UDC 111.1

The Role of Ontological Engineering for AIED Research

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Abstract. Ontology has been collecting a lot of attention recently. In fact, it has potential for resolving several key problems such as semantic tag design for semantic web, semantic integration, knowledge sharing/reuse, etc. However, it is also true that people have different understanding of ontology. This article is written to contribute to clarification of the understanding of ontology and ontological engineering and to promotion of its utility. Although the discussion is made in the context of Artificial Intelligence in Education domain, I believe the content is pretty general.

What is an ontology and what is it not?

My first answer is that an ontology is something conceptual for making things shareable and reusable via computational semantics. Originally, *Ontology* is a branch of philosophy in which philosophers have investigated a formal account of being. In computer science, ontology is roughly understood as a system of fundamental concepts represented in a computer-understandable manner. Ontology has attracted much attention these days for two reasons: It provides us with (1) a common conceptual backbone on which we can develop sharable and reusable knowledge-intensive systems and (2) interoperability of information and knowledge sources. Ontological engineering is a successor of knowledge engineering and is expected to be a key technology in the new generation of knowledge processing.

Let us consider the differences between two kinds of ontologies: *Semantic Web (SW)-oriented ontology*, and *Concept-oriented ontology*. SW-oriented ontology is a computer understandable vocabulary which defines meaning of metadata (e.g. Learning Object Metadata :LOM) and is mainly used for realizing semantic interoperability among information resources with metadata. It tends to be shallow, since it does not necessarily discuss deep conceptual structure of the target world. On the other hand, Concept-oriented ontology deals with fundamental concepts which need deep consideration of the target world. Typical examples include upper ontology [11], and functional ontology [3].

I here discuss ontology from the Concept-oriented viewpoint. An ontology is not a vocabulary. Vocabulary is a set of terms. A term (word) and a concept can be considered similar in that each of them is composed of a name (label) and meaning. When we talk about a term (vocabulary), its name, that is, how it is called become an issue, while when we talk about a concept, its name is totally unimportant. A concept is independent of how it is called (named). People are easily trapped by terminological problems when they develop an ontology. However, it is critical to properly distinguish a terminological issue and an ontological issue. If no appropriate term is found, then you can coin a new one to *denote* the concept under consideration. Inappropriate names (labels) do not mean that the implied concept is bad.

How is an ontology different from a knowledge base? Let me cite a phrase found in the email archive of ontology:

Date: Wed, 26 Feb 1997 12:49:09 -0800 (PST)
From: Adam Farquhar axf@HPP.Stanford.EDU
………

- Does it express the consensus knowledge of a community of people?
- Do people use it as a reference of precisely defined terms?
- Does it express the consensus knowledge of a community of agents?
- Is the language used expressive enough for people to say what they want to say?
- Can it be reused for multiple problem solving episodes?
- Is it stable?
- Can it be used to solve a variety of different sorts of problems?
- Can it be used as a starting point to construct multiple (sorts of) applications including: a new knowledge base, a database schema, an object-oriented program?

The stronger the 'yes' answer is to these questions, the more 'ontological' it is.

The above opinion is based on that there is no clear boundary between ontology and knowledge. It is a reasonable understanding when we think of Cyc whose upper part is definitely an ontology and the whole seems to be a knowledge base. The above opinion is somewhat misleading, though many of AI researchers accept it, since it does not try to capture an essential property of an ontology which is something related to concepts rather than vocabulary and is something related to what exists in the target world of interest. My answer to the question is that we need to introduce a concept of relativity when we understand an ontology. I mean, a clear differentiation of an ontology from a knowledge base should come from its role, that is, an ontology gives you a system of concepts which are used to build a knowledge base on top of it, and hence an ontology can be a specification of the KB builder's conceptualization of the target world and is a meta-thing of a conventional knowledge base.

How is an ontology different from the class hierarchy in object-oriented paradigm? They are similar. The developmental methodology of an ontology and that of an object hierarchy is also similar to each other in the upper stream. In the lower stream, however, the former concentrate on declarative aspects and the latter on performance- related aspects. Thus, the essential difference between the two lies in that the ontology research exploits declarative representation, while the OO paradigm is essentially procedural. In OO paradigm, the meaning of class, relations among classes, and methods are procedurally embedded and they are implicit. The ontology paradigm, on the other hand, descriptions are made declaratively in most cases to maintain formality and explicitness.

What is ontological engineering (OE) and how is it different from knowledge engineering?

An ontology, which is a system of fundamental concepts, that is, a system of background knowledge of any knowledge base, offers a conceptualization of the target world and provides us with a solid foundation on which we can build sharable knowledge bases for wider usability than that of a conventional knowledge base. Knowledge engineering has thus developed into ontological engineering. I call this evolution "*From AI to IA*", where AI stands for artificial intelligence and IA for Intelligence Amplifier, Information Access or Intelligent Assistant. What IA requires is not a stand-alone problem solver which solves your problems for you but an intelligent partner who invisibly stays with you all the time and gives you an effective help when necessary. Realization of such an intelligent partner, refinement and augmentation of the conventional knowledge engineering has to be done. In order to fulfill this goal, ontological engineering has been proposed.

Ontological engineering is a methodology which gives us the design rationale of a knowledge base, a kernel conceptualization of the world of interest, semantic constraints of concepts together with sophisticated theories and technologies enabling accumulation of knowledge which is indispensable for knowledge processing in the real world.

This short history can be summarized as follows:

- Knowledge Engineering is research on domain-specific

heuristics for a stand-alone problem solver
- Ontological Engineering is research on general/reusable/sharable/long-lasting concepts for building a KB/model for helping people solve problems.

You often refer to "deep" as a criteria for "good" ontological engineering. What do you mean by "Deep"?

By "Deep", I mean close to the fundamental conceptualization. But we need to note that asking "Is this deep?" is not appropriate. Instead, we need to ask "Is it deeper than that?" This is because the concept of "deep" is relative in its nature. Deeper knowledge explains why the shallower knowledge is as it is and it can explain broader phenomena than the shallower knowledge can. In other words, "deeper" means "closer to the essentials". The essential property of a thing is the heart of ontological conceptualization. Therefore, the "deeper", the more ontological.

Philosophers are looking for the deep nature of beings, so are you?

Yes, both share a lot in that respect. However, philosophers are scientific and they have no goal to build some concrete things, while I am an engineer who is looking for a methodology for reusable/sharable knowledge. What is important is, unlike usual engineers, I do not to take a hasty way to achieve the goal. Instead, I try to be patient and learn the thinking way of philosophers keeping the standpoint of engineering, that is, to produce a useful thing. Philosophers are good at investigating things as objectively as possible to find essential properties of being. Such an attitude would contribute to realization of sharable and reusable knowledge technology. I believe good balance of the philosophers' and engineers' attitude would bring us a success.

Do you mean that you leave the scientific work to Philosophers?

Yes. For example, a very basic question like "what is meaning at all" should be investigated by philosophers. An upper ontology [11] which should be built on top of a solution of such an inquiry can be investigated by ontological researchers. Engineers have a goal: to build a system, which provides us with an effective guideline which prevents us from falling into an endless discussion.

Ontologies are said to be powerful because they are declarative. Could you elaborate on that?

Declarative knowledge representation is common to many of the AI systems, since it guarantees *the system knows what it knows*, which enables the system to modify its behavior by changing the knowledge it has. If the knowledge is procedurally embedded, that is, knowledge is hard-coded, it cannot change its behavior. It enables a system to explain its behavior. In the case of ontology declaratively represented, it enables a system to justify its knowledge and to guarantee a model produced as an instance is ontology-compliant. An ontology is not used for problem solving directly. It gives a specification of the knowledge/models in the system, while conventional knowledge bases are used for problem solving. The role of an ontology to a knowledge base is to give definitions of concepts used in the knowledge representation and constraints among concepts to make the knowledge base consistent and transparent which are the necessary properties of sharable and reusable knowledge. These are the heart of IA systems.

What is your rationale for selecting a source of knowledge when building an ontology?

Building an ontology means that the developer intends to provide an explanation of the target world that is free – or as free as possible- from any implicit assumptions. Faced with this task, the ontologist considers the various sources of knowledge that are available and makes explicit the reasons for selecting one or several sources. These sources of knowledge can be classified as follows:

- common sense knowledge, which is the knowledge acquired through sensorial experience and accumulated differently depending on culture
- expert knowledge, that is, elaborated and sometimes sophisticated knowledge gained through specialized experience sometimes mixed with applied scientific knowledge
- theoretical knowledge, that is pure speculative knowledge composed of logical discourse to explain or interpret phenomena, and of hypothesis and proofs.

Why and how do ontologists select one or several from these sources? We can think of at least four good reasons: 1) the goal of the ontology constraints the choice, 2) there is no such source of knowledge available, 3) common sense knowledge is reliable enough for the purpose of the ontology, 4) common sense knowledge is reliable, but the purpose of the ontology requires theoretical knowledge.

The first case happens when for instance the goal of the ontology is such that the variations in theories in a given field may need to be avoided. A first example is the Enterprise ontology [7], where the ontologist may intentionally have used only practical knowledge (common sense and expert).

In the second case, one source is simply not available; a simple example is Gene ontology, where direct experience of genes is not possible [7]. In that case, the only source of knowledge is theoretical knowledge, sometimes complemented by experimental knowledge. Another example is Nanotechnology, where similarly, no direct experience is possible; however, some expert knowledge and some theoretical knowledge from parent domains (chemistry, physics) form part of this new field.

An example of the third case is PSL, in the domain of process engineering [7], where the theoretical knowledge exists only – or almost only- in the form of mathematical knowledge, therefore not exploitable to build an ontology.

An example of the fourth case is an ontology of Instructional theories, when the ontologist's intention is to make explicit the variations among theories in order to exploit these variations for selecting theories during the task of designing instruction [1, 9]. Another example is Learning theories for collaborative learning [2].

Would you say that Ontologies open doors to AI in Education(AIED) by bringing the possibility of reusable Knowledge to ITS?

Yes. Ontological engineering plays a critical role in the advancement of knowledge-rich research like AIED which has divers research fields related to it: Artificial intelligence, computer science, cognitive science, learning science, educational science, instructional science, etc. I would like to say *computer mediated knowledge sharing/reuse*, which requires knowledge modeling for computer consumption. This idea leads to knowledge systematization for computer consumption.

As I stated in **From AI to IA** catch phrase, what we expect computers is not to solve a problem but to help people solve a problem. It means that computers can be a *mediator* of knowledge dissemination among people working in various domains. It would be critical to the success of knowledge-rich research fields in this information era.

I am afraid that new problems would be generated by introducing ontologies. Proliferation of idiosyncratic ontologies that would bring AIED to a chaotic state. How to prevent this?

That is one of the serious issues in ontology research. It is the distributed control vs. centralized control issue. In semantic web, an ontology for metadata will be distributed control or no control, while in the knowledge processing community an ontology is something more well-controlled to make it different from just a computer-understandable vocabulary. Nobody accepts "the universal ontology". However, it is also true it cannot be totally arbitrary. Policy of totally distributed ontology easily leads us to a mess of badly designed ontologies. The solution exists in the middle of the two extremes as usual.

A solution to this problem would be to commit to a well-elaborated upper ontology. In theory, an ontology should be developed by a community whose members share the necessity to own a common ontology on which people rely. Furthermore, ontology developers are required to commit to an upper ontology which can guide people build a reasonable ontologies with a sophisticated ontology building environment. Such a way of ontology building prevents you from a mess of ugly ontologies.

If ontologies are goal-oriented and use-oriented (i.e. specific rather than general) then can we build one and share it?

Usefulness and generality usually conflicts each other. This is common to all AI systems. AI has no single principle to govern all the intelligent phenomena, but it has to be realized by accumulation of heuristics, which implies that a system tends to be specific when we want to make it useful, in other words, a general theory/principle is too weak to cope with the reality. The problem, however, we need to differentiate two issues: One is problem solving and the other is knowledge sharing/reuse, since such a conflict only applies to problem solving which requires high performance to a specific problem at the cost of generality. It is just what expert systems do which seriously suffer from lack of reusability of knowledge in a knowledge base. Knowledge sharing/reuse is different. It is based on the philosophy of IA rather than AI which aims at automatic problem solving. Knowledge sharing/reuse needs a general and common background on top of which we can build knowledge to make the knowledge long-lasting and sharable by many people. An ontology is what can provide us with such a common conceptual background.

An upper level ontology is not goal-oriented, but it is objective and general enough to support wide range of things and phenomena. The problem with upper ontology is that we still do not have very convincing one. However, once you commit to a well-elaborated upper ontology, it is obviously better than nothing when you develop your own domain ontology. Even if you come to a disagreement on a specific aspect of domain knowledge organization or of domain ontology building, you can resolve it by using the upper ontology as a guideline.

Do you see a top-down process like standards imposed by IEEE or ISO?

I understand your concern, but it is not the case. Standards should be mainly concerned with non-content(form or format) issue. Each domain ontology needs to be developed by the respective communities in a bottom up manner with a firm consensus on the necessity of an ontology to share and rely on. Only when you use an upper ontology, you might encounter a top-down process. As explained in the above, however, an upper ontology is used only for reference to get guidelines in the ontology building process. Precisely speaking, building an upper ontology is a content issue. However, it is very higher level content which behaves almost like "form" which weakly constraints the real content at the lower level.

A very bottom-up scenario would look like the following:

(1) Many people come to have their own ontology
(2) As a natural process, they see difficulties in interoperability among knowledge/systems.
(3) They realize the need to come together and form a small community to share a common ontology.
(4) They also realize the difficulty to integrate their ontologies without any principle.
(5) They agree upon to use an upper ontology as a common guiding principle.

This looks like a converging idea with the one of Community of practice?

Yes, ontology development should be driven from the mutual benefit and it should help people share the building experience. I would call such a process Ontology-mediated consensus formation. They say it is hard to have a common ontology due to the difficulty in coming to a consensus. But, what I want to take it other way round. That is, an ontology can be used to help people come to an agreement. One of the roles of an ontology is it helps people to explicate what they assume to have taken it for granted. An ontology usually explicates underlying assumptions people do not even notice before they start to build an ontology. When people join a meeting with a common goal of mutual understanding with their own ontology, the ontologies can play the role of mediator through which people can find differences as well as commonalities among their understanding of the common target world. In the worst case, they clearly realized what they cannot agree on.

How do you see ontologies being shared among cultures and what do you think of the multilingual issue?

First of all, an ontology is not a vocabulary but a system of concepts, therefore it is much less language-dependent. If a word does not exist in one language, it does not mean that the people speaking the language cannot understand the concept; it only means that they have not been interested in this concept so far; if you explain this concept to them, they may understand it. It is true that an ontology is cultural-dependent to some extent. However, it is negligible for instance when we talk about science and engineering topics which are mostly objective and universal. I see an Esperanto-like language (JB: EsperOnto?, RM: Yes!). In science, a theory is culture-independent. You may suspect that a Learning theory does not work in some country, which is true. But it is not an ontological issue but a model issue. Any learning theory is of value if it has at least one case (culture) in which it works.

I would like to add that values, which are fundamental in a culture, are not an ontological issue. A culture has a value system where concepts such as freedom, happiness, harmony are give a certain weight, and these values are shared by most people in this culture.

Can you envisage an ontology of theories for Intelligent Tutoring Systems(ITSs) that would be universally meaningful?

I have to say yes from computer science point of view. As far as learning theories, they do not have to explain all the learning phenomena [5]. If a theory works for one case, it is enough. An ontology for ITS theories is something which provides us with a common conceptual structure for reconstructing theories and explaining the reasons why a theory does or does not work for some situations [1]. This implies that such an ontology is said to be universal, though it does not mean it is the only one.

How can ontologists claim for progress (advancement of knowledge) if ontological engineering is only reusing (reorganizing) old ideas in a domain?

a) What is true is that ontological engineering reorganizes existing knowledge, which does seem NOT to create new knowledge in any domain
b) As a modest claim, ontological engineering can discover missing relationships, what have been left implicit and imprecise, which can bring changes or challenges to existing knowledge. Analogically, ontological engineering might correspond to a good *survey paper* in a domain. It will give you a good structure of the problems in a domain by revealing what are missing, what are hidden, and by showing the common understanding of what have been done, etc. It provides a firm ground upon which we can work together to produce new knowledge in the domain. Even if zero progress in the domain knowledge, ontology is a significant progress in knowledge representation in computer science in terms of new concepts, foundations, and methodologies.

Besides progress in terms of advancement of knowledge engineering, do you see any progress in terms of impact on the state-of-the-art technology?, e.g. Semantic Web or data mining?

a) yes, for knowledge engineering, ontology contributes to building shareable and reusable knowledge bases that can last long.
b) for the SW, what they need is a lightweight ontology as a computer understandable vocabulary and it is used as information source for semantic interoperability of web contents.

What is the biggest success of OE that you would like to see in 10 years of now?

a) The biggest success so far is functional knowledge sharing/reuse of engineers' knowledge about devices in the Production Systems Division in Sumitomo Electric Industries, a big share holder of optical fiber and chemical compound semiconductors [4]. They use a functional knowledge description framework based on functional ontology and device ontology developed by my lab in their daily activities. It is the first deployment of ontology engineering at least in Japan. The framework has been developed based on the achievements of a long term project on functional ontology conducted for about 5 years. In Sumitomo Electric Industries, people already got a lot of benefits by using the framework, since there had been no way to represent functional structure of devices in a computer-understandable way in a consistent manner The framework has first enabled them to share functional knowledge.
b) Ontology-mediated knowledge dissemination in the vertical direction. While there exist many theories out there such as learning theories,

instructional theories, instructional design theories, test generation theories, etc., they are not use-ready and hence are not easily available for practitioner/engineers. To develop ontologies of those theories and to make them accessible to those people by building theory-aware workbenches for building intelligent learning support systems is what I dream of in the near future.

I know that you are also interested in practical knowledge: how would you tackle the difficult problem relating theoretical to practical knowledge?

I think that practical knowledge could be raised to theories. What the theory-aware systems do is to realize knowledge flow from theory to practice. I believe ontological engineering can contribute also to enabling knowledge to flow from practice to theory. A possible scenario looks like the following: Take best practices, extract knowledge, describe each piece of knowledge in terms of concepts in the theory ontology, form a theory using the template of a theory which is also described in terms of the concepts in the theory ontology and then decide if it should included in the existing theory base or not. A forum can be set up to implement the last step.

In this way, ontology contributes to enabling interactions between the theory and practice worlds which are unfortunately too often far from each other. I would like to call it Ontology-mediated harmonization.

I am afraid that nuances of theories might be lost by such a knowledge flow method.

You are right. However, I believe it is not a problem. What an ontology gives you is the *skeleton* of conceptual world of the target thing. It tries to explicate the generic underlying conceptual structure common to the various objects in the target world, theories in our case. This is the source of the power of ontology which enables semantic interoperability. We need to be tolerant of the possible loss of nuance of theories to enjoy effective knowledge flow between the two worlds.

In order to achieve such high level goal, we need strong methodologies/tools, don't we?

It is the main job of Ontological engineering. We need to produce a lot of useful tools and methodologies for building and utilizing ontologies. We already have many ontology building tools and environments [10]. We will have ontology-aware systems such as ontology-aware authoring tools with the help of the methodologies and tools. We would eventually obtain a common ground for unifying theoretical and practical knowledge. If we achieve this in 10 years from now, ontological engineering will have done a major contribution to the advancement of knowledge engineering.

How meaningful would the eventual unification of theoretical and practical knowledge be to the field of AIED research?

It would be a real contribution of the ontological engineering to AIED community. Learning and Instructional theories become accessible to practitioners, a lot of practitioners' experiences are accumulated in a well-organized form and are ready to be raised as theories to be formally evaluated. Such a smooth knowledge flow would be realized in AIED community. While ontological engineering seemingly cannot make a contribution to a real progress of a domain, such a contribution, when it comes true, would also change the understanding of ontological engineering which is a ***Content Technology***.

If ontological engineering is domain-independent, could it give AIED researchers the opportunity to make a significant contribution to the field of Computer science?

Definitely, AIED research is a good application field for ontological engineering thanks to its theory-richness, knowledge-richness and high multi-disciplinarity all of which require a sophisticated content technology for enabling smoother knowledge flow and semantic interoperability among them. Theories and technology are refined and extended through experiences. Practicing ontological engineering as a content technology, AIED researchers easily contribute to the progress of ontological engineering as one of the advanced branches of computer science.

AIED not only is a good application field for OE, but moreover is AIED a research field for OE (JB: OE in Education, OEED? RM: maybe so!).

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