Elements of a Computational Theory of Location

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SUMMARY

Location is fundamental to geospatial information. Arguably, it is the most basic notion to be specified in ontologies of the geospatial domain. Existing theories of location provide a useful basis for such ontologies, but are not constructive and therefore not directly applicable in computational settings. This paper introduces the elements of a computational theory of spatial location. The theory is being developed as a corner stone for a geospatial domain ontology in support of semantic interoperability. It is based on generalized localization functions and on image-schematic locating relationships.

KEYWORDS: *geospatial ontologies, location, profiling, image schemas.*

1. INTRODUCTION

What is the meaning of "where"? How can one describe where something or somebody is located? The plethora of possible answers to such questions is a challenge to any attempt at a general and computationally applicable theory of location. In geoprocessing practice, the notion of location is mostly taken for granted, often in the simplistic sense of sets of points described by coordinates. In ontological analyses, various notions of location are described by axioms, but the notions are usually not defined constructively, i.e., no methods are given to compute and test them.

A computational theory has constructive axioms, which describe how to compute its predicates. The need for computational theories of location becomes apparent in semantic interoperability settings, where systems and services based on different notions of location require *semantic translation* to cooperate (see http://musil.uni-muenster.de/index.php?m=problems). For example, a service chain that calculates a plume of chemicals resulting from an accident needs computable notions of the locations attributed to the accident and to the relevant meteorological measurements. It does not necessarily need precise locations, but precise *meanings* of the locating data and operations.

The approach presented here builds on existing treatments of location and extends them to treat location constructively, targeting a typed theory with a higher-order logic. In addition to this formal power, it applies location concepts from cognitive science. Cognitive semantics has put forward the ideas of *profiling* (Langacker 2002) and of *image schemas* (Johnson 1987). Both capture essential aspects of location (e.g., projection, parthood, containment, support, contact, linkage). Their existing formal treatments tend to take the locating aspect for granted. Our approach emphasizes this aspect, with the goal of making the theory of location cognitively plausible.

This presentation introduces the theory informally, through its key concepts of *localization functions* and *locating relationships*. Our goal is to establish the conceptual elements of a theory of location, while avoiding a debate on terminology that would result from a discussion of the meaning of location terms. After discussing previous work in section 2, we introduce localization functions (section 3) and locating relationships (section 4) as the basic building blocks for a computational theory of location. We conclude with a discussion of future work and open problems (section 5).

2. PREVIOUS WORK

A comprehensive, but not constructive, axiomatization of localization is given in (Casati and Varzi 1996). It shows that localization needs its own ontological treatment, independently of mereology (concerned with part-whole relations) and topology (concerned with connectivity). Based on the fundamental notion of a *region*[12] as the exact portion of space taken up by an object, it offers axioms for localization, parthood, and connection. All three types of relations are applied to objects as well as regions, multiplying the axioms and raising questions like "is a region located at itself?" and "is a stone connected to its region?" While a general ontology of space (and time) might face such complications, a computational theory of location should pose and answer the questions occurring in information system settings. Among them is the distinction of locatable objects from others, which cannot be done in Casati and Varzi's theory (and many others), due to the limitations of un-typed first-order logic. Questions about the topological connection between stones and their regions, or between the rotating and cooling of the earth, either do not arise in a typed theory or can remain unsettled in this context.

Smith's theory of niches (Smith and Varzi 2001) builds on the work of Casati and Varzi. It introduces the *niche,* as a neighborhood containing the region of an object, and the notions of retainer, medium, and tenant of a niche. The idea of a retainer, as a boundary for the medium surrounding a located object (for example, the lake holding the water surrounding a fish), appears useful to deal with cases of localization in holes of objects. The theory of niches is supposed to capture naturally the many different uses of the preposition "in". While this would be very attractive, the claim is not proven and the theory needs further development to become applicable in a computational context.

Another extension of region-based theories of location is presented in (Donnelly and Smith 2003). The theory of *layers* avoids the reductionism of regions, recognizing spatial relations between objects, not only between their regions. The layers of objects that are introduced resolve some of the confusion resulting from mereological relations applying across layers. But they seem to provide little else than object identity and a work-around for the missing type system, without the computational power and standard terminology that comes with typed languages and spatial calculi. Also, the paper introduces rather unusual meanings for basic topological notions like coincidence.

Bittner extends location theories to deal with spatio-temporal location, approximate location and multiple levels of granularity (Bittner 2002). His *temporal* and *granularity* extensions are significant, but lie beyond the scope of our current theory. His approach to *vagueness* is slightly different from ours. He deals with approximate location by introducing functions that return approximate locations containing the precise ones. Instead, we introduce vagueness into both, localization functions (which are different from his) and locating relationships, as it applies both to objects (such as mountains or cities) and relations (such as *on* or *at*).

Schmidtke, in her approach to representing extension, uses again a region-based approach. She adds the capability of dealing with extension through size rather than distance. However, her approach rests on point set models of objects and retains the traditional cartographic classification of locating relationships in terms of punctual, linear, and planar objects.

3. LOCALIZATION FUNCTIONS

Going back at least to (Casati and Varzi 1996), most formal treatments of location use the idea of a localization function returning the *region* of an object. Such a function returns, for example, the airspace occupied by your house, or the area of my tablecloth stained by red wine. The idea of a region as the "hole in space" carved out by an object generalizes easily to a localization function for events in space-time. It is characterized by the fact that the object (or event) and its region have the same dimensionality.

[12] This use of the term is intentionally reductionistic and does not carry the rich connotations it has in geography.

Regions are conceptually useful, but represent only a small part of the story of location. The region of an object serves primarily to locate something *else* in relation to the object. For example, a person may be said to be in a house if she is spatially contained in its region. Locations of houses themselves are typically not given by airspace volumes, nor those of red wine spots in terms of the exact area they cover. Houses have addresses, and a spot may be in the middle of the tablecloth. Thus, location often refers to spaces simpler than regions.

The computational corollary of this fact is that the regions of geospatial objects are typically not computable, because they are too complex. It is one thing to declare that the region of an object exists, but quite another to give an explanation of how to compute it. To save the attractive idea of localization functions, but remove the limitations related to regions, we generalize their definition to return *any computable spatial abstraction* of an object. Such generalized localization functions

- determine the region of an object;
- project the region to a lower-dimensional space;
- abstract an object to its topology; or
- pick out some parts of an object and apply a spatial abstraction to them.

Buildings, for example, can be located by projecting their regions to two-dimensional footprints using a localization function and then relating the footprints to the regions of parcels. Or they can be abstracted to discrete locations (addresses) along networks of streets, which are themselves abstracted to their axes. Similarly, one may talk about the corner of a room or a bay of an ocean, focusing on parts.

These abstraction processes are the spatial equivalents of profiling in cognitive linguistics, i.e., the mental act of highlighting those aspects (spatial or not) of a concept that are relevant in an expression. For example, the expression "at home" profiles a home as a point (at which one can be located), while "in their home" profiles it as a container. Consequently, we call the results of our generalized localization functions *profiles.* Regions are just a special case of profiles.

Another difference of our localization functions to those proposed in the literature so far, is that they can be restricted to the types of objects that are considered localizable. By introducing classes of localizable object types, we provide a handle for deciding on the localizability of objects: if an object can be profiled by a localization function, it can be localized. This is one of the most obvious positive effects of a formalization in higher-order logic, where one can make statements about kinds of objects, in addition to those about individual objects. Also, we admit multiple localization functions for each object type. For example, a house can be localized through its footprint or its address or the coordinates of a centroid.

4. LOCATING RELATIONSHIPS

Location is a relational, not a functional concept. Objects are located in relation to other objects, not through their regions or profiles alone. Localization functions return the spatial aspects of objects needed to locate them, but location itself involves a relationship between at least two objects. In such a relationship, a profile of an object obtained from a localization function can play the located or the locating role. For example, an ocean bay can locate a storm or it can be located on a shoreline.

The role of a theory of location is to provide interpretation rules for locating expressions. Our theory does this in terms of profiles of the participating objects and relationships among them. As shown by the examples given so far, various profiles of each related object can determine the meaning of locating relationships. A particular locating expression (e.g., "the house on Main Street") typically does not specify the kind of profiles and relationships it is based on. The point of a location theory is to provide such a specification.

Based on localization functions, any kind of locating relationships can be defined. The theory proposed here derives its locating relationships from image schemas (Johnson 1987). This has the advantage of guiding the search for building blocks of the theory and putting them on a cognitively plausible foundation. The following relationships are being introduced for a start: containment („in"), support („on"), and linkage („at"). Each of these relationships will be modelled as a type class with multiple parameters standing for the located and the locating space, as well as for additional elements like boundaries or paths.

5. CONCLUSIONS

On the route toward semantic reference systems for geospatial information (Kuhn 2003; Kuhn and Raubal 2003), a first important milestone is to cope constructively with the meaning of location. The present paper introduced the elements for a cognitively plausible computational theory of location. It proposed two basic elements: localization functions returning profiles, and locating relationships based on image schemas.

A full paper will apply these ideas to a case study dealing with location in emergency management. It will provide a formalization of the theory in the functional language Haskell and testable models in both, Haskell and the web ontology language OWL. Another ongoing case study on semantic interoperability involves location in transportation networks in the context of navigation services (Kuhn and Raubal 2003). A result of these case studies will be to determine which image-schematic notions serve the theory of location best. At the same time, an extension to spatio-temporal profiles and dynamic localization functions is foreseen.

Locations are often indicated approximately. For example, we say that AGILE 2004 is held in Greece, or that a house is located near a lake, or the spot on my table cloth is to the right of my plate. We will investigate how this vagueness is captured in profiles and in the locating relationships applied to them.

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