Ontologies and Knowledge Bases

Towards a Terminological Clarification

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ABSTRACT

The word "ontology" has recently gained a good popularity within the knowledge engineering community. However, its meaning tends to remain a bit vague, as the term is used in very different ways. Limiting our attention to the various proposals made in the current debate in AI, we isolate a number of interpretations, which in our opinion deserve a suitable clarification. We elucidate the implications of such various interpretations, arguing for the need of clear terminological choices regarding the technical use of terms like "ontology", "conceptualization" and "ontological commitment". After some comments on the use "Ontology" (with the capital "o") as a term which denotes a philosophical discipline, we analyse the possible confusion between an ontology intended as a particular conceptual framework at the knowledge level and an ontology intended as a concrete artifact at the symbol level, to be used for a given purpose. A crucial point in this clarification effort is the careful analysis of Gruber' s definition of an ontology as a specification of a conceptualization.

1 Introduction[1]

The word "ontology" has recently gained a good popularity within the knowledge engineering community, especially in relation with the recent ARPA knowledge sharing initiative [14, 11, 13, 4, 6, 7, 12]. However, its meaning tends to remain a bit vague, as the term is used in very different ways. Limiting our attention to the various proposals made in the current debate within the knowledge sharing community, we can isolate the different interpretations reported in Fig. 1 below, which in our opinion deserve a suitable clarification.

1. Ontology as a philosophical discipline
2. Ontology as a an informal conceptual system
3. Ontology as a formal semantic account
4. Ontology as a specification of a "conceptualization"
5. Ontology as a representation of a conceptual system via a logical theory
   - 5.1 characterized by specific formal properties
   - 5.2 characterized only by its specific purposes
6. Ontology as the vocabulary used by a logical theory
7. Ontology as a (meta-level) specification of a logical theory

Figure 1: Possible interpretations of the term "ontology".

The interpretation 1 is radically different from all the others, and its implications are discussed in the next section. The current debate regards the interpretations 2-7: 2 and 3 conceive an ontology as a conceptual "semantic" entity, either formal or informal, while according to the interpretations 5-7 an ontology is a specific "syntactic" object. The interpretation 4, which has been recently proposed as a *definition* of what an ontology is for the AI community [4, 5], is one of the more problematic, and it will be discussed in detail in the present paper. It may be classified as "syntactic" but its precise meaning depends on the understanding of the terms "specification" and "conceptualization".

According to interpretation 2, an ontology is the (unspecified) conceptual system which we may assume to underly a particular knowledge base. Under interpretation 3, instead, the "ontology" which underlies a knowledge base is expressed in terms of suitable formal structures at the semantic level, like for instance those described in [8, 17].In both cases, we may say

[1]Slightly amended version of a paper appeared in N.J.I. Mars (ed.), *Towards Very Large Knowledge Bases, IOS Press 1995, Amsterdam*

"the ontology of KB1 is different from that of KB2".

Under interpretation 5, an ontology is nothing else than a logical theory. The issue is whether such a theory needs to have particular formal properties in order to be an ontology (for instance, we may impose it must be a "Tbox") or, rather, it is the intended purpose which lets us consider a logical theory as an ontology. The latter position is being supported for instance by Pat Hayes, which in recent e-mail discussions argued that an ontology is an annotated and indexed set of formal assertions about something: "leaving off the annotations and indexing, this is a collection of assertions: what in logic is called a *theory*".

According to interpretation 6, an ontology is not viewed as a logical theory, but just as the vocabulary used by a logical theory. Such an interpretation collapses into 5.1 if an ontology is thought of as a *specification* of a vocabulary consisting of a set of logical definitions. We may anticipate that interpretation 4 collapses into 5.1, too, when a conceptualization is intended as a vocabulary; we shall see however that the problem is how to make clear the meaning of the term "conceptualization".

Finally, under interpretation 7, an ontology is seen as a (meta-level) specification of a logical theory, in the sense that it specifies the "architectural components" (or "primitives") used within a particular domain theory. This point of view is maintained in [18] and, in slightly different form, in [10]. Wielinga and colleagues argue that it is the ontology which specifies, for a theory where some formulas have the form of mathematical constraints, what a constraint is and how it differs from a formula of another kind; Mark argues that an ontology is "a representation of components and their allowed interactions, with the purpose of providing an explicit framework in which to elaborate the rest of the system..."

We shall try to elucidate in this paper the implications of such various interpretations, arguing for the need of clear terminological choices regarding the *technical* use of terms like "ontology", "conceptualization" and "ontological commitment" within the knowledge engineering community. First we propose to use "Ontology" (with the capital "o") as a term denoting a philosophical discipline, then we analyse a number of possible senses of the term "ontology" (with the lowercase "o") where the term is somehow related to specific knowledge bases (or logical theories) designed with the purpose of expressing shared (or sharable) knowledge.

A starting point in this clarification effort will be the careful analysis of the interpretation 4 adopted by Gruber. The main problem with such an interpretation is that it is based on a notion of conceptualization (introduced in [3]) which doesn't fit our intuitions, as has been noticed in [8]: according to Genesereth and Nilsson, a conceptualization is a set of *extensional* relations describing a particular *state of affairs*, while the notion we have in mind is an intensional one, namely something like a conceptual grid which we superimpose to various possible states of affairs. We propose in this paper a revised definition of a conceptualization which captures this intensional aspect, while allowing us to give a satisfactory interpretation to Gruber's definition.

2 Ontology and Ontologies

The first important distinction in the list of interpretations given in the previous section is between interpretation 1 and all the others. We stipulate that when we refer to *an* ontology (with the indeterminate article and the lowercase initial) we refer to a particular determinate object (whose nature may vary in dependence of the choice among interpretations 2-7), while speaking of Ontology (without the indeterminate article and with the uppercase initial) we refer to a philosophical discipline, namely that branch of philosophy which deals with the nature and the organisation of reality. Ontology as such is usually contrasted with Epistemology, which deals with the nature and sources of our knowledge[2].

Aristotle defined Ontology as the science of being as such: unlike the special sciences, each of which investigates a class of beings and their determinations, Ontology regards "all the species of being *qua* being and the attributes which belong to it *qua* being" (Aristotle, *Metaphysics*, IV, 1). In this sense Ontology tries to answer to the question: *What is being?* or, in a meaningful reformulation: *What are the features common to all beings?*

This is what nowadays one would call *General* Ontology, in contrast with the various *Special* or *Regional* Ontologies (of the Biological, the Social, etc.). This distinction corresponds to the Husserlian one between Formal Ontology and Material Ontology [1]. But the Husserlian notion of "formal" does not involve only generality. For Husserl, the task of Formal Ontology is to determine the conditions of the possibility of the object in general and the individuation of the requirements that every object's constitution has to satisfy.

Recently, Nino Cocchiarella defined Formal Ontology as *the systematic, formal, axiomatic development of the logic of all forms and modes of being* [2]. The connection of Cocchiarella's definition with the Husserlian notion is not clear, and, in general, the genuine interpretation of the term "formal ontology" is still a matter of debate [16]. However, Cocchiarella's definition is in our opinion particularly pregnant, as it takes into account *both* 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 existence of certain objects, but rather the rigorous description of their *forms of being*, i.e. their structural features. In practice, Formal Ontology can be intended as the theory of the distinctions, which can be applied independently of the state of the world, i.e. the distinctions:

[2]This definition of "epistemology" is taken from Shapiro's "Encyclopedia of Artificial Intelligence" [15]. Regrettably, the entry "ontology" does not appear there. The philosophical community prefers to use the term "theory of knowledge" for what is here called "epistemology".

- among the entities of the world (physical objects, events, regions, quantities of matter...);
- among the meta-level categories used to model the world (concept, property, quality, state, role, part...).

In this sense, Formal Ontology, as a discipline, may be relevant to both Knowledge Representation and Knowledge Acquisition [7].

3 Kinds of Ontologies

Let us now refine the technical meaning of the word "ontology" when — within the knowledge engineering community – it is used to denote a particular object rather than a discipline. Here a possible confusion arises between an ontology intended as a particular conceptual framework at the semantic level (interpretations 2-3) and an ontology intended as a concrete artifact at the syntactic level, to be used for a given purpose (interpretations 4-7). This is an important distinction, and it is evident that we cannot use the same *technical* term to denote both things. In the current practice, however, the term "ontology" is used ambiguously with both meanings, either to refer to (various kinds of) symbol-level artifacts, or to their conceptual (or semantical) counterparts[3]. Therefore, rather than insisting on a unique precise meaning for such a term, what we propose is to adopt different technical terms to refer explicitly to the two levels, while tolerating an ambiguity in the interpretation of the term "ontology" (with the lowercase initial). We shall use the term *conceptualization* to denote a semantic structure which reflects a particular conceptual system (interpretation 3 in Fig. 1), and *ontological theory* to denote a logical theory intended to express ontological knowledge (interpretation 5). The underlying intuition is that ontological theories are designed artifacts, knowledge bases of a special kind which can be read, sold or physically shared. Conceptualizations, on the other hand, are the semantical counterpart of ontological theories. The same ontological theory may *commit* to different conceptualizations, as well as the same conceptualization may underlie different ontological theories. The term "ontology" will be used ambiguously, either as synonym of "ontological theory" or as synonym of "conceptualization". We need only to be consistent to the choice made within the same statement.

The details of the definitions mentioned above are the subject of the subsequent sections; for the time being, the meaning of statements like those listed in Fig 2 should however be clear enough under the assumptions we have made. In 1-4, the term "ontology" has a clear syntactic interpretations; the interpretation of statement 5 will be discussed later.

4 Kinds of Conceptualizations

Let us notice first that the use of the term "ontology" as related to an ontological theory is compatible with

[3]The most common use is however the former one.

1. Ontological engineering is a branch of knowledge engineering which uses Ontology to build ontologies.
2. Ontologies are special kinds of knowledge bases.
3. Any ontology has its underlying conceptualization.
4. The same conceptualization may underlie different ontologies.
5. Two different knowledge bases may commit to the same ontology.

Figure 2: Different statements making use of the term "ontology".

Tom Gruber's definition of an ontology as "an explicit specification of a conceptualization", since it should be clear that an "explicit" object is a concrete, symbol-level object. The problem with Gruber's definition, however, is that it relies on an extensional notion of "conceptualization" [3] which, while being compatible with the preliminary characterization given in the previous section, does not fit our purposes of defining what an ontology is. We have already pointed to this problem in [9] ; we shall discuss it here in detail, proposing an alternative, intensional definition of "conceptualization" which satisfies our needs.

Let us consider the example given by Genesereth and Nilsson. They take into account a situation where two piles of blocks are resting on a table (Fig 3). According to the authors, a possible conceptualization of this scene is given by the following structure:

$$\langle \{a, b, c, d, e\}, \{\textit{on, above, clear, table}\} \rangle$$

where $\{a, b, c, d, e\}$ is a set called the *universe of discourse*, consisting of the five blocks we are interested in, and $\{\textit{on, above, clear, table}\}$ is the set of the relevant relations among these blocks, of which the first two, *on* and *above*, are binary and the other two, *clear* and *table*, are unary[4]. The authors make clear that objects and relations are extensional entities. For instance, the *table* relation, which is understood as holding of a block if and only if that block is resting on the table, is but the set $\{c, e\}$. It is exactly such an extensional interpretation which originates our troubles.

Let us notice first that the authors used natural language terms (like *on, above*) in the metalanguage chosen to describe a conceptualization. This could perhaps be seen as nothing more than a didactical device. But such linguistic terms do convey essential information in order to understand the criteria used to consider some sets of tuples as the *relevant* relations. Such an extra information cannot be accounted for by the conceptualization itself.

Referring to the example given, consider a different arrangement of blocks, where c is on the top of d, while

[4]In the original example also a function is considered, but for simplicity reasons we omit here to mention functions as a further element in the characterization of a conceptualization.

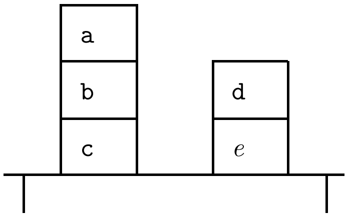

Figure 3: Blocks on a table. From [3].

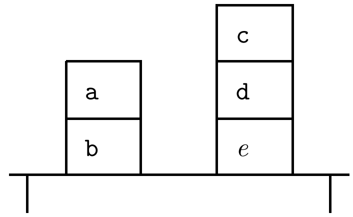

Figure 4: A different arrangement of blocks. A different conceptualization?

a and b together form a separate stack standing on the table (Fig. 4). The corresponding structure would be different from the previous one, generating therefore a different conceptualization. Of course there is nothing wrong in such a view, if one is only interested in isolated snapshots of the block world. But the meanings of the terms used to denote the relevant relations are still the same, since they are invariant with respect to the possible configurations of blocks. In fact, in the metalanguage adopted in their book, Genesereth and Nilsson would use the same terms (*on, above, clear, table*) to denote the new conceptualization. We prefer to say in this case that the states of affairs are different, but the conceptualization is the same. The structure proposed by Genesereth and Nilsson seems to be more apt to represent a *state of affairs* rather than a conceptualization.

In order to capture such intuitions, the linguistic terms we have used to denote the relevant relations cannot be thought of as mere comments, informal extra-information. Rather, the formal structure used for a conceptualization should somehow account for their *meaning*. As the logico-philosophical literature teaches us, such a meaning cannot coincide with an extensional relation.

Sticking to a set-theoretical framework, a standard way to approximate such meaning is to conceive it as an intension (*intensional relation*), taking inspiration from Montague semantics. This means that a single extensional relation is always relative to a possible world[5].

Formally, an intensional relation of arity n on a domain D is a function from a set W of possible worlds to the set 2^{D^n} of all possible n-ary relations on D. Such a function specifies a set of admissible extensions, relative to the domain and the set of possible worlds considered. This means that not only the extension in the actual world, but also those relative to the other possible worlds are specified. We can therefore represent a conceptualization by the following *intensional structure*:

$$\langle W, D, R \rangle$$

where W is a set of possible worlds, D is a domain of objects, and R is a set of intensional relations on D.

According to this intensional interpretation, a conceptualization accounts for the intended meanings of the terms used to denote the relevant relations. Such meanings are supposed to remain the same if the actual extensions of the relations change due to different states of affairs. This means that, for instance, the actual extensions of the relation *on* in the two examples of Fig. 3 and 4 belong to the image of the *same* intensional relation, applied to different worlds. Intuitively, we can see a conceptualization as given by a set of rules constraining the structure of a piece of reality, which an agent uses in order to isolate and organize relevant objects and relevant relations: the rules which tell us whether a certain block is *on* another one remain the same, independently of the particular arrangement of the blocks. These rules can be viewed as conceptual links which put together different extensions belonging to the same intensional relation.

Notice that, given a set of relevant relations specified by linguistic terms like those of our example, there will be in general many conceptualizations of the form given above which satisfy the natural constraints we can attach to the meaning of such expressions. As shown in [8] , a convenient modal theory can be used to give an *approximate characterization* of such intended meaning, with the aim of excluding deviant extensions. For example, we can express the intuitive constraint that a tuple like $< a, a >$ should never belong to the extension of the relation specified by the word "*on*" by stating

$$\Box\ \forall x. \neg on(x, x)$$

Another interesting constraint which may be useful to characterize a unary relation like *block* (not mentioned by Genesereth and Nilsson) is that such a relation can be never "lost" by its instances, i.e. if it

[5]Roughly, we can think of possible worlds like states of affairs or situations.

holds of an object, it holds of that object in all possible worlds:

$$\Box\ (\forall x.block(x) \supset \Box\ block(x))$$

Such a constraint has been called "ontological rigidity" in [8], and has been used to discriminate among various ontological categories of unary relations.

A set of formal constraints like those above, expressed in a suitable modal language, can therefore be used to (partially) *characterize* a conceptualization, in the sense of excluding unintended extensions of the relevant relations even for possible "worlds" different from the one considered. Notice that in general we cannot identify a *single* conceptualization by means of a set of formal constraints, since such a set may have many models. The set of such models is exactly what in [9] we defined as *ontological commitment*[6].

According to these considerations, we cannot see a particular theory as a *specification* of a conceptualization, since conceptualizations can be only partially characterized. What we can specify is a *set* of conceptualizations, i.e. an ontological commitment.

5 A Simple Example

Having discussed in detail the various implications underlying the notion of conceptualization, let us now use a simple example to see how such a semantic notion can be related to syntactic objects like logical theories. Consider the following logical theory:

$T1:$

$$\forall x.apple(x) \supset fruit(x).$$
$$\forall x.pear(x) \supset fruit(x).$$

$$apple(a1).$$
$$red(a1)$$

If we want to isolate the ontological content of such a theory, we can try to individuate, among its axioms, those which we consider to be more strictly related to the intrinsic intended meanings of the predicates used in the language. For example, the following axioms (which are usually related to what is called the *Tbox*) may be intended as capturing part of the meaning of *apple, pear* and *fruit* :

$T2:$

$$\forall x.apple(x) \supset fruit(x).$$
$$\forall x.pear(x) \supset fruit(x).$$

We shall call a set of such axioms an *ontological theory.* An ontological theory contains formulas which are considered to be always true (and therefore *sharable* among multiple agents), independently of particular states of affairs. Formally, we can say that such formulas must be true in every possible world.

An ontological theory like the one above characterizes very roughly the ontological content of the theory from which it is extracted. To better grasp such a content, we should look at the intended conceptualization underlying both T1 and T2, which models (in a much finer way) the ontologically relevant aspects of the *language* used by our initial theory. According to the discussion made in the previous section, such a conceptualization can be *characterized* (in an approximate way) by a suitable modal theory T3. The formulas (theorems) of T2 will be true in every possible world belonging to the intended conceptualization, and therefore will appear as necessary formulas in T3; furthermore, T3 may contain other formulas capturing necessary facts not captured by T2. For the present example, we choose a very simple theory like the following:

$T3:$

$$\Box(\forall x.apple(x) \supset fruit(x)).$$
$$\Box(\forall x.pear(x) \supset fruit(x)).$$
$$\Box(\forall x.apple(x) \supset \Box\ apple(x)).$$
$$\Box(\forall x.pear(x) \supset \Box\ pear(x)).$$
$$\Box(\forall x.fruit(x) \supset \Box\ fruit(x)).$$
$$\neg\Box(\forall x.red(x) \supset \Box\ red(x)).$$

Such a theory expresses some very general constraints on the meaning of our predicates, namely the fact that *apple, pear* and *fruit* form a hierarchy, and that they are "rigid", differently from *red.* We say that T3 is the *specification of the ontological commitment* of T1.

Notice that the same information carried by T3 can be expressed by a meta-level theory, whose domain is given by the nonlogical symbols used in T1. For instance, we can write:

$T4:$

$$apple \leq fruit.$$
$$pear \leq fruit.$$
$$rigid(apple).$$
$$rigid(pear).$$
$$rigid(fruit).$$
$$\neg rigid(red).$$

Such a theory can be usefully adopted as an alternate specification of an ontological commitment, assuming of course that the meaning of predicates like $\leq$ and *rigid* is such that T4 can be immediately converted into T3 by means of suitable translation rules.

6 What Is An Ontology

Let us now go back to our original problem of clarifying the meaning of "ontology". Our goal is to propose a choice among the interpretations 2-7 of Fig. 1, and to give a precise sense to at least some of the statements

[6] In that paper we did not introduce intensions as ingredients of our semantical structures, adopting instead standard modal models. Here we choose a different approach which seems to be better suited to the perspective we want to present.

listed in Fig 2. In the light of the discussion developed so far, we shall restrict our choice to three possible technical senses of the word "ontology".

In sense a), "ontology" is a synonym of "ontological theory". In this case statements 1-4 in Fig 2 have a unique interpretation, while statement 5 means that the two knowledge bases may have a common subtheory, which is an ontological theory. This choice is consistent with interpretation 5 in Fig. 1. As discussed in the previous section, an ontological theory differs from an arbitrary logical theory (or knowledge base) by its semantics, since all its axioms must be true in every possible world of the underlying conceptualization. This means that while an arbitrary logical theory (containing for instance a statement like $apple(a) \vee pear(a)$, expressing uncertainty about the object a) may represent a particular epistemic state, an ontological theory can be only used to represent common knowledge independent from single epistemic states. Due to this formal difference between an ontological theory and an arbitrary logical theory, interpretation 5.2 is therefore discarded in favour of 5.1. T2 is an ontology according to such an interpretation.

In sense b), "ontology" is a synonym of "specification of an ontological commitment". This choice is still consistent with interpretation 5.1. In this case, statements 1-4 still get a unique meaning, while statement 5 has no sense, and it should be substituted by "The ontological commitment of two different knowledge bases may be specified by the same theory". T3 is an ontology according to this interpretation. The language used by T3 is in general richer than the one used by T1: as discussed in [8], the purposes are different, since the purpose of T3 is to convey meaning by using a very expressive language, while the language of T1 is the result of a tradeoff choice between expressivity and computational efficiency. Notice that T3 is an ontological theory like T2, since its formulas are always true.

In sense c), "ontology" is a synonym of "conceptualization". This choice is consistent with interpretation 3 in Fig. 1. In this case statements 1-4 in Fig 2 have no sense, while the occurrence of "ontology" in statement 5 gets a semantic interpretation. In this case, statement 5 is equivalent to "Two different knowledge bases may have the same conceptualization". None of the theories shown in the previous section is an ontology according to this choice.

Let us now see what the meaning of Gruber's definition "an ontology is a specification of a conceptualization" may be. First of all, it is evident that sense c) is incompatible with such a definition. Since we believe we have good reasons to keep the latter, we suggest to avoid the use of "ontology" in a semantic sense unless it is clear from the context.

Let us now consider senses a) and b), which assign the tag "ontology" to T2 and T3, respectively. Strictly speaking, none of them can be considered as a *specification* of a conceptualization, and hence Gruber's definition cannot apply. If we want to mantain its original (good) intuitions, we must weaken Gruber's definition, claiming that an ontology is only a *partial account* of a conceptualization. According to this choice, both T2 and T3 may be called "ontologies".

In fact, such a weakened definition leaves space both for senses a) and b), and this is exactly what we want: the *degree of specification* of the conceptualization which underlies the language used by a particular knowledge base varies in dependence of our purposes: an ontology of kind b) gets closer to specifying the indended conceptualization (and therefore may be used to establish consensus about the utility of *sharing* a particular knowledge base), but it pays the price of a richer language (and therefore, in general, undecidabile and inefficient). An ontology of kind a), on the other side, is developed with particular inferences in mind, designed to be shared among users which *already* agree on the underlying conceptualization.

There are still a couple of senses of "ontology", among those reported in Fig. 1, which are to be discussed, namely senses 6 and 7. The approach which seems to adopt such interpretations is the one followed in the KAKTUS project [18]; here an ontology is defined as "a metalevel viewpoint on a set of possible domain theories". In general, such a viewpoint is a set of metalevel definitions of the syntactic categories used in a knowledge base. The form of such definitions is not clear. What is interesting is that the description of a particular knowledge base according to such metalevel categories may have the form of a theory like T4. There is however an important difference: T4 uses meta-level semantic categories, defined in the language of T3, while Wielinga and Schreiber want to avoid any explicit semantic notion.

In conclusion, we hope to have given a clarification of the notion of "ontology" based on a notion of "conceptualization" defined in a rigorous semantic way; such a framework allowed us to underline the difference between an ontology and an arbitrary knowledge base, and to distinguish among various senses of "ontology" used in the current debate.

7 A Simple Glossary

We report below the informal definitions which we suggest to use as the preferred interpretations of the terms discussed in the present paper.

conceptualization: an intensional semantic structure which encodes the implicit rules constraining the structure of a piece of reality.

Formal Ontology: the systematic, formal, axiomatic development of the logic of all forms and modes of being.

ontological commitment: a partial semantic account of the intended *conceptualization* of a logical theory.

ontological engineering: the branch of knowledge engineering which exploits the principles of (formal) *Ontology* to build ontologies.

ontological theory: a set of formulas intended to be always true according to a certain *conceptualization*.

Ontology: that branch of philosophy which deals with the nature and the organisation of reality.

ontology: (sense 1) a logical theory which gives an explicit, partial account of a *conceptualization*; (sense 2) synonym of *conceptualization*.

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