Ontology (information science)

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In computer science and information science, an **ontology** is a formal naming and definition of the types, properties, and interrelationships of the entities that really or fundamentally exist for a particular domain of discourse. It is thus a practical application of philosophical ontology, with a taxonomy.

An ontology compartmentalizes the variables needed for some set of computations and establishes the relationships between them.[1][2]

The fields of artificial intelligence, the Semantic Web, systems engineering, software engineering, biomedical informatics, library science, enterprise bookmarking, and information architecture all create ontologies to limit complexity and to organize information. The ontology can then be applied to problem solving.

Contents

Etymology and Definition

The term *ontology* has its origin in philosophy and has been applied in many different ways. The word element *onto-* comes from the Greek *ὤν, ὄντος*, ("being", "that which is"), present participle of the verb *εἰμί* ("be"). The core meaning within computer science is a model for describing the world that consists of a set of types, properties, and relationship types. There is also generally an expectation that the features of the model in an ontology should closely resemble the real world (related to the object).[3]

Overview

What many ontologies have in common in both computer science and in philosophy is the representation of entities, ideas, and events, along with their properties and relations, according to a system of categories. In both fields, there is considerable work on problems of ontological relativity (e.g., Quine and Kripke in philosophy, Sowa and Guarino in computer science),[4] and debates concerning whether a normative ontology is viable (e.g., debates over foundationalism in philosophy, and over the Cyc project in AI). Differences between the two are largely matters of focus. Computer scientists are more concerned with establishing fixed, controlled vocabularies, while philosophers are more concerned with first principles, such as whether there are such things as fixed essences or whether entities must be ontologically more primary than processes.

Other fields make ontological assumptions that are sometimes explicitly elaborated and explored. For instance, the definition and ontology of economics (also sometimes called the political economy) is hotly debated especially in Marxist economics[5] where it is a primary concern, but also in other subfields.[6] Such concerns intersect with those of information science when a simulation or model is intended to enable decisions in the economic realm; for example, to determine what capital assets are at risk and if so by how much (see risk management). Some claim all social sciences have explicit ontology issues because they do not have hard falsifiability criteria like most models in physical sciences and that indeed the lack of such widely accepted hard falsification criteria is what defines a social or soft science.

History

Historically, ontologies arise out of the branch of philosophy known as metaphysics, which deals with the nature of reality – of what exists. This fundamental branch is concerned with analyzing various types or modes of existence, often with special attention to the relations between particulars and universals, between intrinsic and extrinsic properties, and between essence and existence. The traditional goal of ontological inquiry in particular is to divide the world "at its joints" to discover those fundamental categories or kinds into which the world's objects naturally fall.[7]

During the second half of the 20th century, philosophers extensively debated the possible methods or approaches to building ontologies without actually *building* any very elaborate ontologies themselves. By contrast, computer scientists were building some large and robust ontologies, such as WordNet and Cyc, with comparatively little debate over *how* they were built.

Since the mid-1970s, researchers in the field of artificial intelligence (AI) have recognized that capturing knowledge is the key to building large and powerful AI systems. AI researchers argued that they could create new ontologies as computational models that enable certain kinds of automated reasoning. In the 1980s, the AI community began to use the term *ontology* to refer to both a theory of a modeled world and a component of knowledge systems. Some researchers, drawing inspiration from philosophical ontologies, viewed computational ontology as a kind of applied philosophy.[8]

In the early 1990s, the widely cited Web page and paper "Toward Principles for the Design of Ontologies Used for Knowledge Sharing" by Tom Gruber[9] is credited with a deliberate definition of *ontology* as a technical term in computer science. Gruber introduced the term to mean a specification of a conceptualization:

> An ontology is a description (like a formal specification of a program) of the concepts and relationships that can formally exist for an agent or a community of agents. This definition is consistent with the usage of ontology as set of concept definitions, but more general. And it is a different sense of the word than its use in philosophy.[10]

According to Gruber (1993):

> Ontologies are often equated with taxonomic hierarchies of classes, class definitions, and the subsumption relation, but ontologies need not be limited to these forms. Ontologies are also not limited to conservative definitions — that is, definitions in the traditional logic sense that only introduce terminology and do not add any knowledge about the world.[11] To specify a conceptualization, one needs to state axioms that do constrain the possible interpretations for the defined terms.[1]

Components

Contemporary ontologies share many structural similarities, regardless of the language in which they are expressed. As mentioned above, most ontologies describe individuals (instances), classes (concepts), attributes, and relations. In this section each of these components is discussed in turn.

Common components of ontologies include:

- *Individuals:* instances or objects (the basic or "ground level" objects)
- *Classes:* sets, collections, concepts, classes in programming, types of objects, or kinds of things
- *Attributes:* aspects, properties, features, characteristics, or parameters that objects (and classes) can have
- *Relations:* ways in which classes and individuals can be related to one another
- *Function terms:* complex structures formed from certain relations that can be used in place of an individual term in a statement
- *Restrictions:* formally stated descriptions of what must be true in order for some assertion to be accepted as input
- *Rules:* statements in the form of an if-then (antecedent-consequent) sentence that describe the logical inferences that can be drawn from an assertion in a particular form
- *Axioms:* assertions (including rules) in a logical form that together comprise the overall theory that the ontology describes in its domain of application. This definition differs from that of "axioms" in generative grammar and formal logic. In those disciplines, axioms include only statements asserted as *a priori* knowledge. As used here, "axioms" also include the theory derived from axiomatic statements
- *Events:* the changing of attributes or relations

Ontologies are commonly encoded using ontology languages.

Types

Domain ontology

A domain ontology (or domain-specific ontology) represents concepts which belong to part of the world. Particular meanings of terms applied to that domain are provided by domain ontology. For example the word *card* has many different meanings. An ontology about the domain of poker would model the "playing card" meaning of the word, while an ontology about the domain of computer hardware would model the "punched card" and "video card" meanings.

Since domain ontologies represent concepts in very specific and often eclectic ways, they are often incompatible. As systems that rely on domain ontologies expand, they often need to merge domain ontologies into a more general representation. This presents a challenge to the ontology designer. Different ontologies in the same domain arise due to different languages, different intended usage of the ontologies, and different perceptions of the domain (based on cultural background, education, ideology, etc.).

At present, merging ontologies that are not developed from a common foundation ontology is a largely manual process and therefore time-consuming and expensive. Domain ontologies that use the same foundation ontology to provide a set of basic elements with which to specify the meanings of the domain ontology elements can be merged automatically. There are studies on generalized techniques for merging ontologies,[12] but this area of research is still largely theoretical.

Upper ontology

An upper ontology (or foundation ontology) is a model of the common objects that are generally applicable across a wide range of domain ontologies. It usually employs a core glossary that contains the terms and associated object descriptions as they are used in various relevant domain sets.

There are several standardized upper ontologies available for use, including BFO, BORO method, Dublin Core, GFO, OpenCyc/ResearchCyc, SUMO, the Unified Foundational Ontology (UFO),[13] and DOLCE.[14][15] WordNet, while considered an upper ontology by some, is not strictly an ontology. However, it has been employed as a linguistic tool for learning domain ontologies.[16]

Hybrid ontology

The Gellish ontology is an example of a combination of an upper and a domain ontology.

Visualization

A survey of ontology visualization techniques is presented by Katifori et al.[17] An evaluation of two most established ontology visualization techniques: indented tree and graph is discussed in.[18] A visual language for ontologies represented in OWL is specified by the Visual Notation for OWL Ontologies (VOWL) (http://vowl.visualdataweb.org).

Engineering

Ontology engineering (or ontology building) is a subfield of knowledge engineering. It studies the ontology development process, the ontology life cycle, the methods and methodologies for building ontologies, and the tool suites and languages that support them.[19][20]

Ontology engineering aims to make explicit the knowledge contained within software applications, and within enterprises and business procedures for a particular domain. Ontology engineering offers a direction towards solving the interoperability problems brought about by semantic obstacles, such as the obstacles related to the definitions of business terms and software classes. Ontology engineering is a set of tasks related to the development of ontologies for a particular domain.[21]

Editor

Learning

Ontology learning is the automatic or semi-automatic creation of ontologies, including extracting a domain's terms from natural language text. As building ontologies manually is extremely labor-intensive and time consuming, there is great motivation to automate the process. Information extraction and text mining methods have been explored to automatically link ontologies to documents, e.g. in the context of the BioCreative challenges.[22]

Languages

An ontology language is a formal language used to encode the ontology. There are a number of such languages for ontologies, both proprietary and standards-based:

- Common Algebraic Specification Language is a general logic-based specification language developed within the IFIP working group 1.3 "Foundations of System Specifications" and functions as a de facto standard in the area of software specifications. It is now being applied to ontology specifications in order to provide modularity and structuring mechanisms.
- Common logic is ISO standard 24707, a specification for a family of ontology languages that can be accurately translated into each other.
- The Cyc project has its own ontology language called CycL, based on first-order predicate calculus with some higher-order extensions.
- DOGMA (Developing Ontology-Grounded Methods and Applications) adopts the fact-oriented modeling approach to provide a higher level of semantic stability.
- The Gellish language includes rules for its own extension and thus integrates an ontology with an ontology language.
- IDEF5 is a software engineering method to develop and maintain usable, accurate, domain ontologies.
- KIF is a syntax for first-order logic that is based on S-expressions.
- MOF and UML are standards of the OMG
- OBO, a language used for biological and biomedical ontologies.
- OntoUML is an ontologically well-founded profile of UML for conceptual modeling of domain ontologies.
- OWL is a language for making ontological statements, developed as a follow-on from RDF and RDFS, as well as earlier ontology language projects including OIL, DAML, and DAML+OIL. OWL is intended to be used over the World Wide Web, and all its elements (classes, properties and individuals) are defined as RDF resources, and identified by URIs.
- Rule Interchange Format (RIF) and F-Logic combine ontologies and rules.
- Semantic Application Design Language (SADL)[23] captures a subset of the expressiveness of OWL, using an English-like language entered via an Eclipse Plug-in.
- SBVR (Semantics of Business Vocabularies and Rules) is an OMG standard adopted in industry to build ontologies.
- TOVE Project, TOronto Virtual Enterprise project

Published examples

- BabelNet, a very large multilingual semantic network and ontology, lexicalized in many languages
- Basic Formal Ontology,[24] a formal upper ontology designed to support scientific research
- BioPAX,[25] an ontology for the exchange and interoperability of biological pathway (cellular processes) data
- BMO,[26] an e-Business Model Ontology based on a review of enterprise ontologies and business model literature
- CCO and GexKB,[27] Application Ontologies (APO) that integrate diverse types of knowledge with the Cell Cycle Ontology (CCO) and the Gene Expression Knowledge Base (GexKB)
- CContology (Customer Complaint Ontology),[28] an e-business ontology to support online customer complaint management
- CIDOC Conceptual Reference Model, an ontology for cultural heritage[29]

- COSMO,[30] a Foundation Ontology (current version in OWL) that is designed to contain representations of all of the primitive concepts needed to logically specify the meanings of any domain entity. It is intended to serve as a basic ontology that can be used to translate among the representations in other ontologies or databases. It started as a merger of the basic elements of the OpenCyc and SUMO ontologies, and has been supplemented with other ontology elements (types, relations) so as to include representations of all of the words in the Longman dictionary defining vocabulary.
- Cyc, a large Foundation Ontology for formal representation of the universe of discourse
- Disease Ontology,[31] designed to facilitate the mapping of diseases and associated conditions to particular medical codes
- DOLCE, a Descriptive Ontology for Linguistic and Cognitive Engineering[14][15]
- Dublin Core, a simple ontology for documents and publishing
- Foundational, Core and Linguistic Ontologies[32]
- Foundational Model of Anatomy,[33] an ontology for human anatomy
- Friend of a Friend, an ontology for describing persons, their activities and their relations to other people and objects
- Gene Ontology for genomics
- Gellish English dictionary, an ontology that includes a dictionary and taxonomy that includes an upper ontology and a lower ontology that focusses on industrial and business applications in engineering, technology and procurement. See also Gellish (http://gellish.wiki.sourceforge.net/) as Open Source project on SourceForge.
- Geopolitical ontology, an ontology describing geopolitical information created by Food and Agriculture Organization(FAO). The geopolitical ontology includes names in multiple languages (English, French, Spanish, Arabic, Chinese, Russian and Italian); maps standard coding systems (UN, ISO, FAOSTAT, AGROVOC, etc.); provides relations among territories (land borders, group membership, etc.); and tracks historical changes. In addition, FAO provides web services <http://www.fao.org/countryprofiles/webservices.asp?lang=en> of geopolitical ontology and a module maker <http://www.fao.org/countryprofiles/geoinfo/modulemaker/index.html> to download modules of the geopolitical ontology into different formats (RDF, XML, and EXCEL). See more information on the FAO Country Profiles geopolitical ontology web page <http://www.fao.org/countryprofiles/geoinfo.asp?lang=en>.
- GOLD,[34] General Ontology for Linguistic Description
- GUM (Generalized Upper Model),[35] a linguistically motivated ontology for mediating between clients systems and natural language technology
- IDEAS Group,[36] a formal ontology for enterprise architecture being developed by the Australian, Canadian, UK and U.S. Defence Depts.
- Linkbase,[37] a formal representation of the biomedical domain, founded upon Basic Formal Ontology (http://www.ifomis.org/bfo/).
- LPL, Lawson Pattern Language
- NCBO Bioportal,[38] biological and biomedical ontologies and associated tools to search, browse and visualise
- NIFSTD Ontologies from the Neuroscience Information Framework: a modular set of ontologies for the neuroscience domain. See http://neuinfo.org
- OBO-Edit,[39] an ontology browser for most of the Open Biological and Biomedical Ontologies
- OBO Foundry,[40] a suite of interoperable reference ontologies in biology and biomedicine
- OMNIBUS Ontology,[41] an ontology of learning, instruction, and instructional design
- Ontology for Biomedical Investigations, an open access, integrated ontology for the description of biological and clinical investigations
- ONSTR,[42] Ontology for Newborn Screening Follow-up and Translational Research [4] (https://nbsdc.org/pdf/ONSTR_ICBO2013_NikolicEtAl_CameraReadyPaper.pdf), Newborn

Screening Follow-up Data Integration Collaborative, Emory University, Atlanta, GA. See also https://nbsdc.org/projectmission.php
- Plant Ontology[43] for plant structures and growth/development stages, etc.
- POPE, Purdue Ontology for Pharmaceutical Engineering
- PRO,[44] the Protein Ontology of the Protein Information Resource, Georgetown University
- Program abstraction taxonomy program abstraction taxonomy (http://www.eden-study.org/articles/2007/problems-ontology-programs_ao.pdf)
- Protein Ontology[45] for proteomics
- **SNOMED CT** (**S**ystematized **No**menclature of **Med**icine -- **C**linical **T**erms)
- Suggested Upper Merged Ontology, a formal upper ontology
- Systems Biology Ontology (SBO), for computational models in biology
- SWEET,[46] Semantic Web for Earth and Environmental Terminology
- ThoughtTreasure ontology
- TIME-ITEM, Topics for Indexing Medical Education
- Uberon,[47] representing animal anatomical structures
- UMBEL, a lightweight reference structure of 20,000 subject concept classes and their relationships derived from OpenCyc
- WordNet, a lexical reference system
- YAMATO,[48] Yet Another More Advanced Top-level Ontology

The W3C Linking Open Data community project coordinates attempts to converge different ontologies into worldwide Semantic Web.

Libraries

The development of ontologies for the Web has led to the emergence of services providing lists or directories of ontologies with search facility. Such directories have been called ontology libraries.

The following are libraries of human-selected ontologies.

- COLORE[49] is an open repository of first-order ontologies in Common Logic with formal links between ontologies in the repository.
- DAML Ontology Library[50] maintains a legacy of ontologies in DAML.
- Ontology Design Patterns portal[51] is a wiki repository of reusable components and practices for ontology design, and also maintains a list of *exemplary ontologies*. Started within the NeOn (http://www.neon-project.org) EU project.
- Protégé Ontology Library[52] contains a set of OWL, Frame-based and other format ontologies.
- SchemaWeb[53] is a directory of RDF schemata expressed in RDFS, OWL and DAML+OIL.

The following are both directories and search engines. They include crawlers searching the Web for well-formed ontologies.

- OBO Foundry is a suite of interoperable reference ontologies in biology and biomedicine.[54][55]
- Bioportal (ontology repository of NCBO)
- OntoSelect[56] Ontology Library offers similar services for RDF/S, DAML and OWL ontologies.
- Ontaria[57] is a "searchable and browsable directory of semantic web data" with a focus on RDF vocabularies with OWL ontologies. (NB Project "on hold" since 2004).
- Swoogle is a directory and search engine for all RDF resources available on the Web, including ontologies.
- OOR (http://www.oor.net) - the Open Ontology Repository initiative (http://OpenOntologyRepository.org) - http://oor.net

- ROMULUS (http://www.thezfiles.co.za/ROMULUS/) is a foundational ontology repository aimed at improving semantic interoperability. Currently there are three foundational ontologies in the repository: DOLCE, BFO and GFO.

Examples of applications

- In general, ontologies can be used beneficially in enterprise applications.[58] A more concrete example is SAPPHIRE (Health care) or *Situational Awareness and Preparedness for Public Health Incidences and Reasoning Engines* which is a semantics-based health information system capable of tracking and evaluating situations and occurrences that may affect public health.

Criticisms

Werner Ceusters has noted the confusion caused by the significant differences in the meaning of word ontology when used by philosophy compared with the use of the word ontology in computer science, and advocates for greater precision in use of the word ontology so that members of the various disciplines using various definitions of the word ontology can communicate. He writes 'before one is able to answer the question 'what is an ontology?', one must provide first an answer to the question 'what does the word ontology mean?'.[59]

It's also not clear how ontology fits with Schema on Read (NoSQL) databases.

See also

- Commonsense knowledge bases
- Controlled vocabulary
- Folksonomy
- Formal concept analysis
- Formal ontology
- Gene Ontology
- General formal ontology
- Lattice
- Ontology
- Ontology alignment
- Ontology chart
- Ontology editor
- Open Biomedical Ontologies
- Open Semantic Framework
- Soft ontology
- Terminology extraction
- Weak ontology
- Web Ontology Language

Related philosophical concepts

- Alphabet of human thought
- Characteristica universalis
- Interoperability
- Metalanguage
- Natural semantic metalanguage

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External links

Wikimedia Commons has media related to ***Ontology***.

- Knowledge Representation (http://www.dmoz.org/Reference/Knowledge_Management/Knowledge_Representation/) at Open Directory Project
- Library of ontologies (http://protegewiki.stanford.edu/wiki/Protege_Ontology_Library)
- GoPubMed (http://www.GoPubMed.com) using Ontologies for searching
- ONTOLOG (http://ontolog.cim3.net/wiki) (a.k.a. "Ontolog Forum (http://ontolog.cim3.net/forum/ontolog-forum/)") - an Open, International, Virtual Community of Practice on Ontology, Ontological Engineering and Semantic Technology
- Use of Ontologies in Natural Language Processing (http://trimc-nlp.blogspot.com/2013/08/nlp-driven-ontology-modeling-for.html)
- Ontology Summit (http://ontolog.cim3.net/cgi-bin/wiki.pl?OntologySummit) - an annual series of events (first started in 2006) that involves the ontology community and communities related to each year's theme chosen for the summit.
- Standardization of Ontologies (http://kore-nordmann.de/talks/09_04_standardization_of_ontologies_paper.pdf)

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