# Ontology: Towards a New Synthesis

Barry Smith[1] and Christopher Welty[2]
[1]Department of Philosophy, University at Buffalo
Buffalo, NY 14260, USA
phismith@buffalo.edu
[2]Computer Science Dept., Vassar College
Poughkeepsie, NY 12604, USA
weltyc@cs.vassar.edu

**Abstract —**This introduction to the second international conference on Formal Ontology and Information Systems presents a brief history of ontology as a discipline spanning the boundaries of philosophy and information science. We sketch some of the reasons for the growth of ontology in the information science field, and offer a preliminary stocktaking of how the term 'ontology' is currently used. We conclude by suggesting some grounds for optimism as concerns the future collaboration between philosophical ontologists and information scientists.

**Categories & Descriptors —** *Information Systems, Artificial Intelligence.*

**General Terms —** Ontology, conceptual modeling, domain modeling, formal ontology in information systems.

**Keywords —** History of ontology in philosophy and computer science.

Philosophical ontology is the science of what is, of the kinds and structures of objects, properties, events, processes and relations in every area of reality. Philosophical ontology takes many forms, from the metaphysics of Aristotle to the object-theory of Alexius Meinong. The term 'ontology' (or *ontologia*) was itself coined in 1613, independently, by two philosophers, Rudolf Göckel (Goclenius), in his *Lexicon philosophicum* and Jacob Lorhard (Lorhardus), in his *Theatrum philosophicum*. Its first occurrence in English as recorded by the OED appears in Bailey's dictionary of 1721, which defines ontology as 'an Account of being in the Abstract'.

Regardless of its name, what we now refer to as philosophical ontology has sought the definitive and exhaustive classification of entities in all spheres of being. It can thus be conceived as a kind of generalized chemistry. The taxonomies which result from philosophical ontology have been intended to be definitive in the sense that they could serve as answers to such questions as: What classes of entities are needed for a complete description and explanation of all the goings-on in the universe? Or: What classes of entities are needed to give an account of what makes true all truths? They have been designed to be exhaustive in the sense that all types of entities should be included, including also the types of *relations* by


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which entities are tied together.

For some 2000 years after Aristotle himself, ontology developed hardly at all, to such a degree that it formed a central part of what was habitually referred to as *philosophia perennis.* With the scientific revolution, however, philosophical taxonomies began to reflect sometimes radical developments in our understanding of the universe, and generally accepted classifications began to change.

Different schools of philosophy have offered different approaches to the provision of such a classification. One large division is that between those philosophers who sought a substance-based ontology and those who sought an ontology based on events or processes. Another large division is between what we might call adequatists and reductionists. Adequatists seek a taxonomy of the entities in reality at all levels of aggregation, from the microphysical to the cosmological, including also the middle world of human-scale entities in between. Reductionists, in contrast, see reality in terms of some one privileged level of existents; they seek to establish the 'ultimate furniture of the universe' by decomposing reality into its simplest constituents, or they seek to 'reduce' in some other way the apparent variety of types of entities existing in reality.

Just as the roots of ontology were intertwined with the early development of philosophy and grew along with it, so, in recent years, ontology has become intertwined with the development of artificial intelligence and of information systems science. From the very start, *logicist* AI focused attention on systems that *know,* or have the power to simulate knowledge, through the use of automated reasoning mechanisms. As these mechanisms became more standardized over time, the theories expressed in them became a focus of attention. These theories, often called *knowledge-bases* before that term began its unfortunate association with expert systems, were collections of terms with associated axioms designed to constrain unintended interpretations and to enable the derivation of new information from ground facts. The operation of the automated reasoning mechanisms over these knowledge-bases was considered an example of artificial intelligence. Knowledge-bases were often crafted in ways that both reflected common-sense human knowledge in a declarative way and took advantage of the powers of the particular automated reasoning system used.

It is important to note that many considered, and still consider, the reasoning mechanisms themselves to be the important scientific challenge, and the knowledge-bases to be nothing more than examples having no intrinsic significance. Others, however, argued that the knowledge-bases themselves ought to be subject to scientific inquiry. They pointed to the high degree of arbitrariness characterizing existing knowledge-bases, and to the lack of rigor applied in their development.. In this way the field of *knowledge engineering* was born [38], though not in time to save the ill-fated attempts to commercialize expert systems.

Independently of this, those working in the computer science sub-field of database management systems (DBMS) were also discovering that, after database technology had begun to stabilize, the far more important and subtle problem of *conceptual modeling* still remained [19]. The early years of database conceptual modeling were marked for the most part by ad hoc and inconsistent modeling, leading to the many practical problems of database integration we face today.

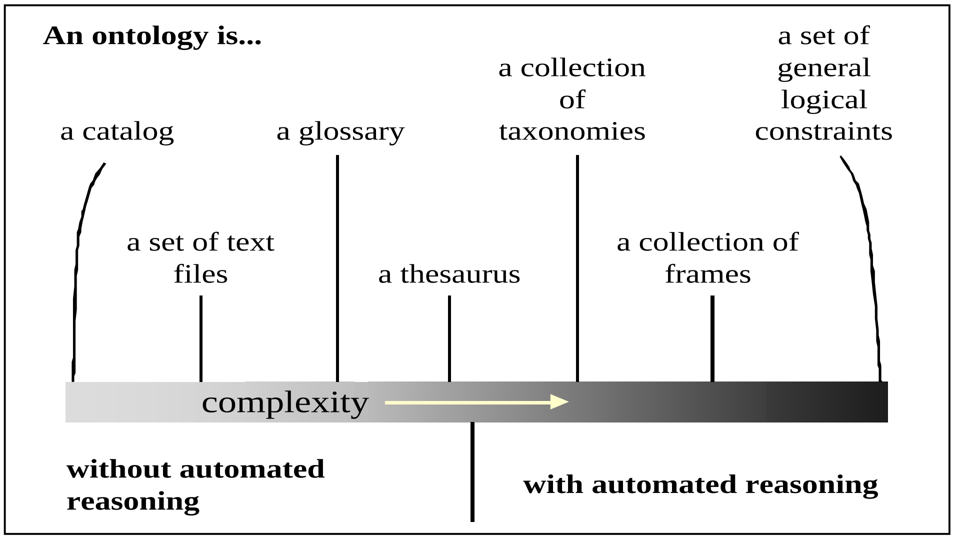
Independently of these developments, yet another sub-field of computer science, namely software engineering, encouraged in particular by advances in object-oriented languages, began to recognize the importance of what came to be known as *domain modeling* [2]. This work reflected a situation in which quite specific practical problems needed to be faced by software developers as the increasing size and complexity of programs meant in turn increasing difficulties in maintaining such programs and putting them to new uses. The idea was to build declarative representations of the procedures one is attempting to model – for example business processes of ordering or scheduling – in a way which would allow application systems to re-use program elements [9]. This field, too, was severely debilitated by a lack of concrete and consistent formal bases for making modeling decisions.

The step from each of these three starting-points to ontology is then relatively easy. The knowledge engineer, conceptual modeler, or domain modeler realizes the need for declarative representations which should have as much generality as possible to ensure reusability but would at the same time *correspond to the things and processes they are supposed to represent.* Thus he starts asking questions like: What is an object/process/attribute/relation? What is a transaction, a person, an organization? How do they depend on each other? How are they related?

The step to ontology was indeed taken by isolated individuals from each of these areas. In the main, however, the core ideas of information systems ontology were developed by thinkers working completely from scratch. It was John McCarthy who first recognized the overlap between work done in philosophical ontology and the activity of building the logical theories of AI systems. McCarthy affirmed already in 1980 that builders of logic-based intelligent systems must first "list everything that exists, building an *ontology* of our world" [23]. This view, inspired by McCarthy's reading of Quine [28], was taken over by Patrick Hayes in his work on naïve physics [16]. Most AI efforts in the logicist camp focused on capturing information about the world that is compatible with the perspective of human common sense, and these efforts were closely allied with research on the topic of common-sense reasoning [7]. A similar perspective, but with broader ambitions and with an even more explicit recognition of an overlap with philosophy, was proposed by John Sowa, who refers to 'an *ontology* for a possible world – a catalogue of everything that makes up that world, how it's put together, and how it works' [37] p. 294.

Despite encouragement from these influential figures, most of AI chose not to consider the work of the much older overlapping field of philosophical ontology, preferring instead to use the term 'ontology' as an exotic name for what they'd been doing all along – knowledge engineering. This resulted in an unfortunate skewing of the meaning of the term as used in the AI and information systems fields, as work under the heading of 'ontology' was brought closer to logical theory, and especially to logical semantics, and it became correspondingly more remote from anything which might stand in a direct relation to existence or reality. Some may argue that this meaning is appropriate for a computer system, as a logico-semantic theory will, in fact, define the kinds and structures of objects, properties, events, processes and relations *that exist in the system*. On the other hand, many are now arguing that the very lack of grounding in external reality is precisely what created the problems, so pressing for the information industry today, of *legacy system integration*. How can we make older systems with different conceptual models but overlapping semantics work together, if not by referring to the common world to which they all relate?

From early uses of the term 'ontology' in the new AI sense, as for example in Alexander, *et al*. [1], the significance of the term grew, and as the disparate fields of knowledge engineering, conceptual modeling, and domain modeling began to converge and discover each other, so, too, did the range of variations in its meaning. By 1993 the use of the term was already quite widespread in each of these sub-fields of computer science. Although often credited with starting its use in these fields, Tom Gruber's contribution in 1993 was actually that of making the first credible attempt at defining the term [11]. But his definition, "an ontology is a specification of a conceptualization," left room for too many possible interpretations, and despite an attempt to clarify and formalize the definition further by Guarino [13], new meanings of the term 'ontology' continued to proliferate. Welty, Lehmann, Gruninger, and Uschold reported in 1999 on a wide spectrum of information artifacts that had been at some time classified as ontologies [39]. The results of their work are shown in the figure on the next page.




Information systems as simple as catalogs, in which each product type has a unique code (e.g. the item number), have been dubbed 'ontologies'. A catalog is, in a sense, the ontology of the things a company sells. A slightly more complex information system may provide simple natural language texts and allow string matching. Glossaries are information systems that provide natural language descriptions of terms, thus imposing some structure on the text (indexing by terms). Thesauri are standardized information systems that provide, in addition to descriptions of terms, also relations to other more general or more specific terms within a common hierarchy. The fields of knowledge representation, database development, and object-oriented software engineering all employ ontologies conceived as taxonomies in which properties of more general classes are *inherited* by the more specific ones. Frame-based systems provide, in addition to taxonomic structure, relations between objects and restrictions on what and how classes of objects can be related to each other. Finally, the most expressive and complex information system ontologies use the axioms of full first order, higher order, or modal logic. All these types of information systems satisfy Gruber's definition, and all are now common bedfellows under the rubric of 'ontology.'

Out of this apparent chaos, some coherence is beginning to emerge. Gradually, computer scientists are beginning to recognize that the provision, once and for all, of a common, robust reference ontology – a shared taxonomy of entities – might provide significant advantages over the ad hoc, case-by-case methods previously used. Finally, more than just a select few information scientists are realizing that perhaps philosophy does have something useful to say about the objects of their work.

The rise of ontology in computer science reflects a victory of content over process, a victory which has been, somewhat paradoxically, reinforced as a result of the fact that, as software itself has become ever more sophisticated, software developers and computer theorists have increasingly found it possible to focus on the data upon which their systems operate rather than on the functionality and procedural aspects of the systems themselves. The significance of this change was captured in a famous remark by Dijkstra in 1986, who pointed out in *The Mathematical Intelligencer* that calling what computer scientists do 'computer science' is akin to calling what surgeons do 'knife science'. For the term 'computer science' encourages too narrow a focus on the tool, rather than on what the tool does and on the objects, relations, processes and purposes in reality which the tool is designed to address. And we can note that, as information systems insinuate themselves into ever more regions and dimensions of our lives, so the territory which must be covered by 'information science', too, is becoming ever more comprehensive – to the extent that the point may have been reached where this term might also have to be rejected as a constricting misnomer.

The growth of ontology can be seen in this light to reflect the efforts on behalf of at least some computer and information scientists to look beyond the artefacts of computation and information to that big wide world beyond to which these artefacts relate. The work of Guarino and Welty [14], to take just one example, introduced information systems ontologists to philosophical treatments of the notions of identity and unity as formal tools for analyzing ontological decisions. Their work, along with that of the GOL group in Leipzig and others, is based on the idea that the project of developing a robust common reference ontology can profit from the theories developed by philosophers over 2000 years of ontological research. One claim that is made on behalf of the systems which result is that they are easier to maintain and that they enjoy the benefits of interoperability. Already successes of this approach are being seen at companies such as IBM, OntologyWorks, and Document Development Corporation (DDC).

This is not to say, of course, that philosophy has nothing to learn from the computer scientist's view of ontology. Recent developments in modal, temporal and dynamic logics as also in linear, substructural and paraconsistent logics have demonstrated the degree to which advances in computer science can yield benefits in logic – benefits not only of a strictly technical nature, but also sometimes of wider philosophical significance. Something similar can be true, we suggest, in relation to the developments in ontological engineering referred to above. The example of the successes and failures of information systems ontologists can first of all help to encourage existing tendencies in philosophical ontology (nowadays often grouped together under the heading 'analytic metaphysics') towards opening up new domains of investigation for philosophers, for example the domain of social institutions [24][30], of patterns [20], of artefacts [8][32], of dependence and instantiation [24], of holes [6], and parts [31][34]. Secondly, it can shed new light on the many existing contributions to ontology [33][5], whose significance was for a long time neglected by philosophers in the shadow of Kant and other enemies of metaphysics. Thirdly, if philosophical ontology can properly be conceived as a kind of generalized chemistry, then information systems can help to fill one important gap in ontology as it has been practiced thus far, which lies in the absence of any analogue of chemical experimentation. For one can, as C. S. Peirce remarked [27] (4.530), 'make exact experiments upon uniform diagrams,' and the new tools of ontological engineering might help us to realize Peirce's vision of a time when operations upon diagrams will 'take the place of the experiments upon real things that one performs in chemical and physical research.'

Finally, the lessons drawn from information systems ontology can support the efforts of those philosophers who have concerned themselves not only with the development of ontological *theories*, but also – in a field sometimes called 'applied ontology' [21] – with the *application* of such theories in domains such as law [22], or commerce [10], or medicine [29], or geography [26][36]. The tools of philosophical ontology have been applied to solve practical problems, for example concerning the nature of intellectual property or concerning the classification of the human foetus at different stages of its development. Collaboration with information systems ontologists can support such ventures in a variety of ways, first of all because the results achieved in specific application-domains can provide stimulation for philosophers, but also – and not least importantly – because information systems ontology is itself an enormous new field of practical application that is crying out to be explored by the methods of rigorous philosophy.

## Further Reading

The reader interested in learning more about philosophical and information system ontology, is encouraged to consult, in addition to these proceedings and those of the first FOIS conference [13], also the LADSEB annotated bibliography of formal ontology and conceptual analysis: http://www.ladseb.pd.cnr.it/infor/ontology/Papers/Ontobiblio/TOC.html

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