Cognitive Semantics and Spatio-Temporal Ontologies

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Cognitive semantics has established close ties between semantics and spatial cognition. Yet, applications of cognitive semantics to the design of spatio-temporal ontologies remain difficult and rare. Ideas such as image schemas, prototypes and radial categories, basic level categories, mental spaces, and conceptual blendings are still largely unexplored in their potential for ontology engineering. The only idea that has received wide-spread attention in the ontology community so far is that of conceptual spaces (Gärdenfors 2001).

The following special issue presents work at the intersection of several lively research areas contributing to ontology engineering. It originates in a workshop on the *Potential of Cognitive Semantics for Ontologies* that was held in conjunction with FOIS 2004, the International Conference on Formal Ontology in Information Systems (http://www.formalontology.org). A substantial part of the workshop contributions addressed the role of space and time, either as shaping cognition or as subjects of ontologies. The call for papers to this special issue built on the workshop contributions, discussions, and results (http://musil.uni-muenster.de/workshop2004/), but was open to any submissions on the role of cognitive semantics in ontologies of space and time. Fourteen papers have been submitted and each of them has been refereed by at least three internationally renowned scientists. Of the selected four papers, two were written by workshop participants and two were contributed by others. This introductory section provides a broader introductory perspective on the topic and relates the four papers to it.

Motivation

To motivate research in this area, one might provocatively ask whether information system ontologies, as used in the semantic web and elsewhere, have anything to do with meaning. Or, more specifically, where do the predicates formalized in ontology languages such as OWL (the web ontology language, http://www.w3.org/2004/OWL/) get their meaning from (Gärdenfors 2004)? Formal semantics treats meanings of symbols in a language as mathematical objects (typically as sets). Yet, semantics, no matter what formalisms are applied to it, is a cognitive phenomenon: it refers to the meaning that symbols have for human beings. It is determined by individual and cultural factors, involving human minds anchored in a spatio-temporal world and constrained by the conventions of a language or information community. This basic position about semantics is best captured by the saying that "words don't mean, people do". Since mental interpretations and community conventions are typically inaccessible, ontology engineers face the problem of capturing enough of the cognitive and social contexts of information in their formalizations. However, current information system ontologies typically explain predicates in terms of more abstract, rather than more meaningful symbols. It is essential that ontology systems assign the same meanings to the symbols as their users do, or provide the necessary transformation mechanisms, lest they will be unusable. So, how do the symbols become meaningful?

Tenets of cognitive semantics

Cognitive semantics is asking similar questions for natural languages as well as for symbol systems in general. It studies, among other issues, what the embodied nature of language can tell us about how human minds construct meanings, or what the socially situated nature of language suggests as social mechanisms and constraints on the use and development of concepts and languages. Some core ideas characterizing a cognitive approach to semantics are:

I. *Meaning is conceptualization in a cognitive model (not truth conditions in possible worlds).*

A semantics for a language is seen as a mapping from the expressions of the language to some cognitive or mental entities. A consequence of the cognitivist position that puts it in conflict with many other semantic theories is that no form of truth conditions of an expression is necessary to determine its meaning. The truth of expressions is considered to be secondary since truth concerns the relation between a cognitive structure and the world. To put it tersely: Meaning comes before truth.

II. *Cognitive models are mainly perceptually determined (meaning is not independent of perception).*

Since the cognitive structures are connected to our perceptual mechanisms, directly or indirectly, it follows that meanings are, at least partly, perceptually grounded. This, again, is in contrast to traditional realist versions of semantics that claim that since meaning is a mapping between the language and the external world (or several worlds or formal models of them), meaning has nothing to do with perception.

III. *Semantic elements are based on spatial or topological objects (not symbols that can be concatenated according to some system of rules).*

The mental structures applied in cognitive semantics are the meanings of the linguistic idioms; there is no further step of translating conceptual structure to something outside the mind. The conceptual schemes that are used to represent meanings are often based on geometric or spatial constructions. The most important semantic structure in cognitive semantics is that of an image schema. Image schemas have an inherent spatial structure. Most image schemas are closely connected to kinesthetic experiences (Johnson 1987). This also relates them to the notion of affordances (Gibson 1977), i.e. to perceivable ways that the environment offers us to experience it.

IV. *Cognitive models are primarily image-schematic (not propositional). Image schemas are transformed by metaphoric and metonymic operations (which are treated as exceptional features in the traditional view).*
Metaphors and metonymies have been notoriously difficult to handle within traditional semantic theories. In contrast, they are given key positions within cognitive semantics. Not only poetic metaphors but also everyday creative and 'dead' metaphors are seen as central semantic features and are given systematic analyses. They are analyzed as transformations of image schemas. As such they are connected to spatial codings of information. In particular, Lakoff (1987, p. 283) puts forward what he calls the 'spatialization of form hypothesis' which says that conceptual forms are understood in terms of spatial image schemas plus a metaphorical mapping. Furthermore, Lakoff’s (1990) ‘invariance hypothesis’ suggests that image schemas are the structures left invariant in metaphorical and metonymic mappings. More recent work generalizes these notions to mental spaces and blendings (Fauconnier and Turner 2002), offering a more powerful and precise framework for conceptual mappings.
V. *Concepts show prototype effects (instead of following the Aristotelian paradigm based on necessary and sufficient conditions).*
The classical account of concepts within philosophy is Aristotle's theory of necessary and sufficient conditions. As a result of a growing dissatisfaction with this theory, an alternative theory was developed within cognitive psychology (Rosch 1978). This is the so-called prototype theory where the main idea is that within a category of objects, like those instantiating a property, certain members are judged to be more representative of the category than others. For example, robins are judged to be more representative of the category 'bird' than are ravens, penguins and emus; and desk chairs are more typical instances of the category 'chair' than rocking chairs, deck chairs, and beanbag chairs. The most representative members of a category are called prototypical members.
Another thesis of prototype theory is that categories are not organized just in terms of simple taxonomic hierarchies. Instead, a 'middle' kind of concepts can be distinguished, which is called the basic level of the categorization. Higher levels are called superordinate and lower subordinate. For example, 'chair' and 'dog' are basic level concepts, while 'furniture' and 'mammal' are superordinate concepts and 'armchair' and 'dachshund' are subordinate. Within cognitive semantics, one attempts to account for prototype effects of concepts. A concept is often represented in the form of an image schema and such schemas can show variations just like birds and chairs. This kind of phenomenon is extremely difficult to model using traditional symbolic structures.
VI. *The foundation for human categorization are similarity judgments, not lists of necessary and sufficient features.*
Consequently, the definition of similarity measures (Tversky 1977) becomes central to the construction and use of ontologies. Similarity notions range from purely syntactic ones (based on alphabetical “distances”) to complex, cognitively more plausible proposals.

With such a long list of widely researched cognitive approaches to semantics, how can it be that there is only sparse work on information system ontologies taking any of these notions seriously, and even less that formalizes and applies them fruitfully?

Why cognitive semantics matters for ontology

Since all information is ultimately for and from human beings, its semantics needs to relate to meanings in human minds. These meanings have observable effects, primarily in the form of actions in the world resulting from understanding. Current notions of meaning applied to ontology emphasize realist semantics (where phenomena in the world are considered to *be* the meaning of expressions) over cognitive semantics (where meaning is a psychological phenomenon, based on phenomena in the world) and situated embodiment (where meaning also involves the social settings of language use). The workshop and this special issue were motivated by a desire to balance and integrate these notions of meaning and work toward more powerful theories of meaning in support of ontology engineering.

Some core questions unifying the work of interest at this intersection of cognitive and information sciences are:

1. How do formal models of semantics (e.g., in the "Semantic Web") become *meaningful* for humans?
2. Do *space and time* play a special role in explaining and representing meaning?
3. What is *special about spatio-temporal* ontologies from a cognitive semantics perspective?
4. What kind of *formalisms* best capture what ideas from cognitive semantics?

Expected benefits to ontology engineering

As editors of this issue and researchers having worked on such questions for many years, we see a number of specific ways in which ontology and ontology engineering, particularly for spatio-temporal applications, is to gain from cognitive semantics. Among them are the following:

- *Grounding ontologies*, i.e. establishing primitives that are both meaningful and suitable as building blocks for ontologies. Whether these primitives are entities, processes, qualities, combinations of these, or yet something else remains to be seen, but cognitive semantics notions offer some candidates (Kuhn 2005).
- Moving space and time from their current status as application domains to become *foundational* aspects of ontology. The findings about the strongly spatial and dynamic nature of human conceptualizations, particularly of abstract domains, suggest a much stronger role for space and time than they currently have.
- Moving ontologies from their predominantly static nature to a stronger *process-orientation* (Grenon and Smith 2004; Raubal and Kuhn 2004). Cognition is increasingly recognized as being shaped by process and action much more than by static structure. Many of the cognitive semantics notions listed above have a dynamic flavor, even if they are still too often described and formalized statically.
- Reconciling *meaning and truth*. Realist semantics has established a notion of meaning that is entirely based on truth (of sentences in some formal models). Cognitive semantics, on the other hand, has sometimes lost sight of observable, hard facts and shared reality when studying individual cognitive phenomena. While it remains a puzzle how one can establish truth without meaning, the ideas

of embodiment and situatedness provide strong and dynamic links between the two.

- Allowing for *perspectivalism* in ontology, without giving in to relativism. It is primarily spatial domains which show how important it is to admit multiple perspectives on reality, e.g. in the form of multiple granularities (Bittner and Smith 2001) or as dependent on the context. However, these perspectives are linked by and grounded in some fundamental properties of the world and of human cognition.
- A cognitively plausible or even adequate understanding and formalization of *conceptual mappings*. Metaphor and blending theories have revealed a great deal about the ways concepts get mapped within and across domains. They have also shown striking parallels with notions in mathematical category theory, offering powerful support for formalizations of mappings. Applications to ontology mappings in spatio-temporal domains can furthermore benefit from an analogy to spatio-temporal reference systems (Kuhn 2003).
- A sound theory of conceptual mappings would lead directly to an *enhancement of human-computer interaction*: Communication between systems and their users is made possible through the mutual understanding of terms and concepts. If we want geospatial services and tools to give better answers to user queries it is necessary to bridge and eventually resolve the discrepancy between user concepts and system concepts. By applying and utilizing conceptual mappings it will be possible for a system to adapt the semantics of its concepts to the user's semantics, which eventually leads to improved human-computer interaction (Raubal 2004).
- *Personalizing* geospatial services: People's information needs depend on situational and personal context. In order to find both *useful* and *usable* solutions to people's geospatial problems it is therefore essential to consider diverse concepts, cognitive and spatial abilities, and strategies during the problem-solving process. A cognitive semantics approach to designing spatio-temporal ontologies underlying these geospatial services accounts for the fact that different people have different conceptualizations of the world and therefore require different answers and presentations of answers to their spatio-temporal questions.

While this list is surely not exhaustive, and shaped by our own work and interests, it should convey the appeal of cognitive approaches also to those who have not yet considered them or struggle with problems to which they might contribute solutions.

The contributions in this issue

The special issue presents a snapshot of ongoing work in this direction, rather than a compendium of achievements. It is primarily meant as an incentive to initiate more work at this fruitful intersection of engineering, computing, mathematics, ontology, and cognition. The four papers following this introduction share the general spirit of bringing information system semantics closer to human cognition, and making ontologies more powerful. They cover a broad spectrum of ideas, ranging from specific cognitive notions and their formalization as upper level ontological categories through empirical work on concept formation and evolution, to more powerful mathematical approaches to deal with mappings between different conceptualizations.

Kai-Uwe Carstensen, in *Spatio-temporal Ontologies and Attention,* proposes to use attentional patterns as upper level categories for spatio-temporal ontologies. Attention produces explicit and unique spatial relations, where the objective configuration of objects would allow for multiple descriptions. For example, by shifting our attention from a table (with many implicit relations to objects on it or surrounding it) and zooming to a specific cup on it, we establish a "microperspective" that generates explicit figure-ground (or trajector-landmark) relations, allowing us to say (and to understand) that "the cup is on the table". A dominant factor in such attentional selections is boundedness, both in space and time. Carstensen sketches upper level ontological distinctions for entities (including objects, masses, events and processes, but excluding qualities and abstractions), based on attentional criteria. The innovation and motivation of this work lies in a treatment of spatial relations that is based on attentional shifts rather than on static geometry or on function. It accounts for both linguistic data and recent evidence on cognitive spatial relation processing. The implications of Carstensen´s approach are potentially even broader: by highlighting the representational aspects of selective attention patterns, it also presents new criteria for the design of cognitively motivated ontologies, and sheds a new light on cross-domain relationships, e.g., in linguistic metaphors.

Olav K. Wiegand proposes *A Formalism Supplementing Cognitive Semantics Based on Mereology.* He focuses on the notion of Gestalt, which has a long history of influencing spatio-temporal theories. The structuring of entities into structures of parts depends on the perspective taken by an observer and therefore calls for cognitive theories. Mereology, which studies part-whole relationships, is therefore one of the areas where logical theories are already being applied to cognitive phenomena. Wiegand goes beyond standard mereological theories and formalizes Gestalts as structured wholes, capturing the interdependence of parts and the context of a certain part-whole relationship. He introduces R-structured wholes as a solution to the vexing question whether part-whole relations are transitive (i.e., whether John's nose is part of the Berlin Philharmonic if John is). An elementary language to describe R-structured wholes is being proposed, with the goal to support reasoning about Gestalts, where reasoning is understood as a sequence of cognitive transformations.

In *Experiments To Examine The Situated Nature of Geoscientific Concepts,* Brodaric and Gahegan provide empirical evidence from geological fieldwork for several ideas in cognitive semantics. In particular, they supply strong support to their own idea of "situated concepts", i.e., concepts like *Dakota Sandstone*, which are more specific than domain universals (*Sandstone*), but more general than individuals (*Dakota*). The specificity may stem from a regional context, but also from other natural, scientific, or human situations, such as a historical context or a new theoretical insight. The generality is important to highlight the categorizing effect of such concepts, distinguishing them from a pure instance labeling. Interestingly, situated concepts depend on actual process instances, rather than on process types, distinguishing them from affordance-related ideas. Situated concepts are necessarily context-dependent; their origin may depend on examples encountered first, and they can evolve over time within a process. Thus, incorporating them into ontologies is a promising way to more dynamic theories of meaning. Through a detailed statistical analysis of clusters in a conceptual space representation, the authors are able to identify and distinguish the influences of field observations, domain theories, and physical or human situations on concept formation and evolution in geological fieldwork. An implication of their results for formal ontology is that meaning representation for some concepts would seem to require representation of their situational context.

Admitting multiple perspectives on space-time raises the question of how to combine them. John Bateman, Stefano Borgo, Klaus Lüttich, Claudio Masolo, and Till Mossakowski address this question in their study of *Ontological Modularity and Spatial Diversity*. The challenge is to select a foundational ontology that does not impose a particular view of space, and a specification mechanism for mappings (morphisms) between multiple ontologies. The authors identify DOLCE as the only foundational ontology allowing for alternative views of space and qualities. Combining it with CASL as an algebraic specification language, they establish a general mechanism for relating modular ontologies and formalizing theory morphisms between them. A standard software engineering technique has, thus, found its way into ontology engineering, and promises the well known benefits of modularity in terms of reuse, refinement, and complexity reduction. The authors introduce the central notion of a *view* (from CASL) to map from one ontological specification to another. They apply their method to a spatial example involving two graph conceptualizations of space (as a transportation network and as a route graph), a region conceptualization (for sections of a town), a qualitative distance notion and simple physical qualities such as color. With the natural inclusion of type and token level knowledge in their specification, it becomes possible to express queries (or, in their case, wayfinding instructions) as theorems to be proven by using multiple logical theories. Their formalization approach also captures the cognitive notion of conceptual blends and should therefore offer great power to capture many cognitive semantics phenomena, especially those arising in information integration.

Acknowledgments

We sincerely acknowledge the great efforts from the submitting authors, and the dedicated help from the reviewers. The participants of the workshop at FOIS 2004 gave us the confidence that the topic warrants follow-up activities like this issue. Too many colleagues and friends to name individually have encouraged, accompanied, taken up, and, most importantly, criticized our work in this area.

List of reviewers

The following colleagues wrote very helpful reviews for one or more submissions to this issue: Ola Ahlqvist, Michel Aurnague, John Bateman, Mike Batty, Melissa Bowerman, Gilberto Câmara, Helen Couclelis, Matt Duckham, Fred Fonseca, Andrew Frank, Mirjam Fried, Antony Galton, Aldo Gangemi, Pat Hayes, Jerry Hobbs, Kim Kastens, Marinos Kavouras, Bernd Krieg-Brückner, Benjamin Kuipers, Ron Langacker, David Mark, Claudio Masolo, Dan Montello, Barry Smith, John Stell, Laure Vieu, Anna Wierzbicka, Stephan Winter, Michael Worboys. Additional reviewing comments were provided by Frank Dylla, Krzysztof Janowicz, Till Mossakowski, Florian Probst.

Dedication

This special issue is dedicated to Joseph Goguen, formerly Professor in the Department of Computer Science and Engineering, University of California at San Diego. He inspired the work that led to the issue, back in 2003, when he suggested organizing a workshop on cognitive approaches to spatial semantics. He then participated at the FOIS workshop as a keynote presenter and active discussant. Though he was planning to submit a manuscript to this issue (on modeling image schemas using nonlinear dynamical systems theory), his health did not permit this. In July 2006, Joseph passed away. He leaves us with an immense range of profound contributions to many areas of science and the arts - and with the obligation and inspiration to carry on.

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