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Formal Ontology, Conceptual Analysis and Knowledge Representation

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Abstract

The purpose of this paper is to defend the systematic introduction of *formal* ontological principles in the current practice of knowledge engineering, to explore the various relationships between ontology and knowledge representation, and to present the recent trends in this promising research area. According to the "modelling view" of knowledge acquisition proposed by Clancey, the modeling activity must establish a correspondence between a knowledge base and two separate subsystems: the agent's behavior (i.e. the problem-solving *expertize*) and its own environment (the problem *domain*). Current knowledge modelling methodologies tend to focus on the former subsystem only, viewing domain knowledge as strongly dependent on the particular task at hand: in fact, AI researchers seem to have been much more interested in the nature of reasoning rather than in the nature of the real world. Recently, however, the potential value of task-independent knowlege bases (or "ontologies") suitable to large scale integration has been underlined in many ways.

In this paper, we compare the dichotomy between reasoning and representation to the philosophical distinction between *epistemology* and *ontology.* We introduce the notion of the *ontological level,* intermediate between the epistemological and the conceptual level discussed by Brachman, as a way to characterize a knowledge representation formalism taking into account the *intended meaning* of its primitives. We then discuss some formal ontological distinctions which may play an important role for such purpose.

1. Introduction

In the tradition of AI, knowledge is defined in a strictly functional way [Newell 1982]. If an external observer is able to ascribe to an agent some goal (finding food, clearing an obstacle) and if the same observer sees that this agent is going about achieving its goals in systematic, rational fashion, then the observer ascribes knowledge to it. Using Newell's words, knowledge is "whatever can be ascribed to an agent, such that its behavior can be computed according to the principle of rationality". The relevant evaluative criterion for knowledge base thus conceived is not truth but functional utility, utility in relation to the goals ascribed to the agent.

Recently, Clancey proposed to shift such a perspective, arguing that "the primary concern of knowledge engineering is modelling systems *in the world*, not replicating how people think" [Clancey 1993, p. 34, our emphasis]. Clancey is a defender of the *modelling view* of knowledge acquisition, according to which a knowledge base is not a repository of knowledge extracted from one expert's mind (as in the *transfer view*), but the result of a modeling activity whose object is the observed behavior of an intelligent agent embedded in an external environment. A similar position is held in [Gaines 1993, Schreiber *et al.* 1993, Gruber 1994].

As the content of a knowledge base refers to an objective reality instead of an agent's "mind", it seems clear that – according to the modelling view – knowledge is much more related to the classical notion of truth intended as correspondence to the real world, and less dependent on the particular way an intelligent agent pursues its goals. More exactly, the modeling activity must establish a correspondence between a knowledge base and two separate subsystems: the agent's behavior (i.e. the problem-solving *expertize*) and its own environment (the problem *domain*). However, current knowledge modelling methodologies tend to focus on the former subsystem, viewing domain knowledge as strongly dependent on the particular task at hand: for instance, in their recent book on KADS methodology, Breuker, Schreiber, and Wielinga explicitly state:

> We prefer to use the term "schema" rather than "ontology" to stress the fact that the domain theory is the product of knowledge engineering and thus does not necessarily describe an inherent structure in the domain (as the word "ontology" would suggest). [Wielinga *et al.* 1993, p. 23]

The potential benefits of such a position are evident, since only *relevant* domain knowledge is taken into consideration; however, if such relevant knowledge is not considered as *part* of the objective reality of the domain, the very basic assumptions of the modeling view are contradicted: if a domain theory does not describe (partially, of course) "an inherent structure in the domain", what is it supposed to represent? Arguably, the agent's mind, which was exactly what the modeling view aimed to avoid.

A further reason for considering domain analysis as a task-independent activity comes from communication concerns: as Clancey underlines, we are often dealing with whole communities of diverse agents who must interact and communicate in different ways and in relation to widely different sorts of tasks; in this case, such interaction will be facilitated to a greater degree the closer a knowledge base approximates the truth as classically conceived. Finally, knowledge modelling is notoriously a very expensive process: recent initiatives like DARPA's Knowledge

Sharing Effort [Neches *et al.* 1991] have underlined the opportunity of increasing the *quality* of formalized bodies of knowledge in such a way that it is possible to share and reuse at least parts of them for a variety of different purposes. Within such a perspective, knowledge can in principle acquire a value *per se*. The more shareable, we might say, the better (and truth in the classical sense is a sort of infinite shareability [Smith 1995]).

In conclusion, a knowledge base will acquire a value per se, only to the extent that the knowledge it contains is in fact true, such as to correspond to the world beyond the knowledge-base. Therefore, the study of *ontology*, intended as a branch of philosophy dealing with the *a priori* nature of reality, can be of benefit to the knowledge-construction process in yielding high-value knowledge bases.

In the past, ontological issues have been rather neglected in classical AI research. In the field of “theoretical” knowledge representation, such kinds of philosophical interests have been almost confined to very specific topics such as granularity [Hobbs 1985] and existential assumptions [Hobbs 1985, Hirst 1991]. In other areas of AI, some interest in ontology has been shown in the past in natural language understanding [Hobbs *et al.* 1987, Bateman *et al.* 1990, Klose *et al.* 1992], and knowledge acquisition [Alexander *et al.* 1986, Monarch and Nirenburg 1987, Wimmer and Wimmer 1992, Paton *et al.* 1993]. In the latter field, ontological issues have recently gained some popularity due to the knowledge sharing initiative [Neches *et al.* 1991, Musen 1992, Gruber 1993, Gruber 1994, Pirlein and Studer 1994]; it should be noticed, however, that in the knowledge sharing community the term "ontology" tends to be used more to denote the content of a particular (top-level) knowledge base rather than to indicate a scientific discipline or a methodology. Finally, ontological principles have been also advocated in the field of object-oriented database design [Wand and Weber 1990, Takagaki and Wand 1991, Bonfatti and Pazzi 1994].

Apart from the notable exceptions discussed in the present paper, AI researchers seem to have been much more interested in the nature of reasoning rather than in the nature of the real world. This tendency has been especially evident among the disciples of the so-called logicist approach: in their well-known textbook on AI, Genesereth and Nilsson [Genesereth and Nilsson 1987, p. 13] explicitly state the “essential ontological promiscuity of AI”, and devote to the issue of *conceptual modelling* just a couple of pages, admitting however that is still a serious open problem.

One of the reasons of the lack of interest towards ontology in classical AI research lies in the fact that problems like ontology and conceptual modelling need to be studied under a *highly interdisciplinary* perspective: besides the basic tools of logic and computer science, an open-minded aptitude towards the subtle distinctions of philosophy and the intricate issues of natural language and commonsense reality is in our opinion necessary.

Unfortunately, the three major proposals which have addressed in a general way the problems of real world modelling within the logicist paradigm, namely [Hayes 1985, Lenat and Guha 1990, Davis *et al.* 1993], suffer in our opinion from a relatively narrow perspective. More or less, they have concentrated on the immediate needs of the AI practice, refusing to take (explicitly) into account the philosophical achievements coming from the study of commonsense reality and natural language phenomena. For instance, Hayes writes that (p. 5)

> It is not proposed to find a philosophically exciting reduction of all ordinary concepts to some special collection of concepts [...]. Maybe such reduction will eventually turn out to be possible. I think it extremely unlikely and not especially desirable, but whether or not it is, is not the present issue. *First* we need to formalize the naive worldview, using whatever concepts seem best suited to that purpose...

Davis is well aware of the relationships between commonsense reality, linguistics and philosophy (p. 14-16; 22-24), but he believes that the objectives and methodologies of AI are substantially different from those of such disciplines, and this seems a good reason to ignore most of their achievements (see [Smith 1994]); finally, Lenat and Guha address the problems of a large-scale representation of commonsense world by using an extremly *ad-hoc* approach largely based on heuristics and introspection, where the ignorance of potential contributions coming from other disciplines is testimonied by the scarcety of the bibliography cited (see also [Stefik and Smoliar 1993]).

The purpose of this paper is to defend the systematic introduction of *formal* ontological principles in the current practice of knowledge engineering, to explore the various relationships between ontology and knowledge representation, and to present the recent trends in this promising research area.

2. Epistemology vs. Ontology in Knowledge Representation

Epistemology can be defined as “the field of philosophy which deals with the nature and sources of knowledge” [Nutter 1987]. The usual logistic interpretation is that knowledge consists of *propositions*, whose *formal structure* is the source of new knowledge. The inferential aspect seems to be essential to epistemology (at least for what concerns the sense that this term assumes in AI): the study of the “nature” of *knowledge* is limited to its superficial meaning (i.e., the *form*), since it is mainly motivated by the study of the inference process.

Ontology, on the other side, can be seen as the study of the organisation and the nature of the *world* independently of the form of our knowledge about it. *Formal* ontology has been recently defined as “the systematic, formal, axiomatic development of the logic of all forms and modes of being” [Cocchiarella 1991]. Although the genuine interpretation of the term "formal ontology" is still a matter of debate [Poli 1994], this definition is in our opinion particularly pregnant, as it takes into account *both* the meanings of the adjective "formal": on one side, this is synonymous of "rigorous", while on the other side it means "related to the *forms* of being". Therefore, what formal ontology is concerned in is not so much the bare existency of certain individuals, but rather the rigorous description of their *forms*. In practice, formal ontology can be intended as the theory of *a priori distinctions:*

- among the entities of the world (physical objects, events, regions, quantities of matter...);
- among the meta-level categories used to model the world (concepts, properties, qualities, states, roles, parts...).

In its current shape, formal ontology can be seen as the confluence between a school of thought which has addressed metaphysical problems within the mainstream of analytic philosophy, and another school more closely related to phenomenology, in the tradition of Brentano and Husserl. The former school includes a multitude of philosophers, which roughly agree on the idea of "descriptive metaphysics" proposed by Strawson [Strawson 1959, Aune 1991]. The latter sees the philophers of the so-called "school of Manchester" [Smith 1982, Smith and Mulligan 1983, Simons 1987, Mulligan 1992] as its principal defenders. A fundamental role is played in formal ontology by *mereology* (the theory of the part-whole relation) and *topology* (intended as the theory of the connection relation). Despite the possibility for these two theories to collapse one in the other in the case of a purely extensional domain limited to spatial or temporal entities, they need to be kept separate in order to characterize an entity independently of its spatio-temporal extension [Varzi 1994]. A standard reference for such issues is [Simons 1987], which presents in an accessible way the original formalizations of mereology made by Lesniewski and Goodman, discussing their limits and their possible extensions[1].

Let us focus now on the role played by epistemological and ontological issues in KR formalisms. The contribution of structured representation languages as KL-ONE [Brachman and Schmolze 1985] was to give an "epistemological" foundation to cognitive structures like frames and semantic networks, whose formal contradictions

[1] For a general reference on metaphysical issues, see also [Burkhardt and Smith 1991]

had been revealed by Woods in his famous "What's in a Link?" paper [Woods 1975]. Brachman's answer to Woods' question was that links should be *epistemological links* instead of *conceptual links*, in the sense that they have to describe the (minimal) formal structure of a concept needed to guarantee "formal inferences about the relationship (subsumption) between a concept and another" [Brachman 1979]. No constraints are imposed on such a formal structure, and the intended meaning of concepts remains therefore totally arbitrary. Emphasis is more on *formal reasoning* than on (formal) *representation:* the very task of representation, i.e. the structuring of a domain, is left to the user.

This dichotomy between formal reasoning and representation is pretty similar to the one between epistemology (indended as study of the forms of knowledge) and formal ontology (intended as the study of the forms of being) discussed above. Since from the first years of AI, such a dichotomy has been noticed by various people, but their concerns have been largely ignored due to the explosion of academic interest on the "reasoning" side, and to some disillusionments as for the early attempts to formalize commonsense reality [McDermott 1987, McDermott 1993]. Woods stated very clearly that the careful specification of the semantics of elementary propositions was extremely important for AI:

> Philosophers have generally stopped short of trying to actually specify the truth conditions of the basic atomic propositions, dealing mainly with the specification of the meaning of complex expressions in terms of the meanings of elementary ones. Researchers in artificial intelligence are faced with the need to specify the semantics of elementary propositions as well as complex ones. [Woods 1975, p. 40-41]

Hayes emphasized the need to focus on knowledge content, not only on knowledge form as common practice in academic AI. He insisted on the importance of a priori, task-independent conceptual analyis, in order to avoid to "get caught into conceptual traps" due to a lack of breadth and depth in the analysis of a domain.

> I will bet that there are more representational languages, systems and formalisms developed by AI workers in the last ten years than there are theories to express in them. This is partly because of the pressure to implement [...], but is also due to a widespread feeling that the *real* scientific problems are concerned with how to represent knowledge rather than with what the knowledge is. [Hayes 1985, p. 34]

In their seminal paper "On the Taxonomy of Part-Whole Relations", Winston, Chaffin and Herrmann also deplore the focus on logical form alone:

> Our interest in distinguishing between different types of relations runs counter to a long tradition in logic in which it has been found productive to ignore differences among semantic relations and to focus on logical form alone. Traditional accounts of syllogistic reasoning, for instance, found it

convenient to assimilate all forms of predication to class membership. For example, “G is regretful” was treated as “G is a member of the class of regretful people”. [Winston *et al.* 1987, p. 439, our italics]

Finally, Guha and Lenat stress the necessity to "bite the bullet" of real-world KR:

The majority of work in knowledge representation has been concerned with the technicalities of relating predicate calculus to other formalisms, and with the details of various schemes for default reasoning. There has been almost an aversion to addressing the problems that arise in actually representing large bodies of knowledge with content. The typical AI researcher seems to consider that task to be ‘just applications work’. But there are deep, important issues that must be addressed if we are to ever have a large intelligent knowledge-based program: What ontological categories would make up an adequate set for carving up the universe? How are they related? What are the important things most humans today know about solid objects? And so on. In short, we must *bite the bullet*. [LenatGuha 1990, p. xvii, our italics]

3. New Trends in the Formal Representation of Commonsense Reality

We think that there can be answers to the problems mentioned in Lenat's quotation above which are different from the brute force of “biting the bullet”. In fact, a new school of thought is slowly emerging in the AI community, which aims to a logical formalization of commonsense reality[1] based on a rigorous characterization of fundamental ontological categories such as those regarding space, time, and structure of physical objects. The main common trait of the researchers involved in such an enterprise is the *strong interdisciplinary aptitude*, especially towards philosophy, linguistics and cognitive science. Such a broader aptitude makes possible – in our opinion – a significant methodological improvement with respect to the approaches taken by Hayes, Davis or Lenat, which although it may apparently complicate some problems, surely benefits from the advantages of a well-founded ground.

One of the first forerunners of such tendency in AI was a work by Hobbs and colleagues bearing the significative title "Commonsense Metaphysics and Lexical Semantics" [Hobbs *et al.* 1987], which integrated Hayes' ideas with some recent trends in lexical semantics. Despite the strong aptitude towards the interdisciplinary problems of natural language, the paper lacks to acknowledge the contribution of philosophy to the study of commonsense reality: what Hobbs calls "Commonsense Metaphysics" is not different from Strawson's program of "Descriptive

[1] To be considered as separated from commonsense *reasoning*; see [Israel 1985].

Metaphysics".

Recently, the consideration shown by AI researchers for such philosophical issues began to increase, mostly due to three independent contributions appeared in the last decade. First, the ideas of formal ontology acquired interest in the eighties thanks to the active research work made in this area by the "school of Manchester" mentioned above. Second, Clarke proposed an axiomatic characterization of mereology based on the topological relation of "connection" [Clarke 1981], which inspired subsequent fruitful applications in the area of spatial reasoning. Finally, Winston, Chaffin and Herrmann [Winston *et al.* 1987] discussed various criteria of ontological classification of semantic relations on the basis of cognitive considerations, with particular attention to the case of part-whole relations.

Clarke's ideas, suitably modified in order to avoid difficulties such as the distinction between open and closed regions, have been exploited by Randell, Cohn and colleagues in order to model various cases of spatial reasoning [Randell and Cohn 1989, Randell and Cohn 1992, Randell *et al.* 1992, Gotts 1994, Cohn *et al.* 1995]. They propose a taxonomy of spatial relations among regions analogous to the one introduced by Allen for temporal relations, and present some efficient algorithms to reason about that.

Clarke's approach is being also used by researchers belonging to the "Space, Time and Movement" group in Toulose, which however are interested in modelling natural-language phenomena involving phyisical objects, and not spatial regions only. In [Aurnague and Vieu 1993], topological and mereological primitives are mixed together, arguing for a stratified architecture based on three levels (geometric, functional and pragmatic). Within the same group in Toulouse, [Sablayrolles 1993] uses Clarke's approach in order to represent the semantics of expressions of motion .

At the university of Hamburg, Eschenbach and Heydrich are studying the relationships between mereology, intended as a general theory of parts and wholes, and restricted domains such as those of sets, topological regions or temporal intervals; on this basis, they reconstruct Clarke's axiomatization of topology using "part-of" as a primitive instead of connection [Eschenbach and Heydrich 1993]. Gerstl and Pribbenow [Gerstl and Pribbenow 1993] are working on the cognitive aspects of the part-whole relation, comparing formal mereology with the approach proposed by Winston and colleagues. Finally, Simmons is studying the relationships between parts and spatial shapes [Simmons 1994].

In Italy, the importance to keep separate mereology from topology has been extensively discussed by in [Casati and Varzi 1994, Varzi 1994]; in Pianesi and Varzi 1994] such distinction has been exploited in order to model the ontological structure of events, while [Franconi 1993] adopts a mereological approach to characterize plural references in natural language. Ontological tools have been adopted in the area of object-oriented databases [BonfattiPazzi 1994], and of medical knowledge modelling [Steve and Gangemi 1994].

The new trends discussed above have all in common the use of ontological and linguistic analysis to model commonsense reality, focusing on particular aspects of such reality; the general relationships between formal ontology and commonsense are discussed in [Smith and Casati 1993]. In the remaining sections, I shall briefly present my own approach, which is centered on the idea of exploiting ontological principles to impact the knowledge representation process *itself*, independently of a particular aspect of the reality.

4. The Ontological Level: Formalizing Ontological Commitment

On the Neutrality of First-Order Logic

First order logic is notoriously neutral with respect to ontological choices. This is one of its strengths, which shows the power of general ideas like completeness and soundness. However, ontological neutrality is not an advantage any more when applied to KR theories or languages: in this case, such formalisms should reflect the *a priori* structure of the real world, and the ontological choices made by the user.

Indeed, most KR formalisms add to first-order logic certain kinds of structures - frames, objects, modules, etc. - designed to capture some interrelations between pieces of knowledge which could not be smoothly captured by pure first-order logic. KR formalisms which are modular in this respect are not only more easily understood, they also have the property that they can be more easily maintained, and they can be shown to have a greater computational efficiency. Moreover, such a modular structure facilitates different sorts of abstraction which can in turn allow for a greater economy of representation.

Take for instance a KL-ONE-like language: concepts and roles offer a powerful *knowledge-structuring* mechanism, whose meaning was intended to reflect important cognitive assumptions. Yet, in contrast to their original purposes, the semantics of these languages is such that concepts and roles correspond to *arbitrary* unary or binary predicates, independently of any ontological commitment about: (i) the meaning of (primitive) concepts; (ii) the meaning of roles; (iii) the nature of each role's contribution to the meaning of a concept [Guarino 1992].

What is needed is a way to constrain and to make explicit the *intended models* of a KR language, in order to facilitate large-scale knowledge integration and to limit the possibility to state something that is reasonable for the system but not reasonable in the real world. We can do that by giving a meta-level characterisation of the language primitives in terms of their ontological nature. For instance, *Brick* and *VerticalClearance* may both be roles of an arch [BrachmanSchmolze 1985], but their nature is different, since the former is a functional component while the latter is a quality. Such ontological nature can be expressed by means of conceptual categories like *concept, role, attribute, part, property, quality, state, event, process, action*... They should be given an axiomatic (or semantic) characterisation, which – though possibly incomplete with respect to the intended semantics – can actually restrict the set of models, approximating that of the intended ones.

The ontological level

When a KR formalism is constrained in such a way that its intended models are made explicit, it can be classified as belonging to the *ontological level* [Guarino 1994]. To better understand such a notion, let us re-visit the distinctions introduced in [Brachman 1979], where KR languages have been classified according to the kinds of primitives offered to the user. We propose the introduction of a further level – the *ontological level* – intermediate between the epistemological and the conceptual one (Fig. 1).

Level	Primitives	Interpretation	Main feature
Logical	Predicates, functions	Arbitrary	Formalization
Epistemological	Structuring relations	Arbitrary	Structure
Ontological	***Ontological relations***	***Constrained***	***Meaning***
Conceptual	Conceptual relations	Subjective	Conceptualization
Linguistic	Linguistic terms	Subjective	Language dependency

Fig. 1. Classification of KR formalisms according to the kinds of primitives used.

At the (first order) *logical* level, the basic primitives are predicates and functions, which have given a formal semantics in terms of relations among objects of a domain. No particular assumption is made however on the nature of such relations, which are completely general and content-independent. The logical level is the level of *formalization*:: it allows for a formal interpretation of the primtives, but their interpretation is however totally arbitrary.

The *epistemological level* has been introduced by Brachman in order to fill the gap between the logical level, where primitives are extremely general[1], and the conceptual level, where they acquire a specific intended meaning that must be taken as

[1] We do not refer to a single predicate, but to the very notion of predicate used as a primitive...

a whole, without any account of its internal structure. He proposed the introduction of a language situated at an intermediate level, where the primitives allow us to specify "the formal structure of conceptual units and their interrelationships *as conceptual units* (independent of any knowledge expressed therein)" [Brachman 1979, p. 30]. In other words, while the logical level deals with abstract predicates and the conceptual level with *specific* concepts, at the epistemological level the *generic* notion of a concept is introduced as a *knowledge structuring primitive*. Concepts themselves – which correspond to unary predicates at the logical level – have an internal structure, as they "bundle" together further concepts or binary relations (roles). The epistemological level is therefore the level of *sructure*. As mentioned before, a language defined at this level is perfectly equivalent to its logical level counterpart; however, a *theory* built in this language should be considered as different from the corresponding “flat” logical theory, since it implicitly assumes some structuring choices which may have cognitive and computational significance, and reflects a number of ontological commitments which accumulate in layers from the very beginning of a knowledge base development process [Davis *et al.* 1993].

At the *ontological level*, such ontological commitments associated to the language primitives are specified explicitly. Such a specification can be made in two ways: either by suitably restricting the semantics of the primitives, or by introducing meaning postulates expressed in the language itself. In both cases, the goal is to restrict the number of possible interpretations, characterizing the meaning of the basic ontological categories used to describe the domain: the ontological level is therefore the level of *meaning*. Of course such a characterization will be in general incomplete, and the result will be an *approximation* of the set of intended models. Moreover, not any formal language will be suitable to such a task: we say that a language is *ontologically adequate* if either (i) at the syntactic level, it has enough granularity and reification capabilities to express the meaning postulates of its own primitives; or (ii) at the semantic level, it is possible to give a formal ontological interpretation to its basic primitives. An example of a formalism that exhibits these characteristics is ITL [Guarino 1991]. As discussed in detail in [Guarino *et al.* 1994b], it is also possible to express the meaning postulates in a language richer than the original one, whose only purpose is the restriction of the original semantics in order to exclude non-intended models. These postulates may also be put together as a separate, reusable theory, to form what is usually called "an ontology" [Guarino and Giaretta 1995].

At the *conceptual* level, primitives have a definite cognitive interpretation, corresponding to language-independent concepts like elementary actions or thematic roles. The skeleton of the domain structure is already given, independently of an explicit account of the underlying ontological assumptions. Within a certain application domain, the user is forced to express knowledge in the form of a specialisation of this skeleton. Commonly used ontologies like the PENMAN upper model [Bateman 90] belong to this level. Notice that they may or may not be accompanied by an explicit account at the ontological level.

Finally, primitives at the *linguistic* level directly refer to verbs and nouns.

Let us explain the introduction of an independent ontological level with a simple example. Suppose we have to represent a red ball. At the *logical level*, a plausible representation may be $\exists x.\ Ball(x) \wedge Red(x)$. At the *epistemological level*, supposing to adopt a KL-ONE-like language, we have to decide what is a concept and what is (the filler of) a role. A good choice may be to consider *Ball* as a concept and *Red* as a filler of a *Color* role. The *result* of this decision can be expressed by a suitable (meta-linguistic) definition mechanism, like the ones used in KIF [Genesereth and Fikes 1991]. However, since the ontological assumptions underlying the meaning of concepts and roles are not made explicit, nothing prevents another user to adopt a different choice: for instance, both *Ball* and *Red* may be considered as concepts, with no role at all. If we want to improve knowledge sharing and reuse, we should be able to somehow restrict the set of possible choices.

A possible solution is to go to the *ontological level*., where terms like *role* and *concept* have a formal, standard interpretation. Such an interpretation may forbid *Red* to be a concept according to the sense of "red" that we have in mind, making clear the ontological assumptions involved in this choice.

Another solution may be to go directly to the *conceptual level*, with the introduction of a pre-defined set of concepts and roles we agree on, which may represent a “standard” for our mini-domain. However, our chances of getting such an agreement and controlling the disciplined development of applications depend in this case on the *principles* we have adopted for the definition of our basic ontological categories; therefore, the solution of the conceptual level (equivalent to the adoption of “off the shelf” ontologies) can be viewed as a successful one only if it builds on a well-defined ontological level. Notice that the necessity of well-founded principles is much more relevant if we want to further specialize logical relations into categories like parts, qualities, properties, states and so on.

5. Ontological Distinctions among Logical Relations

Structuring vs. Non-Structuring Relations

At the ontological level, a central issue is the distinction between the logical relations which contribute to the taxonomic structure of the domain and those which don’t, providing instead additional information on already identified objects. Let us call the former *structuring relations*, and the latter *non-structuring relations*. In this respect, no standard terminology exists in KR formalisms. Unary structuring relations are usually called *concepts*, *kinds* or *types*, and binary structuring relations are called *roles*, *attributes* or *slots*. Non-structuring unary relations are called *(assertional) properties* or sometimes *qualities*, while non-structuring binary relations are usually called *constraints*.

Let us now imagine to begin building a knowledge base starting from a “soup” of various logical relations of different arities: how do we decide whether a relation is a structuring one? Notice that its *arity* doesn’t help us that much, since we may have unary relations like *Closed*, *Broken*, *Red*, *Metallic* which are not usually associated to concepts, as well as binary relations like *GreaterThan*, *ToTheRightOf* which are not usually associated to roles. Consider for instance the two unary relations *Apple* and *Large*, and the two binary relations *Weight* and *GreaterThan*: we cannot explain why assuming *Large* as a concept, or *GreaterThan* as a role, could result in a bad choice.

A preliminary solution to these problems has been presented in [Guarino 1992], where various distinctions have been drawn among unary and binary predicates on the basis of ontological and linguistic considerations. A more refined classification of unary predicates appears in [Guarino *et al.* 1994a], where a formalization of Strawson's distinction between *sortal* and *non-sortal* predicates [Strawson 1959] is proposed. According to Strawson, a sortal predicate (like *apple*) "supplies a principle for distinguishing and counting individual particulars which it collects", while a non-sortal predicate (like *red*) "supplies such a principle only for particulars already distinguished, or distinguishable, in accordance with some antecedent principle or method"[1]. This distinction seems therefore suitable to capture the difference between concepts and properties existing in the KR practice, which has always been acknowledged by advocates of the logicist approach:

> There is to be one tree for kinds of things and another for qualities of things. Kinds must be distinguished from qualities: being a cat must be distinguished (in kind, no doubt) from being red [Israel 1983].

In order to formalize such a distinction, we have introduced in [Guarino *et al.* 1994a] three meta-level properties aimed to characterize the ontological nature of unary predicates, namely *countability*, *temporal stability* and *ontological rigidity*. They have been defined by extending the original representation language with a modal, mereo-topological framework, which will not be discussed here[2]. Briefly, a

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[1]This distinction is (roughly) reflected in natural language by the fact that sortal predicates correspond to common nouns, while non-sortal predicates correspond to adjectives and verbs; the issue is also related to the semantic difference between count and non-count (or mass) terms.

[2] See [Guarino *et al.* 1994] for a general discussion on the importance to extend a representation language in order to formalize its ontological commitment.

predicate is *countable* if, whenever it holds for an object x, it does not hold for a *connected* part of x. This is a refinement of a countability criterion proposed in [Griffin 1977], with "connected part" substituted to "part". In this way, a predicate like *PieceOfWood* (which is uncountable according to Griffin since a part of a piece of wood is still a piece of wood) can be considered as countable if we assume that only a *detached* part of a piece of wood is itself a piece of wood. A predicate is *temporally stable* if, whenever it holds for an object at a time, then it must hold for the same object at another time. According to [Givón 1979], noun-predicates like *Student* are temporally stable, while verbal forms like *Studies* are not. A predicate will be a *sortal predicate* if it is both countable and temporally stable; in our proposal, unary structuring predicates (i.e., concepts) must all be sortals.

Within sortal predicates, a further distinction is made between *substantial sortals* like *Apple* and *non-substantial sortals* like*Student*, formally capturing some ideas proposed in [Wiggins 1980]. To this purpose, we have introduced the notion of *ontological rigidity:* a predicate is ontologically rigid if, whenever it holds for an object, it *must* hold for that object in any possible world. In other words, if an object has a rigid property, it cannot lose this property without losing its identity: an apple cannot cease to be an apple while still remaining the same object, while a student can easily have a temporary existence as a student. Substantial sortals are ontologically rigid, and they correspond to what in KR terms may be called *types*; non-substantial sortals are non-rigid, and they correspond to what have been called *role-types* [Sowa 1988].

Such distinctions have three main purposes. First, they allow the knowledge engineer to make clear the *intended meaning* of a particular predicate symbol. This is especially important since we are constantly using natural language words for predicate symbols, relying on them to make our statements readable and to convey meanings not explicitly stated. However, since words are ambiguous in natural language, it may be important to “tag” these words with a semantic category, in association with a suitable axiomatisation, in order to guarantee a consistent interpretation[1]. This is unavoidable, in our opinion, if we want to share theories across different domains.

A second important advantage of clear ontological distinctions is the possibility of a *methodological foundation* for deciding between the various representation choices offered by a KR formalism: for example, within a hybrid terminological framework, for deciding whether a predicate should go in the TBox or ABox, or how a KL-ONE role should be related to a correponding concept.

1 Notice that we do not mean that the user is forced to accept some *one* fixed interpretation of a given word: simply, we want to offer some instruments to help specifying the intended interpretation.

Formal Ontology and Reasoning

Finally, it is important to notice that formal ontological distinctions not only affect the "static" interpretation of a knowledge base in order to approximate its intended semantics, but they may also impact the *reasoning services* offered by a KR formalism. For example, a terminological reasoner may take advantage of the fact that some kinds of concepts form a tree, while in general they do not [Sowa 1988]; it may maintain indices for instances of concepts but not for instances of properties; it may provide domain-checking facilities for properties but not for concepts[1].

Most interesting, it is possible to control the process of updating a knowledge base on the basis of ontological considerations. As discussed in [Katsuno and Mendelzon 1991], an update differs from a generic revision process since it "consists of bringing the knowledge base up to date when the world described by it changes". In this case, it seems natural to exclude from such a process those beliefs which express our basic ontological assumptions: in other words, if a given logical theory is a faithful representation of a particular state of the world, when such a state changes we should only consider for revision those beliefs which depend on the world state, while keeping those which remain true in all intended models. The explicit account of the notion of ontological commitment discussed in [Guarino *et al.* 1994b] offers a way to specify such intended models, and therefore it allows us to individuate such set of invariant beliefs.

As an example, let us suppose that the following theory is true at a time t:

A: Pen(a)
B: Functions(a)
C: $\mathrm{Pen}(x) \wedge \mathrm{Functions}(x) \supset \mathrm{Writes}(x)$

Suppose now that $\neg\mathrm{Writes}(a)$ is true at a time t'; what of the assertions A, B, C should be retract in order to avoid the inconsistency of our theory? If, as part of the ontological commitment of the underlying language, we state that *Pen* is a rigid predicate and C is a meaning postulate for what a pen is, then we have that both A and C must hold in any intended model, and therefore only B can be retracted in order to maintain consistency.

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1 The last two examples are due to Bob MacGregor. It seems reasonable to offer the user a reasoning service which is quicker in checking whether an individual is an instance of a concept rather than in verifying one of its properties; moreover, assuming that any individual belongs to a concept, it may be easy to check the inconsistency of a property assertion regarding a new individual, while this cannot be done in case of a concept assertion.

Conclusions

In conclusion, I would like to underline again the necessity of a strongly interdisciplinary perspective within the KR community. I hope to have shown that disciplines like philosophy and linguistic can offer a concrete contribution to the everyday practice of knowledge engineering, as they seem to shed some new light to a crucial AI problem like the representation of commonsense reality. In this respect, it may be interesting to report the following quotation from Drew McDermott:

> Those were the good old days. I remember them well. Naive Physics. Ontology for Liquids. Commonsense Summer. [...] Wouldn't it be neat if we could write down everything people know in a formal language? Damn it, let's give a shot! [...] If we want to be able to represent *anything*, then we get further and further from the practicalities of frame organization, and deeper and deeper into the quagmire of logic and philosophy. [McDermott 1993]

I believe that this quagmire is well worthwhile getting into.

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Bibliography

Alexander, J. H., Freiling, M. J., Shulman, S. J., Staley, J. L., Rehfus, S., and Messick, S. L. 1986. Knowledge Level Engineering: Ontological Analysis. In *Proceedings of AAAI 86*. Philadelphia: 963-968.

Aune, B. 1991. Metaphysics of Analytic Philosophy. In H. Burkhardt and B. Smith (eds.), *Handbook of Metaphysics and Ontology*. Philosophia, Munich: 539-543.

Aurnague, M. and Vieu, L. 1993. A Three Level Approach to the Semantics of Space. In C. Z. Wibbelt (ed.) *The Semantics of Preposition: From Mental Processing to Natural Language Processing.* Mouton de Gruyter, Berlin: 393-439.

Bateman, J. A., Kasper, R. T., Moore, J. D., and Whitney, R. A. 1990. A General Organization of Knowledge for Natural Language Processing: the PENMAN upper model. USC/Information Sciences Institute, Marina del Rey, CA.

Bonfatti, F. and Pazzi, L. 1994. Ontological Foundations of Object State and Identity. In this volume.

Brachman, R. J. 1979. On the Epistemological Status of Semantic Networks. In N. V. Findler (ed.) *Associative Networks: Representation and Use of Knowledge by Computers*. Academic Press: 3-50.

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

Burkhardt, H. and Smith, B. (eds.) 1991. *Handbook of Metaphysics and Ontology*. Philosophia, Münich.

Clancey, W. J. 1993. The Knowledge Level Reinterpreted: Modelling Socio-Technical Systems. *International Journal of Intelligent Systems*, **8**: 33-49.

Clarke, B. L. 1981. A Calculus of Individuals Based on "Connection". *Notre Dame Journal of Formal Logic*, **22**: 204-18.

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

Cohn, A. G., Randell, D. A., and Cui, Z. 1995. Taxonomies of Logically Defined Qualitative Spatial Relations. In this volume.

Davis, R., Shrobe, H., and Szolovits, P. 1993. What is in a Knowledge Representation? *AI Magazine*(Spring 1993): 17-33.

Eschenbach, C. and Heydrich, W. 1993. Classical Mereology and Restricted Domains. In this volume.

Franconi, E. 1993. A Treatment of Plurals and Plural Quantifications based on a Theory of Collections. *Minds and Machines*, **3**: 453-474.

Gaines, B. 1993. Modeling as Framework for Knowledge Acquisition Methodologies and Tools. *International Journal of Intelligent Systems*, **8**: 155-168.

Genesereth, M. R. and Fikes, R. 1991. Knowledge Interchange Format, Version 3.0 Reference Manual. Computer Science Department, Stanford University, June 1991.

Genesereth, M. R. and Nilsson, N. J. 1987. *Logical Foundation of Artificial Intelligence.* Morgan Kaufmann, Los Altos, California.

Gerstl, P. and Pribbenow, S. 1993. Midwinters, End Games, and Bodyparts: A Classification of Part-Whole Relations. In this volume.

Givón, T. 1979. *On Understanding Grammar.* Academic Press, New-York.

Gotts, N. M. 1994. How Far Can We "C"? Defining a "Doughnut" Using Connection Alone. In J. Doyle, E. Sandewall and P. Torasso (eds.), *Principles of Knowledge Representation and Reasoning: KR 94.* Morgan Kaufmann, San Francisco (CA): 246-257.

Griffin, N. 1977. *Relative Identity.* Oxford University Press, Oxford.

Gruber, T. 1994. Toward Principles for the Design of Ontologies Used for Knowledge Sharing. In this volume.

Gruber, T. R. 1993. A translation approach to portable ontology specifications. *Knowledge Acquisition*, **5**: 199-220.

Guarino, N. 1991. A Concise Presentation of ITL. In H. Boley and M. M. Richter (eds.), *Processing Declarative Knowledge.* Springer Verlag: 141-160.

Guarino, N. 1992. Concepts, Attributes and Arbitrary Relations: Some Linguistic and Ontological Criteria for Structuring Knowledge Bases. *Data & Knowledge Engineering*, **8**: 249-261.

Guarino, N. 1994. The Ontological Level. In R. Casati, B. Smith and G. White (eds.), *Philosophy and the Cognitive Science*. Hölder-Pichler-Tempsky, Vienna.

Guarino, N., Carrara, M., and Giaretta, P. 1994a. An Ontology of Meta-Level Categories. In J. Doyle, E. Sandewall and P. Torasso (eds.), *Principles of Knowledge Representation and Reasoning: Proceedings of the Fourth International Conference (KR94)*. Morgan Kaufmann, San Mateo, CA: 270-280.

Guarino, N., Carrara, M., and Giaretta, P. 1994b. Formalizing Ontological Commitment. In *Proceedings of National Conference on Artificial Intelligence (AAAI-94)*. Seattle, Morgan Kaufmann.

Guarino, N. and Giaretta, P. 1995. Ontologies and Knowledge Bases: Towards a Terminological Clarification. In N. Mars (ed.) *Towards Very Large Knowledge Bases: Knowledge Building and Knowledge Sharing 1995*. IOS Press, Amsterdam: 25-32.

Hayes, P. 1985. The Second Naive Physics Manifesto. In J. R. Hobbs and R. C. Moore (eds.), *Formal Theories of the Commonsense World*. Ablex, Norwood, New Jersey: 1-36.

Hirst, G. 1991. Existence Assumptions in Knowledge Representation. *Artificial Intelligence*, **49**: 199-242.

Hobbs, J. R. 1985. Granularity. In *Proceedings of IJCAI 85*: 432-435.

Hobbs, J. R. 1985. Ontological Promiscuity. In *Proceedings of ACL 85*: 61-69.

Hobbs, J. R., Croft, W., Davies, T., Douglas, E., and Laws, K. 1987. Commonsense Metaphysics and Lexical Semantics. *Computational Linguistics*, **13**: 241-250.

Israel, D. 1983. Interpreting Network Formalisms. *International Journal of Computers and Mathematics*, **9**(1).

Israel, D. 1985. A Short Companion of the Naive Physics Manifesto. In J. R. Hobbs and R. C. Moore (eds.), *Formal Theories of the Commonsense World*. Ablex, Norwood, NJ.

Katsuno, H. . and Mendelzon, A. 1991. On the difference between updating a kb and revising it. In *Proceedings of KR*: 387.

Klose, G., Lang, E., and Pirlein, T. 1992. *Ontologie und Axiomatik der Wissensbasis von LILOG.* Springer-Verlag, Berlin.

Lenat, D. and Guha, R. V. 1990. *Building Large Knowledge-Based Systems*. Addison-Wesley, Reading, MA.

McDermott, D. 1987. A Critique of Pure Reason. *Computational Intelligence*, **3**:

151-160.
McDermott, D. 1993. Review to D. B. Lenat and R. V. Guha, Building Large Knowledge-Based Systems: Representation and Inference in the Cyc Project. *Artificial Intelligence*, **61**: 53-63.
Monarch, I. and Nirenburg, S. 1987. The Role of Ontology in Concept Acquisition for Knowledge-Based Systems. In J. Boose, T. Addis and B. Gaines (eds.), *Proceedings of EKAW-87*. University of Reading.
Mulligan, K. (ed.) 1992. *Language, Truth and Ontology*. Kluwer, Dordrecht.
Musen, M. A. 1992. Dimensions of Knowledge Sharing and Reuse. *Computers and Biomedical Research*, **25**: 435-467.
Neches, R., Fikes, R., Finin, T., Gruber, T., Patil, R., Senator, T., and Swartout, W. R. 1991. Enabling Technology for Knowledge Sharing. *AI Magazine*(fall 1991).
Newell, A. 1982. The Knowledge Level. *Artifical Intelligence*, **18**: 87-127.
Nutter, J. T. 1987. Epistemology. In S. Shapiro (ed.) *Encyclopedia of Artificial Intelligence*. John Wyley.
Paton, R. C., Nwana, H. S., Shave, M. J. R., Bench-Capon, T. J. M., and Hughes, S. 1993. Foundations of a Structured Approach to Characterising Domain Knowledge. *To appear in Cognitive Systems*.
Pirlein, T. and Studer, R. 1994. An Environment for Reusing Ontologies within a Knowledge Engineering Approach. In this volume.
Poli, R. 1994. Bimodality of Formal Ontology and Mereology. In this volume.
Randell, D. A. and Cohn, A. G. 1989. Modelling Topological and Metrical Properties in Physical Process. In R. J. Brachman, H. J. Levesque and R. Reiter (eds.), *Principles of Knowledge Representation and Reasoning. Proceedings of the First International Conference*. Morgan Kaufmann, Los Altos: 357-68.
Randell, D. A. and Cohn, A. G. 1992. A Spatial Logic Based on Regions and Connections. In B. Nebel, C. Rich and W. Swartout (eds.), *Principles of Knowledge representation and Reasoning. Proceedings of the Third International Conference*. Morgan Kaufmann, Los Altos: 165-76.
Randell, D. A., Cui, Z., and Cohn, A. G. 1992. An Interval Logic of Space Based on 'Connection'. In B. Neumann (ed.) *10th European Conference on Artificial Intelligence (ECAI-92)*. John Wiley & Sons, Chichester: 394-98.
Sablayrolles, P. 1993. A Two-Level Semantics for French Expression of Motion. DFKI Research Report RR-93-12, March 1993.
Schreiber, G., Wielinga, B., and Breuker, J. 1993. *KADS: A Principled Approach to Knowledge-Based System Development.* Academic Press, London.
Simmons, G. 1994. Shapes, Part Structures and Object Concepts. In *Proceedings of ECAI-94 Workshop on "Parts and Wholes: Conceptual Part-Whole Relationships and Formal Mereology"*. Amsterdam.
Simons, P. 1987. *Parts: a Study in Ontology*. Clarendon Press, Oxford.

Smith, B. (ed.) 1982. *Parts and Moments: Studies in Logic and Formal Ontology*. Philosophia Verlag, München.

Smith, B. 1994. Review of "Ernest Davis: Representations of Commonsense Knowledge". *Minds and Machines*, **4**: 245-249.

Smith, B. 1995. Formal Ontology, Commonsense and Cognitive Science. In this volume.

Smith, B. and Casati, R. 1993. Naive Physics: an Essay in Ontology. *Philosophical Psychology*, **?**

Smith, B. and Mulligan, K. 1983. Framework for Formal Ontology. *Topoi*, **2**: 73-85.

Sowa, J. F. 1988. Using a lexicon of canonical graphs in a semantic interpreter. In M. W. Evens (ed.) *Relational models of the lexicon*. Cambridege Univerity Press.

Stefik, M. J. and Smoliar, S. W. 1993. The Commonsense Reviews - Eight reviews of: "Douglas Lenat and R. V. Guha, Building Large Knowledge-Based Systems: Representations and Inference in the CYC Project, Addison-Wesley 1990 ", and "Ernest Davis, Representations of Commonsense Knowledge, Morgan Kaufmann 1990". *Artificial Intelligence*, **61**: 37-179.

Steve, G. and Gangemi, A. 1994. Ontological Analysis for Medical Knowledge Organisation Systems. In *Proceedings of 12th International Congress of the European Federation for Medical Informatics (MIE 94)*. Lisboa.

Strawson, P. F. 1959. *Individuals. An Essay in Descriptive Metaphysics.* Routledge, London and New York.

Takagaki, K. and Wand, Y. 1991. An Object-Oriented Information Systems Model Based on Ontology. In F. Van Assche, B. Moulin and C. Rolland (eds.), *Object Oriented Approach in Information Systems*. Elsevier Science Publishers: 275-296.

Varzi, A. 1994. On the Boundary Between Mereology and Topology. In R. Casati, B. Smith and G. White (eds.), *Philosophy and the Cognitive Science*. Hölder-Pichler-Tempsky, Vienna.

Wand, Y. and Weber, R. 1990. An Ontological Model of an Information System. *IEEE Transactions On Software Engineering*, **16**(11): 1282-1292.

Wielinga, B., Schreiber, G., and Breuker, J. 1993. Modelling Expertise. In G. Schreiber, B. Wielinga and J. Breuker (eds.), *KADS: A Principled Approach to Knowledge-Based System Development.* Academic Press, London.

Wiggins, D. 1980. *Sameness and Substance.* Blakwell, Oxford.

Wimmer, K. and Wimmer, N. 1992. Conceptual Modelling Based on Ontological Principles. *Knowledge Acquisition*, **4**: 387-406.

Winston, M., Chaffin, R., and Herrmann, D. 1987. A Taxonomy of Part-Whole Relations. *Cognitive Science*, **11**: 417-444.

Woods, W. A. 1975. What's in a Link: Foundations for Semantic Networks. In D. G. Bobrow and A. M. Collins (eds.), *Representation and Understanding:*

Studies in Cognitive Science. Academic Press: 35-82.