationships between concepts are introduced: the generic, the partitive, the complementary, and the functional relationship. Using these relations, concept systems can be generated. Most of the current top level ontologies do not contain an ontology of concepts, with the exception of GFO (General Formal Ontology), which includes a structural theory of concepts, see Herre, 2007, 2010. In contrast to GFO, other top level ontologies, notably BFO (Basic Formal Ontology), exclude concepts from ontology, Smith 2004, Smith/Ceusters 2005. GFO reconciles ontology with epistemology by the idea of integrative realism, and by including multiple basic types of categories. From this follows that the approach, taken by GFO, establishes a firm ground for a fruitful interaction between formal ontology, in the spirit of GFO, and KO.

The paper is organized as follows: In section 2 we discuss various aspects of what is called the information crisis, in section 3 we present the basics of the onto-axiomatic method, and .

Section 4 contains an overview on the GFO-framework. Section 5 is devoted to the structure and representation of concepts. In section 6 the notions of core ontology and upper domain ontologies are discussed. Section 7 describes informally a basic schema for the integration and unification of information where the term *information* covers all forms of information, from raw data and data to metadata of various levels of abstraction, to concepts, concept systems, propositions, and knowledge systems. Finally, in section 8 summarize some relevant applications, and furthermore, various challenges for future research are presented.

2. The Need for Knowledge Organization in Times of an Information Crisis

2.1 General Situation

The term *Information Crisis* describes the present situation showing diverse phenomena which are caused by the increase of generation of information which is triggered by new information technologies, including, among others, the web, the provision of ever increasing memory stores, the new possibilities to copy and transfer digital texts, and to create virtual worlds. These processes lead to the situation of information overload and an increasing loss of orientation and context and so meaning in a broader sense.

The information crisis occurs gradually in almost every area of science and society. Psychological and societal problems are related to the danger of deformation of human beings because of losing the ability for directed deep thinking, and the lost of the connection to reality which is substituted by virtual realities, see Benking 1997, Kemper, 2012. This situation also influences the education process, Benking 2002, 2011, Doomen, 2009, and systemic aspects in general (Benking, Rose 1998).

We are facing nowadays a rapid expansion of data, information, and knowledge, notably in biology and medicine, see Blake 2006, and McCray 2006, but also in other fields, for example in the humanities. This situation leads to the problem of data verification and interpretation and, in general, to the task of connecting and contextualizing and framing information and transforming data to knowledge, Müller-Jung, 2013.

2.2 Structured Multi-Lingual and Multi-Scale Switching Systems

The task and challenge is to order information in a intelligible, comprehensible, and coherent way. We have looked into tree-structures and but also spatial grids as ordering systems, in particular switching systems like the Information Coding and Classification System (ICC) developed by Dahlberg, 1997, 2008, and expanding on this approach the Functional Classification (FC) system developed by Judge, 1984 for the retrieval of international multi-lingual meta-data and meta information, Benking/Kampffmeyer 1993. Later presented in form of a Cognitive Panorama, Benking 1992, 1996, 2005 for bridging repositories and indexing and connecting, not just collecting general overview and orientation information. This Cognitive Panorama as a Conceptual Superstructure was proposed in projects conceived by the Environmental Experts of the Economic Summit (EEES) of the G7 group of nations strongly supported by the OECD and administered by the United Nations Environmental Programme (UNEP-HEM) (Keune, Murray, Benking 1991, Benking, Kampffmeyer 1992/1993, Benking 2005, and was included in 2002 into the 2nd edition of the Encyclopedia of Systems and Cybernetics (Francois 1997).

The objective and mandate was to ease access and improve compatibility in general through data-harmonization and meta-data development procedures. The objective was to provide an additional, multi-modal reference space as a "container" not only for different sign systems, but also data "along and across scales" and we would add subject areas in different terminologies and languages here, to assist and augment the human capacity to communicate, visualize, and negotiate also comparable, not only compatible general information. The development of a unifying theory, integrating all these aspects and thus providing a sufficient expressive basis for Knowledge Organization, is work in progress which intends to bridge old and new approaches and theories. Restricted in space in this publication we feel there is a strong case a combination of axiomatic thinking (Stachowiak 1991) with a combination of an extended General Model Theory (GMT), Stachowiak 1972a/b, 1997 and Systematic Neopragmatism, Stachowiak,1986-95 Wernecke, 1994) and General Formal Ontology (GFO) to be detailed below.

2.3 Axiomatically founded Organization of Information

We defend the thesis that the information overload is caused by a lack of organization of knowledge and by insufficient methods for abstraction and interpretation of data. This problem addresses basic questions pertaining to the understanding of the scientific method. There is a current trend towards a new paradigm of science aimed at replacing traditional methods of science by a data-driven science which is focused on computer-aided analysis of patterns in data. Understanding of data is then supported by statistical analysis and the correlation between data.

It is well-known, as Derman, 2013, emphasized, that correlation between data does not imply causation, and a deeper understanding of data can only achieved by theories or models. We believe that theory formation and modeling, based on the axiomatic approach, are the central principles for organization of knowledge, and for interpretation and abstraction of data. The overall aim is the development of an ontologically founded unifying theory of knowledge organization which integrates the many facets of knowledge and information.

This axiomatic approach, outlined in sections 3-7, makes use of a top level ontology, of principles of ontological reduction, and of methods, supporting theory formation and modeling.

3. The Onto-Axiomatic Method

Information is available in various levels of detail, from rough data, to metadata and knowledge. Metadata are used to describe data, hence, they add more precise meaning to data, the semantics of which remains often underspecified. Since the metadata itself must be specified by some formal representation, the meaning of which should be explained, we arrive at an infinite regress which must be brought to an end by some basic principle, see

Herre/Loebe, 2005. In our approach this infinite regress is blocked by using a top level ontology that provides the most basic layer for a semantic foundation. Furthermore, the meaning of the top level ontology's categories and relations is established by the axiomatic method, introduced in mathematics by Hilbert, 1918. We call this method, which integrates the axiomatic method with a top-level ontology, the *onto-axiomatic method*.

The main building blocks of knowledge are concepts, relations, and axioms, specified in a suitable formal language. The concepts are classified into primitive and defined concepts. Given the primitive concepts, we can construct formal sentences which describe formal-logical interrelations between them. Some of these sentences are accepted as true in the domain under consideration; they are chosen as axioms without establishing their validity by means of a proof. These axioms define the primitive concepts implicitly, because the concepts' meaning is captured and constrained by them. The onto-axiomatic method establishes new principles for structuring and ordering of knowledge; in Herre, Loebe, 2005, a three level architecture is introduced.

The most difficult methodological problem concerning the introduction of axioms is their justification. In general, four basic problems are related to an axiomatization of the knowledge of a domain. Which are the appropriate concepts and relations for a domain (problem of conceptualization) ? How we may find axioms (axiomatization problem)? How can we know that the axioms are true in the considered domain (truth problem)? How can we prove that the resulting theory is consistent (consistency problem)?

The choice and introduction of adequate concepts is a crucial one, because the axioms are built upon them. Without an adequate conceptual basis we cannot establish reasonable and relevant axioms for describing the domain. An inappropriate choice of the basic concepts for a domain leads to the problems of irrelevance and conceptual incompleteness. We distinguish four basic types of domains: domains of the material world, domains of the mental-psychological world, domains of the social world, and, finally, abstract, ideal domains. Basic ideas on these ontological regions were established by Hartmann, 1950, and further elaborated by Poli, 2001.

Examples of material domains are, for example, biology, physics, chemistry, and parts of geography. These domains belong to the field of natural sciences, and they allow - to some extent - the use of experiments. One source for discovering of axioms in such empirical domains is the generalization on the basis of a set of single cases. This kind of reasoning is called inductive inference. Another source of axioms are idealizations, and usually any science uses such idealizations. The psychological-mental domain is more difficult to deal with because experiments can be only partially applied. Experiments must be repeatable and objectivisable, but how these conditions can be achieved for subjective phenomena, such as feelings, intentional acts, self-consciousness, and thoughts is unclear. We hold that subjective phenomena are founded on material structures; though, we believe that a strong reduction of mental phenomena to material ones is not possible.

A particular complex domain exhibits a social system which includes individual agents and their interactions. Hence, social systems contain mental-psychological phenomena. On the other hand, social systems are grounded on a material basis which includes economy. The fourth type of domain is related to ideal entities. A typical domain of this type is mathematics, which can be, in principle, reduced to set theory. Set theory belongs to an ideal platonic world which is independent from the subject. Such ideal domains principally exclude experiments, hence, they raise the question of how we gain access to knowledge about them. It is an important task of the onto-axiomatic method to develop means to support the solution of the basic problems mentioned above. This is work in progress.

4. The GFO-Framework

In this section we give an overview on the GFO-framework; a more detailed exposition is presented in Herre, 2010, and Herre, Burek, a.o. 2007. General Formal Ontology (GFO) is a top level ontology which is being developed at the University of Leipzig.

4.1 Categories, Instances, and Modes of Existence

The term *entity* covers everything that exists, where existence is understood in the broadest sense. We draw on the theory of Ingarden 1964, who distinguishes several modes of being: absolute, ideal, real, and intentional entities. The basic distinction of entities is between categories and instances. A category is an entity, being independent of time and space, which can be predicated of other entities. The predication relation is closely related to the instantiation relation, and the feature of being instantiable holds only for categories.

On the opposite, individuals are singular entities which cannot be instantiated. The instances of a category must not be individuals, they can be categories again. Categories are entities expressed by predicative terms of a formal or natural language that can be predicated of other entities. Predicative terms are linguistic expressions T that state conditions to be satisfied by an entity. There is a close relation between categories and language, hence, any analysis of the notion of a category must include the investigation of language.

4.2 Universals, Concepts, and Symbols

We draw on the ideas of Gracia, 1999, who distinguished various basic types of categories. We distinguish at least three kinds of categories: universals, concepts, and symbol structures. *Universals* are categories which are independent of the mind; they are classified into intrinsic and ideal universals. Intrinsic universals are constituents of the mind-independent real world, they are associated to invariants of the spatio-temporal real world, Goppold, Benking 1999, and they are something abstract that is in the things. Ideal universals are independent of the material real world, as for example numbers, geometric entities, and platonic ideas.

Concepts are categories that are represented as meanings in someone's mind. Concepts are a result of common intentionality which is based on communication and society. We hold that universals can only accessed through concepts, hence for the establishing of knowledge the category of concepts is the most important one. *Symbols* are signs or texts that can be instantiated by tokens. There is a close relation between these three kinds of categories: a universal is captured by a concept which is individually grasped by a mental representation, and the concept and its representation is denoted by a symbol structure being an expression of a language. Texts and symbolic structures may be communicated by their instances that a physical tokens.

4.3 Ontological Basic Distinctions

Entities are classified into categories and individuals. The basic entities of space and time are chronoids and topoids; these are considered as individuals. The ontology of space and time is inspired by ideas of Franz Brentano, 1976. Individuals are divided into concrete and abstract ones. Concrete individuals exist in time or space, whereas abstract individuals are independent of time and space. According to their relations to time, concrete individuals are classified into continuants, presentials and processes. Processes happen in time and are said to have a temporal extension. Continuants persist through time and have a lifetime, which is a chronoid. A continuant exhibits at any time point of its lifetime a uniquely determined entity, called presential, which is wholly present at the (unique) time boundary of its existence.

Examples of continuants are this ball and this tree, being persisting entities with a lifetime. Examples of presentials are this ball and this tree, any of them being wholly present at a certain time boundary t. Hence, the specification of a presential additionally requires the declaration of a time boundary. In contrast to a presential, a process cannot be wholly present at a time boundary. Examples of processes are particular cases of the tossing of a ball, a 100m run as well as a surgical intervention, the conduction of a clinical trial, etc. For any process p having the chronoid c as its temporal extension, each temporal part of p is determined by taking a temporal part of c and restricting p to this sub-chronoid. Similarly, p can be restricted to a time boundary t if the latter is a time boundary or an inner boundary of c. The resulting entity is called a process boundary, which does not fall into the category of processes.

4.4 Levels of Reality

We assume that the world is organized into strata, and that these strata are classified and separated into layers. The term *level* denotes both strata and layers. This approach is inspired by Hartmann, 1965, and Poli. 2001. GFO distinguishes at least four ontological strata of the world: the material, the mental-psychological, the social stratum, and the region of ideal entities. Every entity of the world participates in certain strata and its levels. We defend the position that the levels are characterized by integrated systems of categories. Hence, a level can be understood as a meta-category the instances of which are certain types of categories. Among these levels specific forms of categorical and existential dependencies hold. For example, a mental entity requires an animate material object as its existential bearer. The strata to which categories should be placed must then be determined. Concepts are rooted in the psychological and social stratum, and the investigation of this ontological region must use results of cognitive science, see Murphy, 2004, Gärdenfors, 2000. We hold that symbolic systems and universals in the tradition of Aristotle belong to the material stratum.

4.5 Integrative Realism

GFO introduces a new form of realism. Realism assumes the existence of a mind-independent real world. Yet the basic assumption of the GFO-approach is grounded on the idea of integrative realism. This kind of realism includes the mind as a part of ontology, and postulates a particular relation between the mind and the independent material reality. This relation connects dispositions of a certain type, inhering in the entities of material reality, with the manifold of subjective phenomena occurring in the mind. This relation can be understood as unfolding the real world disposition X in the mind's medium Y, resulting in the phenomenon Z. In this ternary relation the mind plays an active role. In GFO, continuants are viewed as cognitive creations of the mind that possess features of a universal, occurring as the phenomenon of persistence, but also of spatio-temporal individuals, grounded on the presentials, which the continuants exhibit. This approach is supported by results of cognitive psychology, notably in Gestalt theory, see Wertheimer, 1912, 1922. The integrative realism reconciles ontology and epistemology.

The theory of integrative realism differs from the kind of realism defended by BFO (Spear 2006). Recently, there started a debate - initiated by Merril, 2010 - about the interpretation and role of philosophical realism, and, in particular about the type of realism, defended by Smith in numerous papers, cf. Smith, 2004, 2006. We believe that integrative realism overcomes weaknesses of the type of philosophical realism defended by Smith, 2004.

4.6 Development of Ontologies

We summarize the basic steps for the development of an ontology, according to the GFO-methodology. An ontology usually is associated to a domain, hence, we must gain an understanding of the domain which is under consideration.

1. Step: Domain Specification, Task specification, and Proto-Ontology

A domain is determined by the entities to be considered, by classification principles and a set of views. The first step is the construction of a domain specification DomSpec(D) and a specification TaskSpec(D) of the tasks which are intended to be solved by the ontology's usage. In particular, a description of the entities of the domain D must be established. The considered entities are determined by the assumed views, whereas the classification principles provide the means for structuring the set Ent(D) of entities. Usually, there is source information which is associated to the domain, in particular a set *Terms*(D) of terms denoting concepts in the domain. The system ProtoOnt(D) = (DomSpec(D) ∪ TaskSpec(D), Terms(D)) is called a *proto-ontology*. A proto-ontology of a domain contains the relevant information needed to make the further steps in developing an *axiomatized ontology* about D.

2. Step: Conceptualisation.

A conceptualization is based on a proto-ontology; the result of this step is a *graduated conceptualization* (see section 5). Hence, the principal and elementary concepts of the domain must be identified or introduced. The resulting concepts belong either to the concepts denoted by the terms of Terms(D) or they are constructed by means of the classification principles. A further sub-step is pertained to the desired aspectual concepts which are derived from the elementary concepts. Finally, we must identify relations which are relevant to capture content about the individuals and concepts. It would be helpful if a meta-classification of relations is available. GFO provides already a basic classification of relations which must be extended and adapted to the particular domain D.

3. Step: Axiomatisation. During this step axioms are developed. This needs a formalism, which can be a graph-structure or a formal language. We expound in more detail the construction of a formal knowledge bases supported by a top level ontology TO. Generally, an axiomatized ontology *Ont = (L, V, Ax(V))* consists of a structured vocabulary V, called ontological signature, which contains symbols denoting categories, individuals, and relations between categories or between their instances, and a set of axioms *Ax(V)* which are expressions of the formal language L. The set *Ax(V)* of axioms captures the meaning of the symbols of V implicitly.

A final axiomatization for Conc(D) can be achieved by starting with a top-level ontology, say GFO, and then constructing by iterated steps an ontological mapping from Conc(D) into a suitable extension of GFO. An advanced elaboration of this theory, which is being investigated by the Onto-Med group, is presented in Herre 2006..

The construction of an ontological mapping, which yields an axiomatization of the conceptualization, includes, according to Herre/Heller, 2006, three main tasks:

1. Construction of a set *PCR* of primitive concepts and relations from the set $\{Def(t) : t \in Conc\}$ (*problem of primitive basis*)
2. Construction of an extension *TO(1)* of *TO* by adding new categories *Cat* and relations *Rel* and a set of new axioms. $Ax(Cat \cup Rel)$ (*axiomatization problem*)
3. Construction of equivalent expressions for $Def(t) \cup PCR$ on the basis of *TO(1)* (definability problem).

The development of tools and methods, supporting the axiomatisation step, is an important research topic.

5. Graduated Conceptualizations and the Structure of Concepts

In this section we consider some principles for the organization of conceptual systems.

5.1 Graduated Conceputalizations

The set Conc(D) of concepts, associated to a domain D, is divided into a set of principal concepts of D, denoted by PrincConc(D), into a set of elementary concepts, designated by ElemConc(D), into a set of aspectual concepts of D, symbolized by AspConc(D), and into logically defined concepts, denoted by LogConc(D). These sets of concepts form an increasing chain, i.e., we suppose that PrincConc(D) $\subseteq$ ElemConc(D) $\subseteq$ AspConc(D) $\subseteq$ LogConc(D). The principal categories are the most fundamental of a domain. For the biological domain, the concept of organism is considered as principal. The system (PrincConc(D), ElemConc(D), AspConc(D)) is called a graduated conceptualization for the domain D.

The elementary categories of a domain are introduced and determined by a classification based on the domain's classification principles; they should contain a taxonomy as a scaffold. In addition to the elementary categories there is an open-ended set of aspectual categories, derived from the fact that any entity stands in many relations to other entities. The notion of aspectual analysis has a relation to the notion of facet analysis in Ranganathan, 1933. The notions of aspectual composition and deployment are concerned with the construction of new concepts from constituents.

New concepts can be introduced along dimensions or basic aspects. Basic aspects are concepts or basic relations of a top-level ontology, which is in the sequel GFO. An intuitive, informal relation aspect(X, Y_1, ..., Y_n, Z) means: X is a domain concept, Y_i is a basic concept, or a basic relation of GFO and Z a category derived from X using the concepts or relations Y_i

in the role of an aspect. Therefore, Z is an aspectual concept of X via $Y_1,..., Y_n$. Let us consider an example. The notion X of hedgehog is a concept, a species. The notion of space and time are basic concepts of GFO; then the concept Z, the instances of which are those hedgehogs living in Germany (spatial location Y_1), during the time-interval Y_2 (temporal location) exhibits an aspectual derivation of X via Y_1, Y_2.

5.2 Structure of Concepts

The structure and architecture of concepts is concerned with their composition and parts, as well as their formal representation, types, and combining relations. The instantiation relation, denoted by the symbol ::, is one of the combining relations for concepts; it uncovers the type of the concepts. The set of types is the smallest set of expressions, containing the symbol 0 and which is closed with respect to the following condition: If $\tau_1,..., \tau_n$ are types, then the set $\{\tau_1,..., \tau_n\}$ is a type. The type of a concept or an individual is inductively defined as follows. Individuals have the type 0. A concept C has type τ, denoted by type(C), if $\{type(a) \mid a :: C\} = \tau$. A concept is said to be well-founded if it possesses a type. There might be concepts which are not well-founded. An ontology of non-well-founded concepts must include ideas of non-well-founded set theory, see Aczel 1988, Devlin 1993.

A primitive concept has type {0}, hence, all its instances are individuals. Any non-primitive concept is called higher-order concept. The biological concept "species" has structural type {{0}} because every instance is itself a concept having the type {0}. Domain level concepts, also called meta-concepts of domains, have as their instances all concepts associated to the corresponding domain; hence, they are always higher order concepts.

Furthermore, concepts may have conceptual parts, derived from combining relations. In the most simple case a concept may be considered as set of properties, see: Ganter, 1996. A conceptual part of a concept is either itself a concept or a designation of an individual. The relation of categorial part, denoted by catp(x.y), with the meaning that x is a categorial part of the concept y, can be interpreted into two directions. The first interpretation is that every concept of the transitive closure of C is a categorial part of C. The second interpretation expresses the idea that the categorial parts are arguments of more complicated combining relations, based, say, on a relations of type "has-property". A very complex type of concepts exhibit whole theories, the parts of which are concepts of different structural type that are related and connected by relations and logical functors.

5.3 Examples. Elementary concepts, aspectual concepts, and structural types.

The notion of elephant is an elementary biological concept, based on biological classification principles. Aspectual derivatives can be important for a further sub-classification of a concept C. For example, it might be important to subdivide a certain group of individuals into subgroups according to certain properties and relational conditions. A specialist for environmental studies, for example, might be interested in investigating the elephants living in a certain location of Africa during a certain interval of time. This is obviously a concept, but it is not derived by a biological classification principle. A knowledge field, say biology, can be understood as a concept the instances of which include all the field's concepts. With this interpretation a knowledge field is always a concept of higher order.

6. *Core Ontologies and Upper Domain Ontologies*

6.1 Core Ontologies

A core ontology of a domain D must capture what the domain D and its sub-domains are about. First ideas on core ontologies are discussed in Valente, 1996. We make further steps in the explication of this notion. In constructing a core ontology for D we firstly identify relevant sub-domains D(1),…D(m), and then introduce sets ElemConc(D), ElemConc(D(i)), …, ElemConc(D(m)) of elementary concepts. For every set ElemConc(D(i)) we introduce a meta-category, denoted by Meta(D(i)) MetaConc(D), having the concepts of ElemConc(D(i)). ElemConc(D) as its instances. A conceptualization for a core ontology for the domain can be understood as containing the following set of concepts CoreConc(D)= ElemConc(D(1)) ∪ ... ∪ ElemConc(D(i)) ∪{MetaConc(D(i)) : 1 ≤ i ≤ k } ∪ {MetaConc(D)}. A core ontology for D can be, then, defined by an axiomatization of CoreConc(D); for this purpose a set CoreRel(D)) of core relations must be added. These axioms must describe what the domain and its relevant sub-domains are about. For the field of biology, for example, these axioms must explain what a biological organism is, and how it can be separated from other fields, as chemistry, and physics. A possible approach for such an axiomatization for the core concepts of biology is to understand a biological organism as an autopoietic system.

6.2 Upper Domain Ontologies

Upper ontologies of a domain D, based on a graduated conceptualization (PrincConc(D), ElemConc(D), AspConc(D)), exhibit a part of the taxonomy of the elementary concepts. It contains the more general concepts associated to the domain; hence, an upper domain ontology for D can be understood as a top level ontology for this particular domain. Upper domain ontologies for domains are important for the integration of knowledge. An example is the ontology GFO-Bio which is an upper ontology for the whole field of biology, Hoehndorf et al. 2008.

7. *Towards a Basic Schema for Integration and Unification of Information*

In this section we outline a basic schema for integration of information which contributes to the ontological foundation of the Cognitive Panorama, as already outlined in chapter 2.2. above. For this purpose we introduce two basic dimensions of information. One dimension considers the source of the information, being one of the following ontological regions, the material region, the region of ideal entities, the region of psychological entities, and the region of societal entities. The other dimension pertains to the abstraction levels of information, which are captured by a relation *abstr* (X,Y), with the meaning: X is an abstraction of Y, where X and Y are information entities. Both dimensions are grounded on an upper ontology for data analysis, denoted by UpperOntoData. This ontology contains at least five sub-ontologies: an ontology of *time and space*, an *ontology of data acquisition*, an *ontology of properties,* an *ontology of relations,* and an *ontology of interpretation contexts*.

The intended ontology, being work in progress, is a top level ontology, because it does not describe particular domain specific information. The abstraction levels for information, based on the relation abstr(X,Y), form a chain of information entities which cover raw data, metadata, concepts, and propositions. There is a manifold of combinations between both aforementioned dimensions. The weight w of a material entity e, for example, is presented by a real number r which is combined with a quality q, inhering in the entity e. The weight-qualities q are divided into equivalence classes [q] expressing the same weight. The weight-entity, being an information entity, can be presented by a pair ([q], r). Details of this type of analysis are presented in Uciteli et al. 2011.

8. Applications and Future Research

Formal ontology and its applications is in its initial stage. We consider various types of applications, and collect several open problems being at the borderline of formal ontology and knowledge organization in LIS.

8.1 Applications

There are three types of applications of ontology: Computer-based applications harmonization of concepts, and theory formation, including analysis, and modeling.

(1) Computer-based applications use ontologies as a component of software. There is broad spectrum of applications in the field of the semantic web. Examples of such applications are presented in Hoehndorf/Ngonga/Herre , 2009a (The three ontology method for software development), Hoehndorf et al. 2009b (An ontology based wiki for annotation of data), Hoehndorf et al. 2008 (A biological core ontology).

(2) Harmonization of concepts are needed to develop a common basis for communication and for establishing a discipline. The result of a harmonization process is an ontology which explicates and organizes the conceptual knowledge of a field.

(3) Theory formation, analysis and modeling is concerned with the development of top level ontologies, which are used for the ontological analysis of a field of interest. Formal ontology as a science provides a support for theory formation and for the creation of models for a domain. An example of this kind of application is the theory of sequences as expounded in Hoehndorf, et al. 2009c. Other applications of this kind are presented in Baumann/Loebe/Herre 2012 on the ontology of time. These investigations are often inspired by philosophy, in particular by Brentano, 1976.

8.2 Future Research

We overview some tasks for future research. Benking 2005, and Gnoli 2008, in the library sciences, asked whether KO principles can be extended to a broader scope, including hypertext, multimedia, museum objects, and monuments. Multimedia includes here also a combination of text, audio, graphics, images, animation, video, or interactivity content forms.

We believe that the presented GFO framework with upper-level ontologies can contribute to addressing these challenges. The above mentioned basic schema is intended to include such entities which must be analyzed and classified within a suitable ontology of information entities. There are proposals for such an ontology of information entities, notably, the information artifact ontology IAO, though, it turns out that the IAO is insufficient to address these challenges.

Gnoli, 2008 further asked whether ontological and epistemological approaches can be reconciled. We believe that this possible on the basis of integrated realism, the multiple category approach, and the connection of different levels of reality at different scales and detail. A further question by Gnoli 2008 pertains to an ontological foundation of KO. We believe that the current paper is work in progress, a step towards such an ontological foundation, and provides an outlook onto bridging subject fields, media and repositories as described in chapter 2.2 based on early meta-database and international harmonization projects.

The elaboration of the sketched integration and unification schema, and the ontological foundation of the cognitive panorama is a topic of future research. Also is the structure and formal representation of concepts, notably of higher order concepts, not yet sufficiently understood nor have we found ways to include non-coded vague data satisfactorily.

The theory of levels is one of the most difficult unsolved problems in ontology. A number of open problems pertain to levels, among them the ontology of multiple inheritance taxonomies, the clarification of views and the ontology of multiple view domains, as well as a deeper understanding of classification principles. We hope that we were able to provide some directions for further research and to outline a little more clearly the challenges ahead.

Literatur

Aczel, P. Non-well-founded sets. CSLI Lecture Notes 14, Stanford, CA, 1988

Baumann, R., Loebe, F., Herre, H. 2012 Ontology of Time in GFO Proceedings of the 7th International Conference on Formal Ontology in Information Systems, FOIS 2012, Graz, Austria.

Benking, H., Kampffmeyer, U. Acess and Assimilation - Pivotal Environmental Information Challenges GeoJournal 26.3 1992, Kluwers Academic Publishers,

Benking, H.,, Kampffmeyer, U.: 1993 Harmonization of Environmental meta-information with a thesaurus based multi-lingual and multi-medial information Systems (multiple access strategies), In: Earth and Space Science Information Systems, pp. 688-695, (eds. Zygielbaum, A.) American Institute of Physics; AIP proceedings 283, ISY, NASA, JPL, Pasadena

Benking, H. 1996 Concept and Context Mapping - Towards common Frames of Reference In Terminology and Knowledge Engineering, Section 1: Terminology and Philosophy of Science TKE 1996, INDEKS Verlag, p. 35-47 Vienna 1996

Benking, H. 1997 Fluchtwelten oder Sinnwelten - Cyberspace als Spielzeug und Orientierungshilfe?, In Künstliche Paradiese - Virtuelle Realitäten, Künstliche Räume in Literatur-, Sozial- und Naturwissenschaften, Hrsg.: Krapp, H., Wägenbaur, T, Verlag, Fink, Wilhelm, ISBN : 978-3-7705-3253-7

Benking, H. Ohne Zusammenhang kein Zusammenhalt- Ein Essay auf der Suche nach gemeinsamen Orientierungen und Konstruktionen "Kultur der Verweigerung" Das konstruktive Nein, Eds. Reginald Földy, Clemens Heidack, Böhlau Verlag, Wien 2002, ISBN-10: 3205990986

Benking, H. Raum und Virtualität: Potential oder Leere? Die Bergwelt als Beispiel und Ursprung für den Zugang und die Auseinandersetzung mit "neuen" Welten, In: INST, Realität und Virtualität der

Berge, Weltmuseum der Berge, TRANS - Studies on the Changing of the World, Volume 1, The Unifying Aspects of Cultures, ISBN 3-9501947-0-3, 2002

Benking, H, Skizzen für Weltbilder und Welthäuser- Haus-Aufgaben zum Thema Weltbetrachtung und Naturverständnis, Reihe Postmaterialismus, Band 4. Die Natur, Methodische Voraussetzungen für die Entwicklung eines postmaterialistischen Naturbegriffs, 103-112, (Benedickter R. (Hrsg).) Passagen Verlag, 2004

Benking, H., Granularity, Topicality, and Generalization of Information, In: International Symposium on Generalization of Information ISGI 2005; The International Council for Science (ICSU), and CODATA, the ICSU Committee on Data for Science and Technology, ISKO_CODATA, http://www.codata-germany.org/ISGI_2005/ISGI_Order_Information.pdf ISBN 3 -00-016253-4

Benking, H 2011, Ignorance or Compassion? Limits and potentials of human concepts, maps and models with regard to nature, in Ecological Awareness: Exploring Religion, Ethics and Aesthetics, Bd. 3,, Studies in Religion and the Environment, : (Eds: Bergman, Eaton) http://www.lit-verlag.de/isbn/3-8258-1950-7, published on behalf of the European Forum, for the Study of Religion and the Environment, LIT Verlag 2011, ISBN 978-3-8258-1950-7

Benking, H., Rose, J.: 1998 A House of Horizons and Perspectives - A cognitive deep openspace for positioning, comparing, merging and morphing our metaphors, models, maps and views, In: "The Compatibility of Social Systems", The 42nd Annual Conference of the International Society for the Systems Sciences, ISSS~ISIS, Atlanta, 1998

Blake, J.A., Butt, C.J. Beyond the data deluge: Data integration and bio-ontologies. Journal of Biom Inf 39 (2006), 314-320

Brentano, F. Philosophische Untersuchungen zu Raum, Zeit und Kontinuum. Felix Meiner Verlag, Hamburg, 1976

Dahlberg. I Ontical Structures and Universal Classification. Bangalore, Sarada Ranganathan Endowment for Library Science, 1978.

Dahlberg. I, Information coding classification; principles, structure and application possibillities. International Classification, 9, 1982, 2, pp 87-93 (Reprinted with 3-digit schedule in: INDEKS GmbH. Classification Systems and Thesauri, 1950-1982. Frankfurt, INDEKS Verlag, 1982).

Dahlberg, I 1997, "Zur 'Begriffskultur' in den Sozialwissenschaften: Lassen sich ihre Probleme lösen?" in EuS 7 (1996)] Westdeutscher Verlag, now Lucius & Lucius Verlagsgesellschaft mbH EuS 8 (1997) 2 Anhang, pp. 115-116 ETHIK UND SOZIALWISSENSCHAFTEN, Streitforum für Erwägungskultur, Erwägen Wissen Ethik (EWE) / Deliberation Knowledge Ethics

Dahlberg, I.: The Information Coding Classification (ICC): A Modern, Theory-Based Fully-Faceted. Universal System of Knowledge Fields. Axiomathes (2008), 18: 161-176

Derman, E. Little Big Data. Frankfurter Allgemeine, Feuilleton, 6.03.2013.

Devlin, K. The Joy of Sets, Springer, 1993

Doomen, J. Information Inflation. Journal of Information Ethics, 18 (2), pp. 27-37. 2009

François Ch. International Encyclopedia of Systems and Cybernetics. München: K. G. Saur 1997. 2 volumes 2nd edition, 2011 ISBN 3-598-11357-9 http://www.degruyter.com/view/product/161455

Ganter, B. R. Wille. Formal Concept Analysis, Springer, 1996

Gärdenfors, P. 2000. Conceptual spaces: The geometry of thought, A Bradford Book. Cambridge, MA: MIT Press.

Gnoli, C. 2008. Ten Long-Term Research Questions in Knowledge Organisation, in: Knowledge Organization, 35(2/3), 137-149. Gnoli, C. 2011 Ontological Foundation in Knowledge Organization. In: La organizaccion del conocimiento, 29-34. Ed. F. J. Garcia Marco, 2008

Gnoli, C. 2011 Ontological Foundation in Knowledge Organization. In: La organizaccion del conocimiento, 29-34. Ed. F. J. Garcia Marco, 2011

Goppold, A, Benking, H, Spatio-Temporal Perspectives: A new way for cognitive enhancement, proceedings of HCI International (the 8th International Conference on Human-Computer Interaction) on Human-Computer Interaction: Ergonomics and User Interfaces-Volume I - Volume I, Pages 476-480, L. Erlbaum Associates Inc., 1999, ISBN:0-8058-3391-9

Gracia, Jorge, J. E. Metaphysics and its Tasks: The Search for the Categorial Foundation of Knowledge, State University of New York Press, Albany, 1999

Gruber, TR A translation approach to portable ontologies. Knowl Acquis 1993; 5: 199- 220

Hartmann, N. Der Aufbau der realen Welt. Walter de Gruyter and Co, Berlin 1965

Herre, H., Heller, B. 2006a Semantic foundations of medical information systems based on top-level ontologies. Journal of Knowledge-Based Systems 19(2):107–115.

Herre, H., Heller, B.; Burek, P.; Hoehndorf, R.; Loebe, F. & Michalek, H.. General Formal Ontology (GFO): A Foundational Ontology Integrating Objects and Processes. Part I: Basic Principles. Research Group Ontologies in Medicine (Onto- Med), University of Leipzig, 2007 http://www.onto-med.de/Archiv/ontomed2002/en/theories/gfo/part1-drafts/gfo-part1-v1-0-1.pdf

Herre, H. GFO: A Foundational Ontology for Conceptual Modeling, In: Poli, R. Obrst, L. (ed.) Theory and Applications of Ontology. Vol. 2, Berlin: Springer, July 2010a.

Herre, H. The Ontology of Medical Terminological Systems - Towards the Next Generation of Biomedical Ontologies. In: Poli, R. Obrst, L. (ed.) Theory and Applications of Ontology. Vol. 2, Berlin: Springer, July 2010b.

Herre, H. Loebe, F. 2005. A Meta-ontological Architecture for Foundational Ontologies. In: Meersman, R. Tari, Z. (ed.) On the Move to Meaningful Internet Systems 2005: CoopIS, DOA, and ODBASE:Proceedings of the OTM Confederated International Conferences, CoopIS, DOA, and ODBASE 2005, Agia Napa, Cyprus, Oct 31 – Nov 4, 2005 (Part II). Lecture Notes in Computer Science Vol. 3761, pp. 1398-1415. Berlin: Springer.

Hilbert, D. (1918). Axiomatisches Denken. Mathematische Annalen, 78:405–415, 3, S. 142-151.

Hjorland, B. What is Knowledge Organization (KO)? Knowledge Organization, 35 (2008), p. 86-101

Hjorland, B. Concept Theory. Journal of the American Society for Information Science and Technology, 60(B), 1519.1536, 2009

Hoehndorf, R., Loebe, F., Poli, R., Herre, H. Kelso, J. GFO-Bio: A biological core ontology. Applied Ontology Vol. 3(4), pp. 219-227. 2008

Hoehndorf, R. Kelso, J., Herre, H. 2009c The ontology of biological sequences. BMC Bioinformatics Vol. 10 (377) 2009

Hoehndorf, R., Ngonga Ngomo, A.-C., Herre, H. 2009a, Developing Consistent and Modular Software Models with Ontologies. In: Fujita, H., Marik, V. (ed.) New Trends in Software Methodologies, Tools and Techniques Proceedings of the 8th International Conference, SOMET-2009, 2009, p. 399-412

Hoehndorf, R., Loebe, F., Bacher, J., Backhaus, M., Gregorio Jr., S., Prüfer, K., Visagie, J., Uciteli, A., Herre, H., Kelso, J. 2009b, BOWIKI: an ontology-based wiki for annotation of data and integration of knowledge in biology. BMC-Bioinformatics Vol. 10 (Suppl 5):S5 2009

Ingarden, R. 1964. Der Streit um die Existenz der Welt I (Existentialontologie). Tübingen: Max Niemeyer Verlag.

McCray, A.T. Conceptualizing the world: Lessons from History. Journal of Biom Inf 39 (2006) 267-273

Judge, A.J.N. Functional Classification in an Integrative Matrix of Human Preoccupations International classification 11 (1984), 2, pp 69-76 and 11 (1984),

Merril, G. H. (2010). Ontological realism: Methodology or misdirection? *Applied Ontology*, 5:79–108.

Murphy, G. L. The Big Book of Concepts, Bradford Book, Cambridge Massachusetts, 2004

Keizer, N.F.; A. Abu-Hanna, J.H.M. Zwetsloot-Schonk: Unterstanding Terminological Systems, Terminology and Typology, Method Inform Med 2000, 39, 16-21

Kemper, P., A. Mentzer, J. Tilmanns (Eds.) Wirklichkeit 2.0. Reclam, Stuttgart, 2012

Keune, H., Murray, A.B., Benking, H., Harmonization of environmental measurement, GeoJournal, March 1991, Volume 23, Issue 3, pp 249-255,
Nelson, SJ, Johnston, D., Humphreys, BL. Relationships in Medical Subject Headings (MeSH), Chapter 11. In: Bean CA, Green R. (eds.) Relationships in the Organization of Knowledge. New York: Kluwer Academic Publishers; 2001. p. 171-184.
Poli, R. The basic Problem of the Theory of Levels of Reality. Axiomathes 2001; 12: 261-283
Ranganathan, SR, Colon Classification, (1933), Asia Madras, London
Searle, J. The Construction of Social Reality, Penguin Books, 1995
Smith, B. 2004. Beyond concepts: Ontology as reality representation. In FOIS, International conference on formal ontology and information systems,73–84, Turin: IOS Press.
Smith, B.,Ceusters, W. and R. Temmermann. 2005. Wüsteria. In Proceedings Medical Informatics Europe 2005, Geneva; Studies in Health Technology and Informatics 116:647–652.
Spear. A.D.. Ontology for the Twenty First Century: An Introduction with Recommendations. IFOMIS, Saarbrücken, Germany, Dec 2006.
Stachowiak, H.: Rationalismus im Ursprung, Die Genesis des axiomatischen Denkens, Springer Verlag, Wien New York 1971
Stachowiak, H. Allgemeine Modelltheorie, Springer Verlag 1972a
Stachowiak H. 1972b Models, In: Scientific Thought. Some Underlying Concepts, Methods, and Procedures. Paris: Mouton,UNESCO http://unesdoc.unesco.org/images/0000/000022/002251eo.pdf
Stachowiak H. Pragmatik : Handbuch pragmatischen Denkens (Hg.), 5 Bände, Hamburg: Meiner 1986-1995; Lizenzausgabe Darmstadt: Wissenschaftliche Buchgesellschaft 1997 5 volumes
Uciteli, A., S. Groß, H. Herre: 2011. An Ontologically founded Architecture for Information Systems in Clinical and Epidemiological Research. BMC Biomedical Semantics.
Valente, A. Breuker, J. Towards principled core ontologies. Proceedings of the 10th Knowledge Acquisition Workshop (KAW'96), Banff, alberta, Canada; ed. By Gaines, BR, Musen, MA, 1996: 301-320
Wernecke, J., Denken Im Modell – Theorie und Erfahrung im Paradigma eines pragmatischen Modellbegriffs, Philosophische Schriften Band 13, Dunker& Humblot, 1994
Wertheimer, M. 1912. Experimentelle Studien über das Sehen von Bewegung. Zeitschrift für Psychologie 161–265.
Wertheimer, M. 1922. Untersuchungen zur Lehre von der Gestalt. I. Prinizpielle Bemerkungen.
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