

Diverse perspectives on ontology: A joint report on the First IAOA Interdisciplinary Summer School on Ontological Analysis

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Abstract. The aim of the following report is to outline the content of the lectures given during the First IAOA Interdisciplinary Summer School on Ontological Analysis (July 16–20, 2012, Trento, Italy). The report emphasizes some of the *hot* topics or open questions discussed during the sessions, while reflecting a variety of perspectives on the goals of ontological analysis and the importance of interdisciplinarity in dealing with certain problems.

Keywords: Ontological analysis, conceptual modeling, description logics, philosophy, WordNet, KYOTO project

1. Purpose and significance of the report

The First Interdisciplinary Summer School on Ontological Analysis, organized by the International Association for Ontology and its Applications (IAOA), gathered nearly a hundred experts and students coming from various disciplinary backgrounds to discuss the emerging field of applied ontology.

The event, which took place in Trento, Italy, from the 16th through the 20th of July 2012, was a first attempt to approach ontological analysis by crossing various disciplinary boundaries. The philosophers, linguists, logicians, computer scientists, and engineers present at the event and affiliated with universities and research centres across the globe (24 nations) gathered around a common interest in ontology and its applications in the computational management and semantic integration of large amounts of heterogeneous data. A number of participants were employees of companies that deal with production and administrative services. Their presence at the event marked the current expansion of ontology to industry and highlighted the need to connect academia and industry.

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The school program was structured into four main sessions/lectures (logics, philosophy, conceptual modeling, and linguistics) that repeated each day. During the workshop, the participants had a unique occasion to hear and compare how researchers and practitioners from various fields employ both formal and informal methodological tools for ontological representation purposes. Each speaker presented a specific approach to ontology and its application: Nicola Guarino gave an overview of applied ontology and ontological analysis; Kevin Mulligan focused on the central questions of philosophical ontology; Christiane Fellbaum and Amanda Hicks addressed the methodological and practical issues in natural language processing and cognitive science; Giancarlo Guizzardi presented ontology-driven conceptual modelling; Chiara Ghidini and Luciano Serafini focused on formal logics for knowledge representation.

The aim of the following report is to outline the content of the lectures proposed, while emphasizing some of the “hot” topics or open questions that emerged during the discussions. Concurrently, the report aims at providing more than a mere summary of the program. Building upon the authors’ different educational backgrounds, the report reflects a variety of perspectives on the goal of ontological analysis and the importance of interdisciplinarity in dealing with certain problems.

Therefore, we here provide insight into some of the most recent thought concerning the limits and potentials of ontology as explored through different domains.

2. Introduction to applied ontology and ontological analysis

Nicola Guarino introduced the workshop with a short but notable overview of applied ontology. In different seminal papers published in the 1990s, Guarino defines an ontology as “a logical theory accounting for the intended meaning of a formal vocabulary, i.e. [a theory with an] ontological commitment to a particular conceptualization of the world” (Guarino, 1998b). This definition is mainly based on Tom Gruber’s idea that an ontology is an “explicit specification of a *conceptualization*” (Gruber, 1993), i.e. the formal encoding of what exists in a domain of reality according to a specific interpretation. Nevertheless, Guarino revised Gruber’s proposal, claiming that, for ontological purposes, it is necessary to consider a conceptualization in a broader sense, i.e. in terms of an *intensional relational structure*, while Gruber was accounting just for an *extensional* one. The main difference is that in Gruber’s definition the conceptualization reflects a specific state of affairs, while according to Guarino, concepts (i.e. meanings) are defined from a set of maximal world states into particular world states. In this way, the meanings of concepts are fixed in a broader sense (among *possible worlds*) going beyond a single state of affairs.

Following these ideas, during the workshop an ontology was presented as a specific theoretical or computational artifact developed for the purpose of understanding and communication, as well as to allow automatic semantic reasoning over the content of information. Indeed, according to Guarino, an ontology “[expresses] the intended meaning of a vocabulary in terms of primitive categories and relations, describing the nature and structure of a domain of discourse in order to account for the competent use of a vocabulary in real situations” (cf. Guarino, 2012, slide n. 21). In other words, ontologies make explicit people’s assumptions about the nature and the structure of the world. Particularly, they are very helpful to delineate *what exists* according to different conceptualizations of one and the same reality, while enabling people to share different points of view about the same world. When implemented in computational systems, ontologies are linguistic tools for finding a common way to communicate with each other through the use of information systems.

During his opening lecture, Guarino pointed out that computer scientists have mainly focused on the logical structure of ontologies and the reasoning tasks of ontology-driven information systems, while

putting aside the problem of the content of such representation, i.e. the semantic specifications of the ontologies (cf. Guarino, 2012, slide n. 5). Nevertheless, such specifications play a central role in ontological representations. Logic is notoriously neutral about content, and before representing any piece of knowledge for ontological purposes, it is necessary to conduct an *ontological analysis* of the same. In this perspective, applied ontology can greatly benefit from the exploitation of formal philosophical ontology, first of all from the theory of parts, the theory of wholes, the theory of essence and identity, and the theory of dependence (cf. Smith, 1998). Moreover, we believe that various philosophical debates about the scientific classification (Dupré, 1981; Jansen, 2009) and representation in science (Giere, 2010; Knuuttila, 2011) can additionally inform ontological analysis by providing conceptual tools and methods for ontology design.

One major point particularly stressed was that the interdisciplinary approach to the ontological analysis respects the precious contributions of diverse domain experts in achieving agreement on how to represent people's varying assumptions about the world. Simply put, if we want to acknowledge that applied ontology is emerging as a new discipline or science, interdisciplinarity between philosophy, cognitive science, linguistics, logic and engineering must be its main feature. Only by striking a balance between different approaches can we deal with the complexity of knowledge and ontological representation, while "ignoring this intrinsic interdisciplinarity nature makes [computational ontologies] almost useless" (cf. Guarino, 2012, slide n. 21).

3. Logic for knowledge representation

Luciano Serafini and Chiara Ghidini gave a series of lectures on the exploitation of logic languages for the formal representation of human knowledge, with particular attention to the first-order logic (FOL) and the family of description logics (DLs).

Unlike non-logic based languages of knowledge representation, languages based on FOL and DL have well-known formal semantics. In this way, the possible interpretations of the language symbols can be (formally) constrained and the reasoning tasks about a piece of knowledge can be better controlled and investigated.

The great benefit of using FOL for knowledge representation is its neutrality with respect to ontological choices. However, in order to represent both terminological agreements and assertional knowledge in a knowledge-based system, there is a need to depart from mere FOL and overcome its neutrality in order to depict the ontological choices made by the user. In other words, FOL must be extended to the representation of ontological commitments of a conceptualization about a domain of reality (i.e. some area of specific interest out of the totality of possibility), and the family of description logics (DLs) is one of the most used for this purpose (Baader et al., 2007).

Serafini gave an introduction to DLs with particular attention to the *Attributive Language* (AL) which is a minimal language that is of practical interest. DLs model *concepts, roles and individuals*, i.e. classes of entities, relations and particular instances of such classes. It is worth noting that the different family of DLs are not just useful to represent the content of knowledge, but also to automatically perform epistemological reasoning. Indeed, DLs are basically built to trade off the expressive power of a logical language with its decidability, i.e. the capability of a formal language to distinguish different models on the one side, and the ability to always conclude a decision procedure with a positive or negative answer on the other.

A DL knowledge base is built on a fundamental distinction between the terminological and assertional knowledge, where the first is accounted for as TBox and the latter as ABox, so that the knowledge base

is a pair $K = (T, A)$. As specified by Guarino (Guarino, 1998b), the difference between TBox and ABox allows clarifying the distinction between the general representation of concepts (the ontology) and specific knowledge about specific cases.

One of the main axiomatic relations in DLs is the subsumption relation between concepts, which can be written as: “C is_a D,” where C is the subsumed concept and D the concept that subsumes. Specifically, the relation means that every particular instance of the class C is necessarily an instance of the class D. In this way, a DLs concept hierarchy is a subsumption hierarchy between concepts of different generality.

Serafini gave also an introduction to multi-context logic (MCL), i.e. a system of logic where knowledge and reasoning are defined in terms of two principles, locality and compatibility. *Locality* is the idea of using only parts (modules) of available knowledge, while considering the context in which it is presented. Hence, a *context* specifies the part being used while reasoning, i.e. a theory (set of sentences in a logical language, closed under logical consequence) associated with a region in a contextual space. *Compatibility* stresses the idea that what is asserted in a context influences knowledge and reasoning in other contexts. In other words, there is a compatibility issue when the reasoning is performed in different contexts. The calculus of a multi-context logic is defined in terms of context and bridge rules, which correspond to the formalization of the compatibility, in order to support interoperability among ontologies.

Multi-context logics drove the development of Distributed Description Logic (DDL), a family of DLs that formalizes *local TBoxes* and bridge rules between pairs of local TBoxes. DDL has a sound and complete algorithm computing subsumption, and it is a very useful formal language to state mappings between concepts from different ontologies. Indeed, in real applications, ontologies are *distributed* – they are fragmented and connected via *semantic mappings* (e.g. ‘is equivalent to’, ‘is more general than’, ‘is more specific than’). A context version of the Ontology Web Language (OWL) has been developed; it is called *Context OWL* (C-OWL). Nevertheless, its main problem is that semantic web languages do not support the representation and reasoning of context-sensitive knowledge.

To complete the series on ontological tools for knowledge representation, Ghidini gave a thought-provoking lecture about parthood, componenthood and containment relations which are widely used in formal ontologies for different purposes. She showed the possibility to treat such relations in DLs in a computationally advantageous way, although not all their formal properties can be properly expressed in such a family of logics. Thus, Ghidini, following Bittner and Donnelly (2007), proposed a computational ontology made of two components: a DL base for automatic reasoning, and a FOL base to express metadata and make explicit those properties of relations that cannot be expressed in computationally efficient DLs.

4. Ontological analysis: The philosophical perspective

Kevin Mulligan provided a general but very interesting overview of the main topics of philosophical ontology. He did not engage technical philosophical discussions, but gave instead an introduction on how to approach ontological analysis from a philosophical point of view.

The line of Mulligan’s argument addresses the classical question “What is philosophical ontology?”. He claimed that (philosophical) ontology is not an empirical science since its claims are non-contingent truths and falsities such as the truths of mereology. Indeed, while a scientist may be interested in the content of a particular fact, a philosopher, on the contrary, would rather ask the meta-question “What

is a fact?”. The distinction between the two perspectives may become clear by stressing the difference between ontology and logic, as well as the classical difference between contingent and necessary truths. Similarly, he suggested reserving the term “metaphysics” for combination of ontology and claims about the real world, about contingent facts. This terminological distinction between “ontology” and “metaphysics” is not a common one. But the difference behind the distinction is an important one.

Briefly said, both (formal) logic and (formal) ontology are interested in some kind of generality. Nevertheless, the former deals with the form of statements, while the latter deals with the general (formal) structure of actual and possible reality. In other words, the difference concerns the nature of the relations that are investigated. For instance, the *implication* is a logical connective between two statements, while *ontological identity* refers to the formal dimension of such a relation between real objects. Moreover, the domain of ontology can be also limited by considering what, in Mulligan’s terminology, “wears the ontological trousers”. Consider the following two lists, provided by Mulligan (Ingarden, 1964):

- objects, properties, relations, classes/sets, state of affairs, connectors;
- changes, creatures, events, powers, processes, tendencies, things/substance, qualities, masses/stuff, places, time, modes of being, types/kinds.

Which of the items listed wears the ontological trousers? Surprisingly, Mulligan posited that the second list does. List 1 is comprised of *connectors*, while the things in list 2 are *types, modes of being, existential moments*. In particular, the first list is the so-called “logical ontological family”, because of the isomorphism between these ontological categories and logical categories it contains. In other words, it is *logically driven* in the sense that its elements could be reduced to pure logical categories and relations. On the other hand, the second list contains categories that express the “realm of metaphysical possibility” (Lowe, 2006).

Mulligan also introduced the notion of *connectors*. One omnipresent category in natural language is that of *connective*. By connective, Mulligan meant any expression that takes at least one sentence to make a new sentence. He then noted that applied ontology tends to ignore the category of *connective*. If a connective has a semantic value, then it is called *connector*. But this definition leads to other questions. Indeed, what is a *semantic value*? It is usually said that the semantic value of a common noun is an object, of a sentence is a state of affairs, and so forth. But, according to Mulligan, such thinking is lazy. Can connectives, in principle, have a semantic value? Consider for example disjunction, or negation as disjunctions: there is *nothing* in the world that is a negation, disjunction or, moreover, conjunction. These notions merely connect sentences. Therefore, Mulligan went on to say, in philosophical ontology the search for a theory of connectives/connectors is a core concern only of logic-driven ontology and not of fundamental ontology.

A further difficulty is the fact that in ordinary language we use modality as predicates, but actually modal logic uses connectives. Therefore, it is necessary to make a distinction between modality as connective (*de dicto* modality) and modality as predicate (*de re* modality). More precisely, “*de re* represents a modality which refers to a property of the thing itself (*res*), whereas *de dicto* represents a modality that refers to an expression (*dictum*)” (Guizzardi, 2007, p. 15).

Mulligan also mentioned an important distinction between essentiality and modality, since according to him, necessity and possibility can function as connectives, while essentiality does not. So, what is the relation between essentiality and modality? Philosophy of modality could provide an answer to this question, in particular Fine’s theory. According to Fine, there are two main kinds of necessity: metaphysical necessity (MN) and natural necessity (NN):

- MN. Consider the proposition “It is not raining now in Trento or it is raining now in Trento”. Its necessity is metaphysical by virtue of the nature of negation and disjunction. So, metaphysical necessity means that a proposition is true by virtue of its logical form.
- NN. Consider, then, the proposition “Kevin Mulligan has his origin from x and y ”. It is impossible for Kevin Mulligan to have different origins from the origin he has. So, in this case, the proposition is necessarily true by virtue of *the nature of substances of particular kinds*.

The question of *types* is another philosophical debate that Mulligan called to attention. He criticized philosophers’ customary use of ‘instantiation’ and ‘exemplification’ as synonymous. The same applies for properties and types. Indeed, there is a distinction among types (species, substantive universals, kinds), properties and their bearers. Instantiation refers to the relation, adopting a distinction taken from philosophy of language, between *types* and *tokens*. On the other hand, exemplification refers to the single occurrence of a general property.

Another issue highlighted by Mulligan is the contrast between *idealialia* and *realia*. What is to be an ideal entity? An ideal entity is outside space and time (naively conceived). In other words, an entity is ideal if you cannot trace it through space and time. The opposite applies for *realia*. Examples of ideal entities are the following: numbers, sets and classes, geometrical forms, propositions, concepts, meanings, types (also kinds and species). *Realia* are quite easy to understand. Consider for example the fact that ‘Sam is sad and Adam is sad’. Consider, next, that ‘Sam is in Beijing and Adam is in New York’. Where is ‘sadness’ located? If put in this sense, multiple-exemplifiable properties are universals, and so they are ideal entities, as they are not traceable through space and time.

Moreover, there are *idealialia* which are exemplifiable (properties, relations) and others that can be instantiated (types, kinds, essences), and yet others which can be neither exemplified or instantiated (classes, sets). Some *idealialia* are pure (such as numbers), others are impure (biological kinds, word types, kinds of artifacts). Usually, as we have said, exemplification and instantiation are synonyms. However, according to Mulligan, instantiation only relates to types, kinds and essences, while exemplification refers to properties.

Both exemplification and instantiation can be contingent or not contingent. Consider again the example ‘Sam is sad’. Sam contingently exemplifies sadness. On the other hand, the fact that ‘Sam is a man’ is not contingent, because, by definition, Sam non-contingently exemplifies the property of being a man. The same type of distinction can be made in the case of instantiation. Sam contingently instantiates the type Child and non-contingently instantiates the type Human Being.

The discussed examples outline the utility of philosophical analysis in informing computational ontology by specifying distinctions between types and tokens, necessary and contingent statements, i.e. the ways in which we conceptualise reality.

5. Ontology-driven conceptual modelling

The main objective of Giancarlo Guizzardi’s lectures was to introduce the participants of the workshop to the theory and practice of conceptual modeling for improving domain ontology engineering. A general introduction to ontology-driven conceptual modeling was given, including its origins in software engineering as well as the theoretical foundations from various fields (formal ontology, cognitive science, philosophical logics, and linguistics).

Mylopoulos (1992) defined conceptual modeling as “the activity of formally describing some aspects of the physical and social world around us for purposes of understanding and communication [...]”. In

other words, conceptual modeling aims at representing reality using computational models so that different human users can share unambiguously their varying understandings of reality. In this way, according to Guizzardi, there is a clear link between conceptual modelling and ontology, because both of them share the same purpose. Particularly, Guizzardi presented a (computational) ontology as a “reference model of consensus to support different types of semantic interoperability task” (Guizzardi, 2012, slide n. 31).

One of the major challenges for ontology-driven conceptual modelling is the elaboration of a conceptual modeling language, the modeling primitives of which reflect the distinctions of an appropriate underlying (descriptive) ontology (cf. Guizzardi, 2012, slide n. 36). The key problem that modelers may face is how to define the object-types to be included in the language and how to state relationships between them. Basically, Guizzardi, following Guarino and other colleagues during the workshop, proposed the use of a formal ontology of properties to drive the definition of a conceptual modelling language. According to this formal theory, object-types are defined as the extensions of properties and every object-type is provided with meta-properties. These meta-properties are identity, rigidity, dependence and unity, and their role is to make clear the logical consequences of certain ontological choices.

The main object-types obtained through this strategy and presented during the lectures were: kind and subkind (rigid sortal types); phase and role (anti-rigid sortal types); category (rigid non-sortal type); role mixin (anti-rigid non-sortal type); mixin (semi-rigid non-sortal type). Regarding the problem of defining relations, Guizzardi was particularly focused on the mereological relation of parthood. Combining mereology and the quantified alethic modal logic (QS5), he stated the difference between optional, mandatory, immutable and essential parts. The constraints on using such relations were highlighted with several examples, making the point that conceptual models always involve some compromise in granularity: a representation we may think is adequate and monolithic on face value can be more critically examined for various inflections of meaning that make a difference in certain contexts (one question implicitly posed for students’ consideration: whether an engine is ‘part of’ a car the same way someone’s brain is ‘part of’ their body).

Guizzardi also provided a brief introduction to the second version of the Unified Modeling Language (UML 2), precisely about the so-called class diagram of such a language. Moreover, he gave a quick overview of the OntoUML Editor, a tool based on the Unified Foundational Ontology (UFO) for the development of well-founded conceptual modelling.

Although the content of the lecture was meant to be adaptable to specific domains, it revealed to us a larger difficulty with conceptual modeling itself – namely, whether the entities and categories defined by UML are truly sufficient for representing any subject area well. In other words, to what extent does a language such as UML serve as a meta or upper ontology, and what are the steps for effectively applying it to a given domain? These concerns are implicit in the practice of ontology. We believe they merit more attention among “working ontologists” and any institutes we have formed as professionals and scholars.

Furthermore, while distinctions about classes and relations are central to ontology, another consideration is the customary dependence on deductive, intuition-based methods of ontology development. Perhaps an empirical, data-based approach is called for as modern technology increasingly allows the gathering of large amounts of information. This creates an opportunity to use real-world phenomena to verify theoretical insights from various disciplines relevant to ontology. In other words, many ontologies seem to be developed from pure reasoning or “expert knowledge” without much documentable validation (such as quantification of the content that is modeled, or other deep exploration). Often the examples given in the support of ontological development or reasoning are simplistic and made-up rather

than coming from data generated by real-world problems. However, this concern is alleviated by a look at language usage and lexical modeling in the next section.

6. Lexicographic and ontological applications: The cases of WordNet and the KYOTO project

The *Princeton WordNet (PWN)*¹ was conceived and created in 1986 through the joint effort of Christiane Fellbaum and George Miller (1920–2012). Their work rapidly captured international interest. Over the years, PWN has been reproduced in numerous different languages, including EuroWordNet (Vossen et al., 1998), BalkaNet (Tufis & Barbu, 2001; Tufis et al., 2004a, 2004b) and IndoWordNet (Bhattacharyya, 2010).

Wordnets have proved to be useful for many NLP applications.² The WN database can be easily queried manually and automatically. Its network structure based on lexical and semantic relations enables users to automatically measure and quantify the meaning similarity among words. It reveals the systematicity of a lexicon, as it allows investigation of how a language encodes and lexicalizes concepts.

WN is defined by its creators “a large-scale model of human lexical-semantic organization” (Fellbaum, 2012), vaguely resembling a thesaurus. Words are mapped in it through senses; relations among words express semantic similarity.

Discussions took place during the Summer School about whether or not to call WN “a lexical ontology”, but the final agreement was to position this model at the crossroads between a lexicon and an ontology³.

Like a lexicon, WN represents all three aspects of word knowledge: phonology, morphology and syntax, while mainly focusing on the lexical-semantic representation of a word. Like an ontology, it is comprised of basic concepts, resembling the language-independent concepts (entities) entailed in an ontology and defined by properties (e.g. rigidity and non-rigidity) through axioms.

PWN and most other wordnets are continuously undergoing extensions and revisions. However, there are several language barriers or theoretical limitations that WN builders need to address.

One basic yet unsolved limitation in AI and language is the little knowledge we possess about mental processes guiding language acquisition and language use. This greatly hinders a mapping process. The constraint was recognized by WN developers, who started with psycholinguistic claims to justify their findings but gradually discarded them and eventually relied upon empirical AI work.

Moreover, consensus has still not been achieved in the definitions of some basic language concepts (i.e. the meaning of the same words in a speaker community). This applies for instance to the terms ‘lexicon’ (defined in WN as “a large, systematically organized, organic and dynamic language repository”), ‘word’ (defined in WN as a “form-meaning mapping”) and ‘meaning’.⁴

The EU funded the *KYOTO*⁵ ontology (2007–2011; here simply referred to as “KYOTO”) as an example of real-world application of WN. Its major goal is to facilitate data mining and sharing as extracted

¹The use of “WordNet” or WN in capital letters (as a trademarked term by Princeton) refers to the conceptual structure of the Princeton WordNet (PWN) and the other WordNets. The latter are referred to in the text with the general term “wordnets”.

²For further information about PWN and the Global WordNet Association, visit wordnet.princeton.edu/. For a list of all current WN including freely available ones and the latest PWN (current version 3.1., also free), visit www.globalwordnet.org/.

³“WordNets represent the word ‘cat’ in context, while ontologies represent what is to be a cat”, (Hicks, 2012). “Is WordNet an ontology? A lexicon? A thesaurus? Not quite either. But it’s often referred to as a “lexical ontology”” (Fellbaum, 2012).

⁴For the purpose of this report we won’t go into details. Further explication can be found in Fellbaum, 2012.

⁵The acronym “KYOTO” stands for Knowledge Yielding Ontologies for Transition-based Organization.

from ecology-related texts across seven different EU languages.⁶ WWF and the ECNC⁷ count among its domain users. The top, middle and domain ontology⁸ was built by integrating Basic Concepts taken from WordNet and domain terms identified by the domain experts and integrating them into an upper ontology, which is basically Dolce Lite Plus Ontology (Guarino, 1998b; Masolo et al., 2003) with modifications.

The *KYOTO project* which enabled the creation of the KYOTO ontology was subdivided into three parts: first, extracted terms from Wikipedia were organized when possible into semantic relations and/or WN in their specific language. The second step was the intervention of domain experts who were able to draft a first ontology of the terms marked and to define their differences and similarities across languages and cultures. This generated a “fact” database (series of annotated documents), eventually extracted by Kybots (Knowledge Yielding Robots)⁹ (third step).

KYOTO middle builds upon the WN basic concepts, but adds 73 new perdurants (processes and states) and 123 new endurants (objects and substances). KYOTO top extends the role and physical-quality hierarchy (e.g. *amount-of-matter-quality*, *feature-quality*, *physical-object-quality*) and adds quality types (*dispositional and relational*). Roles are arranged in the ontologies according to the kind of entity that bears them (e.g. a *physical-object-role* is played by a physical object).

Meanings and concepts are mapped in WN by virtue of two major logical relations, *is_a* (valid for hyponymy and hyperonymy, equal to the ontological relation *kindOf/partOf*) and *has_a* (mainly used for meronymic and holonymic relations, equal to the ontological *partOf*).

Is_a as logical relation can lead to confusion in the distinction of ontological subclasses. This was particularly noticed during the annotation of KYOTO, where terms were therefore noted twice, once in the former, and once in the domain-specific knowledge. Gangemi et al. (in Huang et al., 2010) requested the introduction of an *instance_of* relation in WN, which would enable a better distinction between concept-to-concept (subsumption) and individual-to-concept relation (instantiation).

The way in which subclasses are conceived in WN differs from the way properties are conceived in ontologies. In WN, subsumption relations are basically expressed through hyperonymy, which corresponds in ontology to the logical relation “Every *x* is a *y*”. The fact for instance that ‘pet’ is a hyponym of ‘animal’ and ‘cat’ an hyponym of ‘pet’, is shared by both WN and ontology.

Nevertheless, hyperonymy in WN may lead to inferences once the relation becomes more complex. By assuming for instance that every pet has an owner, we should wrongly assume also that every cat has an owner (Hicks & Herold, 2011). Because it was conceived as an ontology, the KYOTO data repository takes into account properties, such as rigidity and non-rigidity, adopting the distinction between rigid and non-rigid concepts (e.g. *cat* versus *pet*) as proposed by Guarino and Welty in OntoClean (Huang et al., 2010). The introduction of the rigidity property in KYOTO also helps to better define subsumption.¹⁰

The systematicity which underscores PWN and every existing WN reveals similarities between languages as well as gaps not only within one language, but among many (e.g. the existence and extent of kinship terms).

⁶English, Spanish, Basque, Italian, Dutch, Japanese and Simplified Mandarin Chinese, as for 2010.

⁷The World Wildlife Fund and the European Centre for Natural Conservation.

⁸Ontologies can be *upper* or *top* (e.g. BFO, SUMO); *middle* (e.g. Information Artifact Ontology) and *domain* (e.g. Gene Ontology, Protein Ontology), according to the different levels of specification and application used.

⁹For more information see Vossen et al., 2008.

¹⁰The general rule for subsumption adopted for KYOTO is indeed: “non-rigid terms should not subsume rigid terms or roles should not subsume types” (Hicks, 2012).

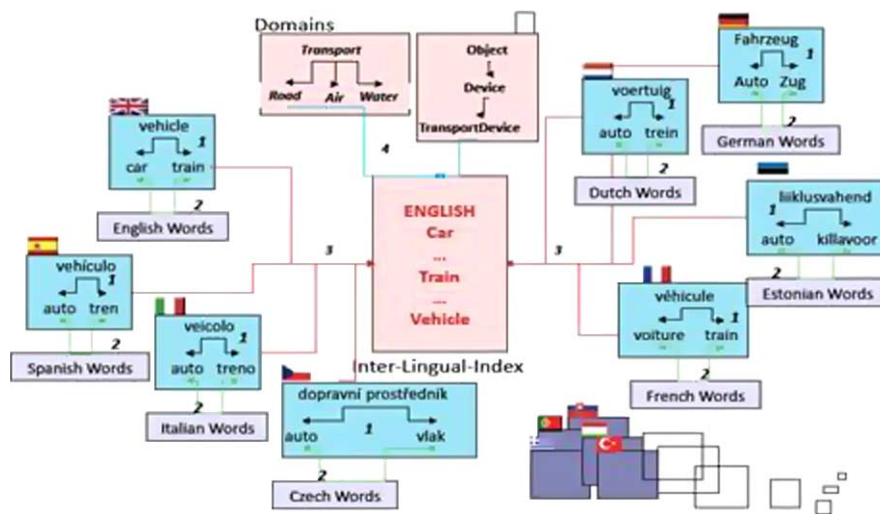


Fig. 1. Example of WN as “interlingua” (Fellbaum, 2012; acknowledgement to Piek Vossen for the image). (Colors are visible in the online version of the article; <http://dx.doi.org/10.3233/AO-130121>.)

The question whether it is possible to build a universal lexical model, for which all words from different languages are interconnected, is still open. Even if it is demonstrated that languages with the same or similar etymological origin share similarities (e.g. Indo-European languages), we are far from having a completed and comprehensive ontology working as an “interlingua” (see Fig. 1). Its existence would undoubtedly foster inferencing and automatic reasoning in keeping with the goals of logicians and others working on knowledge representation or data management.

7. Conclusion

Ontology is a very old branch of philosophy, usually accounted as the *science of being*, i.e. it is interested in pure existence, in order to find an account of what exists and which conditions must be satisfied by all that exist. In Husserl’s terms, ontology is both formal, because it investigates the fundamental structures of entities independently from any specific domain of reality, and material, because it provides a list of categories (of being) with the purpose of describing the existence of specific entities in specific portions of reality. Ontology can be formalized by the means of a formal logical language, with the explicit purpose to develop a *language of being*, i.e. a way to capture the most general features of what exists while taking the benefits of modern symbolic logics.

For some time already, the theories of formal philosophical ontology have been applied to the sciences for the management of large, semantically heterogeneous silos of data from different sources. This application has motivated the emergence of the applied ontology or ontological engineering.

Summing up the different talks given during the workshop, we have shown in this report that the job of applied ontologists is that to create reusable modules of knowledge that can be implemented in information systems to facilitate human communication from the one side, and to improve human-machine interaction from the other side (while also addressing semantic interoperability and data integration issues). However, representing knowledge is a very difficult job. Conceptual modeling is essentially meta-modeling, an inherently ontological exercise; this higher-order abstraction strives to turn implicit knowledge explicit. Scientists need to deal (at least) with people’s assumptions about the world, their

needs for using computational tools and the way they use natural languages. Therefore, it seems obvious that an engineering discipline cannot by itself do the whole job and fulfill all purposes.

Philosophical ontology has a very long tradition, and it is undeniable that its formal theories (mereology, topology, the theory of participation, the theory of dependence, etc.) have many benefits. In fact, applied ontology may enable philosophy to be genuine in Lowe's (2006) sense, investigating categories of metaphysical possibility rather than controlling for consistency in definitions. Besides its metaphysical approach, philosophical analysis intertwines with ontological practice in providing a methodological framework for computational purposes (Merrill, 2010; Smith & Ceusters, 2010). Clearly, philosophy by itself cannot say anything about empirical investigations (although it may help in determining the scientific agenda), just as computer science cannot say anything about the relation between a whole object and its parts, or the ontological dependence of a quality from its bearer. Conceptual modeling's validity can be improved by formal language, but even the mere application of logical formal languages is not enough. Knowledge representation formalisms can only suggest how to represent knowledge in a syntactically correct and semantically sound way for computational purposes. But here again, there is nothing in logic which is able to suggest us what kind of thing is an object, or what kind of ontological relation exists between a continuant (endurant) and an occurrent (perdurant).

Nevertheless, computer scientists are sometimes sceptical about the relation between their engineering tasks/needs and the philosophical insights about ontological problems. However, this is not always the case. The workshop organized by the International Association for Applied Ontology had the great benefit of promoting an interdisciplinary approach to applied ontology. It pushed the idea that insights from different areas – philosophy, linguistics, conceptual-modelling, cognitive science and logics – are necessary for the representation of human knowledge (about “reality”) in computational models. The challenge of defining a set of real-world categories to be applied to articulate conceptualization of different domains of reality can take several benefits from the exploitation of an interdisciplinary approach, one that is not trouble by but rather views as beneficial the identities and methods of contrasting insights to the reality.

Ontological analysis plays a key role in this entire process. Indeed, if engineering-related tasks are not combined with well-founded ontological theories about the ontological types that are assumed to exist in the investigated reality, there is little chance of arriving at sound computational representations.

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References

- Baader, F. et al. (2007). *The Description Logic Handbook. Theory, Implementation and Application* (2nd edn). Cambridge: Cambridge University Press.
- Bhattacharyya, P. (2010). IndoWordNet. In *Lexical Resources and Evaluation Conference LREC*, Malta. Available at: www.cse.iitb.ac.in/~pb/papers/lrec2010-indowordnet.pdf.
- Bittner, T. & Donnelly, M. (2005). *Computational Ontologies of Parthood, Componenthood, and Containment*. In L. Kaelbling (Ed.), *Proceedings of the Nineteenth International Joint Conference on Artificial Intelligence 2005 (IJCAI05)*, Edinburgh, Scotland (pp. 382–387).
- Bittner, T. & Donnelly, M. (2007). Logical properties of foundational relations in bioontologies. *Artificial Intelligence in Medicine*, 39(3), 197–216.

- Burek, P. (2006). *Ontology of Functions A Domain-Independent Framework*. PhD thesis. Leipzig: University of Leipzig.
- Dupré, J. (1981). Natural kinds and biological taxa. *Philosophical Review*, 90(1), 66–90.
- Fellbaum, C. (Ed.) (1998). *WordNet: An Electronic Lexical Database*. Cambridge, MA: MIT Press.
- Fellbaum, C. (2006). Wordnet and wordnets. In Brown, K. (Ed.), *Encyclopedia of Language and Linguistics* (2nd edn.; Vol. 13, pp. 665–670). Elsevier.
- Fellbaum, C. (2012). *Ontology, Lexicon and Cognitive Science*. Slide presentation at the First Interdisciplinary Summer School on Ontological Analysis, July 16–20, 2012, Trento. Available at: <http://iaoa.org/isc2012/courses.php>.
- Fellbaum, C. & Vossen, P. (2012). Challenges for a multilingual wordnet. *Language Resources and Evaluation*, 46(2), 313–326.
- Giere, R. (2010). An agent-based conception of models and scientific representation. *Synthese*, 172(2), 269–281.
- Gruber, T. (1993). A translation approach to portable ontology specifications. *Knowledge Acquisition*, 5(2), 199–220.
- Guarino, N. (1998a). Some ontological principles for designing upper level lexical resources. In A. Rubio, N. Gallardo, R. Castro and A. Tejada (Eds.), *First International Conference on Language Resources and Evaluation* (pp. 527–534). European Language Resources Association.
- Guarino, N. (1998b). Formal ontology and information system. In N. Guarino (Ed.), *Formal Ontology in Information Systems*. Frontiers in Artificial Intelligence and Applications (pp. 3–15). Amsterdam: IOS Press.
- Guarino, N. (2012). *Introduction to Applied Ontology and Ontological Analysis*. Slide presentation at the First Interdisciplinary Summer School on Ontological Analysis, July 16–20, 2012, Trento. Available at: <http://iaoa.org/isc2012/courses.php>.
- Guarino, N. & Musen, M.A. (2005). Applied Ontology: Focusing on content, *Applied Ontology*, 1, 1–5.
- Guizzardi, G. (2005). *Ontological Foundations for Structural Conceptual Models*. PhD thesis. University of Twente.
- Guizzardi, G. (2007). Modal aspects of object types and part-whole relations and the de re/de dicto distinction. In J. Krogstie, G. Sindre & A. Opdahl (Eds.), *Proceedings of the 19th international conference on Advanced information systems engineering (CAiSE'07)* (pp. 5–20). Springer.
- Guizzardi, G. (2012). *Ontology-Driven Conceptual Modeling*. Slide presentation at the First Interdisciplinary Summer School on Ontological Analysis, July 16–20, 2012, Trento. Available at: [http://iaoa.org/isc2012/docs/IAOA-Introduction_\(Day%201\).pdf](http://iaoa.org/isc2012/docs/IAOA-Introduction_(Day%201).pdf).
- Hicks, A. & Herold, A. (2011). Cross-lingual evaluation of ontologies with Rudify. In A. Fred, J.L.G. Dietz et al. (Eds.), *Knowledge Discovery, Knowledge Engineering and Knowledge Management. Communication in Computer and Information Science*. Berlin, New York: Springer.
- Hicks, A. (2012). *The KYOTO Project*. Slide presentation at the First Interdisciplinary Summer School on Ontological Analysis, July 16–20, 2012, Trento. Available at: <http://iaoa.org/isc2012/courses.php>.
- Huang, C.-R. et al. (2010). *Ontology and the Lexicon*. Cambridge University Press: Cambridge.
- Ingarden, R. (1964). *Time and Modes of Being*. Springfield, Illinois: Charles C. Thomas.
- Jansen, L. (2009). Classifications. In K. Munn & B. Smith (Eds.), *Applied Ontology: An Introduction* (pp. 159–172). Frankfurt: Ontos Verlag.
- Knuuttila, T. (2011). Modelling and representing: An artefactual approach to model-based representation. *Studies In History and Philosophy of Science Part A*, 42(2), 262–271.
- Lowe, E.J. (2006). *The Four Category Ontology – A Metaphysical Foundation for Natural Science*. Oxford University Press: Oxford.
- Masolo, C., Borgo, S., Gangemi, A., Guarino N. & Oltramari, A. (2003). WonderWeb Deliverable D18: Ontology Library, ISTC-CNR, Trento, Italy.
- Merrill, G.H. (2010). Ontological realism: Methodology or misdirection? *Applied Ontology*, 5(2), 79–108.
- Miller, G.A. (1995). WordNet: A lexical database for English. *Communications of the ACM*, 38(11), 39–41.
- Munn, K. & Smith, B. (2009). *Applied Ontology an Introduction*. R.M. Elisabeth, J. Seibt & D. von Wachter (Eds.), *Applied Ontology*, 342. Ontos Verlag. Retrieved from <http://www.worldcat.org/oclc/234368809>.
- Mylopoulos, J. (1992). Conceptual modeling and Telos. In P. Loucopoulos and R. Zicari (Eds.), *Conceptual Modeling, Databases, and CASE* (Chap. 2, pp. 49–68). Wiley.
- Smith, B. (1998). The basic tools of formal ontology. In N. Guarino (Ed.), *Formal Ontology in Information Systems Amsterdam*. Frontiers in Artificial Intelligence and Applications (pp. 19–28). Amsterdam: IOS Press.
- Smith, B. & Ceusters, W. (2010). Ontological realism: A methodology for coordinated evolution of scientific ontologies. *Applied Ontology*, 5(3), 139–188.
- Tufis, D. & Barbu, A. (2001). Extracting multilingual lexicons from parallel corpora. In *Proceedings of the ACH/ALLC* (pp. 122–124). New York University.
- Tufis, D., Cristea D. & Stamu, S. (2004a). Balkanet: aims, methods, results and perspectives. A general overview. *Romanian Journal on Science and Technology of Information*, 7(3,4), 9–44. (Special Issue on BalkaNet.)
- Tufis, D., Ion, R. & Ide, N. (2004b). Wordsense disambiguation as a wordnet’s validation method in Balkanet. In *Proceedings of the LREC 2004* (pp. 741–744). Lisbon.
- Varzi, A.C. (2005). *Ontologia*. Roma-Bari: Laterza.

- Varzi, A.C. (2010). On the Boundary between Material and Formal Ontology. In: B. Smith, R. Mizoguchi, & S. Nakagawa (Eds.), *Interdisciplinary Ontology*, 3, 3–8.
- Vossen, P., Bloksma, L., Climent, S., Marti, M.A., Oreggioni, G., Escudero, G., Rigau, G., Rodriguez, H., Roven-tini, A., Bertagna, F., Alonge, A., Peters, C. & Peters, W. (1998). The Restructured Core wordnets in EuroWordNet: Subset 1, EuroWordNet (LE2-4003) D014D015, University of Amsterdam, Amsterdam. Available at www.vossen.info/docs/1998/D021D25.pdf.
- Vossen, P. et al. (2008). KYOTO: A system for mining, structuring and distributing knowledge across languages and cultures. In *LREC 2008 Proceedings*.