Semantic Engineering

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Abstract

The chapter shows how minimal assumptions on difficult philosophical questions suffice for an engineering approach to the semantics of geospatial information. The key idea is to adopt a conceptual view of information system ontologies with a minimal but firm grounding in reality. The resulting constraint view of ontologies suggests mechanisms for grounding, for dealing with uncertainty, and for integrating folksonomies. Some implications and research needs beyond engineering practice are discussed.

1 Introduction

Many computer scientists, geographers, geoscientists, cognitive scientists, philosophers, and knowledge engineers are concerned today with solving semantic problems posed by data about the environment. Their work has diverging goals and heated debates often ensue on foundations. For example, in *Beyond Concepts: Ontology as Reality Representation*, Barry Smith (2004) exposes some confused uses of the term *concept* in ontology. He proposes to replace concepts as the subject matter of ontologies by "the universals and particulars which exist in reality" and goes on to show that this choice yields a more precise understanding of foundational ontological relations, such as *is-a* or *part-of*. While he demonstrates the value of **dis-**

tinguishing universals and particulars, his arguments do not support abandoning the notion of concept, as elusive or abused as it may be. Debates on *universal* and *particular* are older and not easier to settle than those on *concept.* For example, the question what it means for particulars (such as Lake Constance) or universals (such as lake) to "exist in reality" remains unsettled. Thus, Smith's critique of concepts is mainly a (justified) exposure of some sloppy language use and modeling.

In defense of concepts, and in an information system context, this chapter advocates a pragmatic stance and an engineering view of semantics. A vast body of literature on ontology engineering for conceptual modeling (see, e.g., Guarino and Welti 2002; Guizzardi and Halpin 2008) shows how productive it can be to avoid throwing out the baby of concepts with the bathwater of its abuses. I will argue that this is so because

1. information system ontologies are only meant to *constrain the use and interpretation* of terms; they do not specify "the meaning" of these terms, much less "the existence" of universals and particulars in reality;
2. ontological constraint networks are *groundable* in physical properties of the environment; for semantics, no other assumptions are needed about reality.

These two assumptions support a linguistic *and* an engineering reading of concepts, make these two views compatible with each other, and anchor ontologies in reality. They commit to a mind-independent reality, but one in which no objects, universals or particulars need to be posited, only stimuli, which humans can detect and build concepts from.

The first assumption recalls Guarino's characterization of an ontology as "a set of logical axioms designed to account for the intended meaning of a vocabulary" (Guarino 1998). However, following the saying that "words don't mean, people do" and Putnam's arguments that meaning is not an object (Putnam 1975), I consider meaning to be a process. Furthermore, I treat this process as an engineering artifact. Similar to the processes running in a chemical plant, meaning processes can then be constrained in how they run: what people mean when they use a term, and how others interpret the term, can be described and influenced. Dictionaries or feature attribute catalogues, for example, constrain the uses and interpretations of words or geodata, respectively.

The second assumption ties ontological constraints to reality. Instead of a simplistic correspondence between terms and objects in reality, which is clearly untenable, it suggests a minimal and sufficient grounding of ontological constraint networks in elementary physical properties of the world. A related paper (Schneider et al. 2009) demonstrates and formalizes this grounding process, drawing heavily on Gibson's meaningful environment (Gibson 1986). Here, we will just posit the grounding capability as such and relate it by analogy to the grounding of geodetic networks.

Based on these two core assumptions, the chapter lays out an engineering view of semantics. The view has its roots in ontology engineering, but has a purely semantic purpose. It puts concepts (which are considered to be always associated with terms) at the center of attention and acknowledges that their descriptions are necessarily incomplete. Its goal is to enable information users and providers to constrain the uses and interpretations of their terms. *A semantic engineer designs processes of language use and interpretation.*

The chapter first shows that concepts can be treated as symbolic and social entities subject to constraints (section 2). Then, it explains the resulting view of ontologies as constraint networks (section 3), an understanding of grounding resulting from it (section 4), an integration strategy for folksonomies (section 5), and a mechanism for dealing with uncertainty (section 6). It concludes with a discussion of research challenges (section 7).

2 An Engineering View of Concepts

As Smith (2004) states, the lack of convincing definitions of *concept* and related terms like conceptualization is partly due to "the fact that these terms deal with matters so fundamental to our cognitive architecture (comparable in this respect to terms like 'identity' or 'object') that attempts to define them are characteristically marked by the feature of circularity." Replacing *concept* by *universal* and *particular*, however, does not solve this problem, as the age-old debates on realism, nominalism, and conceptualism show. For solving semantic problems, it may be more productive to agree on minimal requirements imposed on the notion of concept. This is what I attempt to do here, limiting foundational claims to relatively uncontroversial ones, and not attempting a formal definition of *concept*. This section states these claims and proposes an interpretation of the popular semantic triangle capturing them.

2.1 A triadic notion of concepts

For the purposes of semantic engineering, it is necessary and sufficient to posit a threefold nature of concepts, involving

- *terms* (symbols, words, expressions),

- which evoke and *express ideas* (thoughts) and
- are used to *refer to reality*.

For example, in speakers of English, the word lake evokes an idea of a water body connected to other water bodies and having properties like a relatively flat surface and a water depth. The word may be used to refer, for instance, to that large amount of blue, wet substance near Constance, as an instance of the kind (lake) or as a named individual (Lake Constance). For German speakers, the words See and Bodensee play the same roles, respectively.

Concepts are considered here to be associated with terms in a language, not detached from them, so that the English word lake and the German word See belong to two different concepts, regardless of whether they are used to refer to the same parts of reality or not (see also Mark 1993). The German term *Begriff* may make this close association between words and thoughts more explicit than the more abstract English term *concept*; its root *begreifen* (touch) furthermore points to the embodied nature of concepts.

2.2 The Semantic Triangle Revisited

The triadic notion of concepts goes back as far as Aristotle (Sowa 2000) and is often represented by a semantic (or semiotic, or meaning) triangle (Ogden and Richards 1923), with one corner for each of the three aspects (Fig. 1).

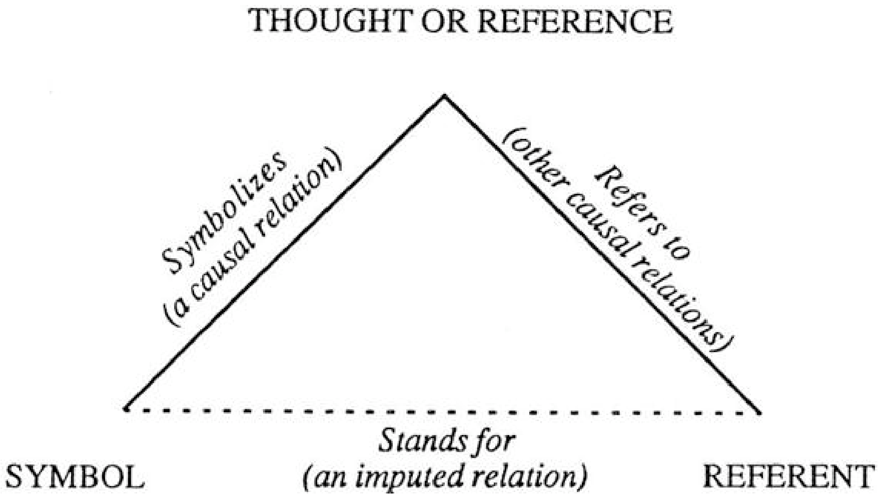

Fig. 1. A form of the meaning triangle, adapted from (Ogden and Richards 1923)

Note that Ogden and Richards (1923) avoid the term "concept" in their triangle altogether and point to many imprecise uses of the term. For the purpose of semantic engineering, it is sufficient to posit that the corners of the meaning triangle represent the three aspects of concepts identified above.

Many discussions of the semantic triangle make assumptions about each corner that are difficult to justify. For example, they label the top corner "Concept", claim that the REFERENT corner represents "Objects", and define SYMBOLs such as to carry some fixed meaning in and of themselves. These and other assumptions about meaning are unnecessarily strong and probably wrong. The following discussion relaxes some assumptions, makes the remaining ones more precise, and emphasizes the social embedding of the triangle, which is normally neglected in its discussion.

First, the top corner of the triangle shall, for our purposes, remain a black box to which semantic engineers have no access, except by assuming that the use of symbols expresses and evokes some thoughts in some people, and that these thoughts are shaped by observations of reality.

Second, the right corner of the triangle is understood here as anything external to minds that is shared in an information (or language) community. It provides physical stimuli, which people can observe and agree on. Reality, in this context, is what we observe and what we talk about using symbols. Objects, particulars, and universals do not need to be assumed to exist in a mind-independent reality; they can be cognitively or socially constructed. This position does not exclude stronger claims about reality, but avoids the two-fold circularity of defining universals "as that in reality to which the general terms used in making scientific assertions correspond" and particulars as "the instances of such universals" in (Smith 2004).

Third, the left corner contains the symbols of the language whose semantics is in question, including symbols denoting relationships (such as flowing into). For artificial languages, like those of information systems, one can *design* these symbols as well as the conditions for their use. This language design capacity reinforces the idea of semantic engineering.

The *edges* of the triangle represent relations between the corners, generated by human activities:

1. People *observe* reality and form thoughts; for example, the repeated occurrence of extended horizontal water surfaces may suggest a category of lakes.
2. People *express* thoughts through symbols; for example, one may notice a water surface, while flying over it, and say "we are flying over a lake".

3. Communication succeeds when others interpret how the symbols *refer* to reality; for example, a seat neighbor on the plane might respond "it must be Lake Constance".

With the edges of the triangle representing *many-to-many* relations, perspectivalism and polysemy are fully admitted, as they should be. Reality induces all kinds of thoughts, depending on perspectives taken, which are in turn expressed in multiple ways as symbols, and the symbols are used to refer to reality in many ways, even within a single language community.

The triadic notion of concepts avoids their reduction to purely linguistic or purely mental entities. The symbolic and mental sides are necessary and inseparable components of concepts and the reference to reality grounds them. The concepts constructed by a language community are not arbitrary, and they are not just entities created by modelers. Rather, they are what Smith calls "tools (analogous to telescopes or microscopes) which we can use in order to gain cognitive access to corresponding entities in reality" – except that *some of* the corresponding entities are mentally and socially constructed, while others are directly observable.

Finally, the proposed view of concepts also acknowledges their social aspects. In information systems, as well as in communication in general, terms can only be used to refer to something if there is a language community establishing and sustaining this use. The semantic triangle does not make this social aspect explicit, which is one of its weaknesses. Implicitly, however, all its corners and edges require concepts to be situated in a community sharing a language (or parts of it).

3 Ontologies as Networks of Constraints

Ontologies, in our semantic engineering view, constrain the use and interpretation of terms in an information community. For example, a hydrology ontology constrains how terms like lake or waterbody should be used and interpreted. The non-logical symbols of an ontology stand for concepts and relations and its logical sentences constrain these. For instance, the constants `lake` and `waterbody` in the sentence

```
lake is-a waterbody
```

stand for the concepts lake and waterbody, respectively. By committing to the ontology, a hydrological information community constrains these two concepts through the `is-a` relation. The consequence is that anything stated about water bodies applies also to lakes. For example, the ontology could state that

```
waterbody has-a waterdepth
```

and thereby also constrain all lakes to have a water depth quality. By adding more and more sentences, such as

```
river is-a waterbody
```

a network of constraints is incrementally being built up, narrowing the possible interpretations and uses of terms.

Some symbols may be introduced in the ontology for completeness or convenience, without necessarily expressing a domain notion. For example, in a sentence

```
every river flows_into a waterbody
```

the relation *flows_into* may express a notion of flowing into used in the hydrology community, but it may also be an auxiliary concept used in the ontology only.

While the notion of *concept* is typically reserved for universals in the literature, ontologies can also constrain terms for particulars, in sentences like

```
LakeConstance instance-of lake
```

or

```
Rhine flows_into LakeConstance.
```

This generalization allows for reasoning on individuals in the ontology, not just in a database or GIS, where this kind of reasoning is typically (and often more efficiently) performed. Gazetteers are a good example for the need of a combined reasoning on universals and particulars (Janowicz and Keßler 2008). Also, ontological specifications of geographic kinds, like lake or mountain, may refer to the (individual) surface of the Earth, of which all their instances are parts.

The semiotic function of ontologies themselves (representing concepts in logical languages) does not require the second meaning triangle that is sometimes proposed (Sowa 2000). The symbols of the ontology can be taken to *be* the symbols of the object language (for example, of hydrology terms), or syntactic variants of them, expressing the same thoughts and referring to the same reality.

4 Grounding Constraint Networks

Treating ontologies as networks of constraints can give us an understanding of what it means to ground them. The nodes and edges of a network of concept specifications can be further constrained by observations. For example, the node *lake* in the ontology can be tied to polygons representing lakes in a GIS database, as proposed in (Bennett et al. 2008), or the node *waterdepth* can be tied to an observation procedure, as in (Schneider et al. 2009). Such observational information is then propagated through the network and further restricts possible interpretations of all connected terms. If it is supplied in symbols that are grounded in physical reality, this grounding propagates through the network.

Grounding is a process of adding information on the variables of a conceptual network through observations anchored in physical stimuli. This idea concurs with Quine's notion of observation sentences (Quine 1960). Anchoring typically occurs in measurement units, other reproducible conventions about measurement (such as agreements on zero values), and fundamental observable properties of the environment (like the fact that two different media are separated by a surface). While a complete theory of ontology grounding remains to be worked out, I will explain the main idea here using a geodetic analogy. A worked out example and the relation to environmental psychology are presented in (Schneider et al. 2009).

Geodesists are familiar with the idea of grounding a constraint network: using triangulation networks, they compute coordinates from observations of distances and directions. The distance and directions are expressed as constraints, which are parameterized in the coordinates and thereby map the coordinate space to an observation space (Vaníček et al. 1982). The networks are grounded through measurement units and externally supplied coordinate values, which are both anchored in the physics of the earth.

The grounding of triangulation networks is called a *geodetic datum*. It ties the social constructions of coordinate systems (in particular, their equator and zero meridian) to the body of the earth. Broadly speaking, the earth's shape determines the ellipsoid on which the coordinates are defined, the mass center anchors it in space, and the rotation axis orients it. The essence of this grounding scheme is to achieve *reproducible* interpretations of coordinates: one can take any coordinates and reconstruct the corresponding real-world location, at least in principle.

A geodetic datum determines the interpretations of the coordinate *concepts* used to describe location, i.e. of coordinates as such, not just of particular coordinate values. It explains the notions of latitude and longitude operationally, by giving a recipe of how they are measured. Seen as networks constraining concepts, triangulation networks constrain the interpretation of coordinates, distances and directions. Practically, these pose no semantic problems, since methods exist to compute the necessary interpretations. For coordinates, these methods are the coordinate reference systems (ISO 2002) commonly used in GIS and other geospatial information technology. For distance and direction measurements, they are the SI system of measurement units (SI). The former, of course, are themselves anchored in the latter.

Conceptually, this interpretation procedure for coordinates supplies an analogy for interpreting terms like lake or waterdepth. Both kinds of interpretation processes, geodetic and general, first map the symbols to observations and then ground this mapping in physical reality. Such an analogy is at the heart of the notions of a semantic reference system and semantic datum introduced in (Kuhn 2003; Kuhn and Raubal 2003). Here, we have extended it to a constraint view of ontologies, to clarify the notion of ontology grounding.

It should be noted that grounding can never be absolute. A geodetic datum rests on geophysical models (e.g., for the mass distribution of the earth) and on astronomical frames of reference (star positions). Strictly speaking, these assumptions harm the reproducibility of coordinate positions. More generally, a semantic datum can only shift the need for interpretation to a reference frame at the next level. Practically, this shift should (by design) solve most semantic problems. Philosophically, however, the caveat may be useful to consider by ontologists making stronger assumptions about reality.

5 Integrating Folksonomies with Ontologies

A further gain of a constraint view of ontologies is that it connects ontologies to folksonomies. Folksonomies are non-hierarchical lists of keywords (tags) linked to information resources. For example, a web site describing a bicycle tour around Lake Constance[1] has been tagged with the terms cycle, tour, austria, bregenz, lake, constance by a user of the social bookmarking site delicious.com[2].

Folksonomies are not related to taxonomies, despite their name, but provide data about the terms people associate with contents. They do not contain logical axioms, but tuples linking terms to resource identifiers (and to the tagging users). These tuples constrain interpretations of the terms used as tags, by showing their use and its evolution over time. They constrain the interpretations bottom-up, complementing the prescriptive top-down constraints of ontologies. For example, delicious.com reveals what contents are tagged by terms like lake and/or river.

[1] http://www.bicyclegermany.com/lake_constance.htm

[2] http://delicious.com/url/a8dccabc65ed02711e150a743f226fff?show=all

Folksonomies are easy to generate and use, do not burden users or producers with difficult modeling tasks, and clearly have something to tell us about the semantics of their terms. They are, in fact, an increasingly popular form of empirical semantic data. Other such forms come from data mining and similar knowledge extraction methods. All these inductive approaches to semantics play a key role in the automated learning and maintenance of terminological constraint systems.

6 Accommodating Uncertainty

Constraint networks provide great flexibility in information handling, by admitting any number of constraints on any of their variables. As a consequence, they have to provide methods to accommodate uncertainty, since the stated constraints may over- or underdetermine an exact solution. In the case of triangulation networks, as well as for many other cases, one considers all variables and observables to be stochastic, i.e., having a probability density distribution (Vaníček 1982). Relative weights on the constraints can then be derived from knowledge or assumptions about this distribution, i.e., about the precision of the constraints.

Zadeh's Generalized Constraint Language (Zadeh 2008) provides the formal framework to extend this idea to general cases of "computing with words". Perception-based statements, i.e., observations, can be precisiated by any suitable means (for example, by probability distributions or fuzzy set membership curves), and their impact on a solution for the network variables can be computed.

This methodology of Zadeh bridges the traditional two-valued logic ontologies to the constraint-based view suggested here, where semantic information is *by default* considered to be uncertain. The main difference to geodetic or other geometrically well-defined cases is that conceptual networks have no clear-cut degrees of freedom. Grounding can therefore not easily be determined to be sufficient, but the geodetic ideas that

- grounding spreads through the network;
- arbitrary observational information can be added;
- assumptions on the relative precision of this information serve to weigh its impact;

remain valid in the "computing with words" scenario of semantic engineering.

7 Conclusions

Semantic engineering constrains interpretations of terminologies. It improves mechanisms for information sharing by using semantic web and social web technology to formulate and evaluate constraints on interpretations. It makes only minimal assumptions about difficult philosophical issues (reference, realism vs. nominalism, cognitive processes), in order to allow for pragmatic solutions to semantic problems.

The proposed engineering view of semantics avoids the pitfalls of treating ideas decoupled from language (and thereby treading on thin ice regarding testability of its hypotheses) or treating terminology decoupled from its use (and thereby limiting semantics to linguistic relations). Instead, it rests on a notion of concepts that necessarily involves expressions in a language and ties them to reality. It specifies concepts in constraint networks and grounds ontological constraints in observations of reality. Thereby, it admits conceptual theories, but avoids engaging in psychological speculation about what ideas people may have about the world. The matter of study (and of engineering design) is how people apply terms to refer to something in the world that is either commonly observable in an information community or traceable to something that is.

What these observable aspects exactly are is a question discussed elsewhere (Schneider et al. 2009). It constitutes one of the core research questions raised by semantic engineering. Frank has proposed ontological tiers to capture references to reality at multiple levels of abstraction (Frank 2001). Here, I refrain from assuming anything about such levels (e.g. about their ordering or about the role of objects) and only posit that observation sentences (in the sense of Quine) exist, so that primitive symbols can be interpreted through ostension. While there may be philosophical quibbles against this position as a general requirement, it appears to rest on solid ground in the context of geospatial information, which is per definition rooted in observations of the environment.

Ontology research has made limited use of the idea that ontologies are networks of constraints on concepts. Yet, concept networks have been a central idea in dealing with semantics for a long time, both in linguistics (Langacker 1987) and in computing (Woods 1985). Networks of constraints are a standard device in many areas of engineering and computing. The chapter has shown that ontologies seen as constraint networks supply mechanisms for grounding, for accommodating uncertainty, and for integrating folksonomies.

Mechanisms for the formal treatment of ontological constraint networks, including their grounding and uncertainty, remain to be refined and implemented. It appears that model theory is a sufficient formal basis, if observable aspects of reality are admitted as models, as proposed, for example, in (Hayes 1985). These models are then algebraic, consisting of observable qualities and their changes, and transcend the naïve set-based model theory of formal semantics.

Picking out *one* symbol and considering only *one* sense of it turns the relations at the edges of the meaning triangle into functions. This allows for a categorical formalization of the triangle, where the *refer* function is treated as a composition of *observe* and *express* functions. Thereby, semantic theories may get connected to theories of change and action (Kuhn 2005), explaining semantics through observable effects of processes. For example, this would make it possible to explain why the seat neighbor in the flight over Lake Constance might leave his seat after the above dialogue to stretch his legs before an expected landing in Zurich.

The combination of linguistic, mental, empirical, and social aspects of concepts advocated here allows for constraining how information producers and consumers interpret terms. It permits agreements on such interpretations in the form of ontologies and it can deal with their evolution over time. This pragmatic position has nothing to do with “cultural relativism”. It rests on the basic scientific paradigm of knowledge derived from observations. It is compatible with, but does not require, a stronger form of realist semantics, but avoids some pitfalls of both, realist and cognitive semantics. For example, it has no need to invoke truth independently of meaning, or to decide which entities have correspondents in reality and which not, nor does it have to assume unverifiable cognitive mechanisms. The only cognitive claim is that humans interpret the terms they use, and that this interpretation is ultimately based on ostension. An appropriate philosophical basis for such a view is radical constructivism (Glasersfeld 2002), which treats human conceptualizations and knowledge as constructions, constrained by observations and interactions with other individuals and with the environment.

Smith’s program of *ontology as science* (Smith 2008) is compatible with, but cannot replace an engineering approach; at least not in the context of geospatial information, which exhibits multiple and often conflicting conceptualizations of reality. A single reference ontology (which Smith pursues for biomedical information) is unlikely to emerge any time soon for geospatial domains.

Meanwhile, putting application terminology on a solid basis in the form of foundational ontologies (such as DOLCE, BFO, CIDOC-CRM, SUMO) helps making sensible general distinctions. For example, universals and particulars, endurants and perdurants, or different types of qualities are usefully distinguished, though the distinction ultimately rests on human conceptualizations. DOLCE's distinctions suggest a notion of primitive qualities, which support grounding in observations. This kind of anchoring of ontologies is likely to support ontology mappings at least as effectively as the abstract scientific notions from a reference ontology, which are almost guaranteed to be interpreted differently in multiple applications.

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