Chapter 1
Unpacking the "I" in GIS: Information, Ontology, and the Geographic World

Helen Couclelis

Abstract As a tool dealing with information rather than matter, GIS shares with other information technologies the conceptual challenges of its medium. For a number of years now, ontology development has helped harness the complexity of the notion of information and has emerged as an effective means for improving the fitness for use of information products. More recently, the broadening range of users and user needs has led to increasing calls for "lightweight" ontologies very different in structure, expressivity, and scope from the traditional foundational or domain-oriented ones. This paper outlines a conceptual model suitable for generating micro-ontologies of geographic information tailored to specific user needs and purposes, while avoiding the traps of relativism that ad hoc efforts might engender. The model focuses on the notion of *information* decomposed into three interrelated "views": that of *measurements* and *formal operations* on these, that of *semantics* that provide the meaning, and that of the *context* within which the information is interpreted and used. Together, these three aspects enable the construction of micro-ontologies, which correspond to user-motivated selections of measurements to fit particular, task-specific interpretations. The model supersedes the conceptual framework previously proposed by the author (Couclelis, Int J Geogr Inf Sci 24(12):1785–1809, 2010), which now becomes the *semantic* view. In its new role, the former framework allows informational threads to be traced through a nested sequence of layers of decreasing semantic richness, guided by user purpose. "Purpose" is here seen as both the interface between micro-ontologies and the social world that motivates user needs and perspectives, and as the primary principle in the selection and interpretation of Information most appropriate for the representational task at hand. Thus, the "I" in GIS also stands for the Individual whose need the tool serves.

Keywords GIS · Ontology · Semantics · Measurements · Context · User perspective

---

H. Couclelis (✉)
Department of Geography, University of California, Santa Barbara, CA 93103-4060, USA
e-mail: cook@geog.ucsb.edu

T. Tambassi (ed.), *The Philosophy of GIS*, Springer Geography,
https://doi.org/10.1007/978-3-030-16829-2_1

Introduction

Viewed as a tool, GIS transforms information rather than matter. It shares with traditional tools the purpose of serving some need of the user, but differs from these profoundly in the conceptual complexity and relative novelty of the stuff it manipulates. Little applied philosophy exists on the mysteries of matter, yet information—in this case, geographic information—has attracted the active attention of professional philosophers as well as engineers and others grappling with the possibilities and limitations of the tool. In this, GIS joins an array of information technologies that are turning to ontology as a means of figuring out practical theories applicable to different domains of interest.

What does an ontology really represent? The engineer and the metaphysician would give very different answers to this question. Both would claim that their work bears some relationship to the real world, yet at first sight, it might be hard to imagine finding much common ground between them. Literally meaning "the study of what exists" in the original Greek, Big-O-Ontology has been variously associated with questions about the world, the Creation, existence, identity, reality, the cosmos, universal flux, things both real and fictional, minds, ideas, consciousness, space and time, language, and Truth (Kavouras and Kokla 2011). But the engineer's questions are practical, originally focused on the technical problems of knowledge sharing, more specifically of interoperability among databases. The small-o ontologies resulting from that quest were meant to describe the finite artificial worlds defined by these databases. Yet before too long issues of cognition and language, of structure and meaning, of concepts and measurements, of physical and nonphysical entities, of space and time, of user needs and culture-specific interpretations, and of reality and philosophy also became part of the ontology discourse (Kavouras and Kokla 2008). Developed from an engineering perspective to meet engineering needs, foundational ontologies in particular have struggled with problems that are often part of mathematical philosophy if not of metaphysics. More recently the Semantic Web has brought additional dimensions of difficulty to the task because web knowledge has no primitives, no core, no fundamental categories, no fixed structure, and is heavily context-dependent. The new dilemma that ontology engineers face is that of serving highly disparate needs using data from highly disparate sources which are themselves part of highly disparate observation and interpretation contexts. Most challenging is the context dependency of web knowledge (indeed, of knowledge in general) since context is, by definition, what lies outside a representation or model. But even traditional kinds of data raise the issue of context as it relates to their interpretation and use if not also their origin. The problem appears intractable as it is the broader social, political, economic, cultural, institutional, and other societal factors that directly or indirectly constitute the context of each application, as well as more immediate factors of needs, resources, and practical constraints. In the tidy world of ontology engineering, the question then becomes how to treat the whole of society as context without running into the impossible task of having first to formalize it.

The notion of society as context is compatible with Gruber's (1993) widely quoted definition of ontology as a "formal, explicit specification of a *shared conceptualization*." Gruber clarifies: "That is, an ontology is a description … of the concepts and relationships that can exist *for an agent or a community of agents*." Further: ontologies must "constrain the *possible interpretations* for the defined terms." (Emphasis added.) The implications are that (1), ontology is not directly about the real world but about some "shared conceptualization"; (2), the concepts and relationships defining an ontology are valid for an observer (agent) or "a community of agents"; (3), there may be several "possible interpretations for the defined terms." An ontology is thus by definition relative to specific agents facing specific tasks individually or as a community (e.g., a scientific or professional community), and its role is to pin down the fluid meanings of terms in ways that serve the needs of that individual or community at some specific time.

Recent advances in cyber-infrastructure development as well as inside the ontology field suggest that the traditional model of axiomatic foundational ontologies, as exemplified by DOLCE, SUMO, BFO, and other such major efforts (Kavouras and Kokla 2008), may need to be significantly amended if not replaced. More than a decade ago, protagonists of the DOLCE (Borgo and Masolo 2010) project and others were expressing reservations about the role of such heavy-weight ontologies in the age of the semantic web, and were proposing alternative, less centralized approaches (Gangemi and Mica 2003). The notion of multiple micro-ontologies, lightweight ontologies, or "microtheories," each developed for a particular use context, has been gaining traction (Adams and Janowicz 2011; Janowicz and Hitzler 2012). So is the idea of modular "local micro-ontologies" made up of interchangeable parts representing relatively uncontroversial pieces of knowledge, likely expressed in the form of engineering design patterns (Gangemi 2005; Gangemi and Presutti 2010). But such approaches raise questions of their own. One issue is concern about the relativism and knowledge fragmentation inherent in the proliferation of indefinite numbers of microtheories and design patterns lacking a common core. Another is the fact that the nagging philosophical questions raised by ontology engineering, some of which are mentioned above, are being pushed aside rather than confronted. The continuing debates over realism, conceptualism, instrumentalism, or constructivism in ontology development (Smith 2010; Scheider and Kuhn 2011), about the role of cognition and culture (Kuhn 2003), about whether nonphysical entities may or may not be primitives in an ontology (Gangemi and Mika 2003), and so on, attest to the persistent significance of the question of *representation* that underlies all forms of modeling, including ontology development.

What then if the representation in question is not directly *of* the real world, but of *information about* the real world? This paper presents a model of information based on a major modification and expansion of the conceptual framework for ontologies of geographic information developed by the author (Couclelis 2009a, 2010). The key modification consists of decomposing the notion of information into three distinct but interrelated "views": (1) that of *measurements* that derive from the empirical world, along with any formal *operations* applicable to these measurements; (2) that of *semantics* that may correspond to the measurements, and (3) that of the *context* of

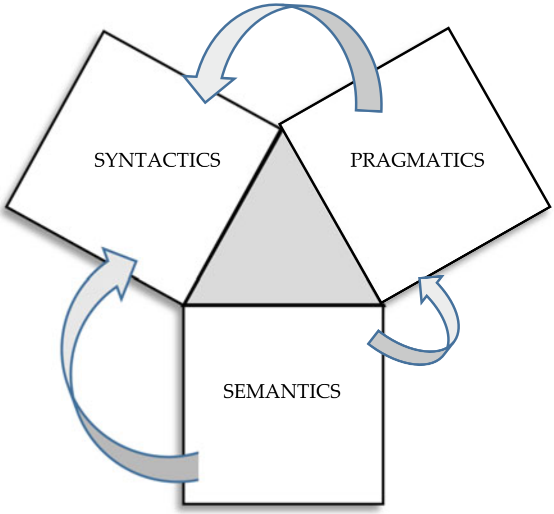

Fig. 1.1 The three views of the model and their connections. The central triangle represents the region where the micro-ontologies are generated

interpretation and use relating to the receiver of the information. Together these three aspects of information enable the construction of user-motivated micro-ontologies tailored to purpose-specific interpretations and selections of measurements (Fig. 1.1). To use a linguistics analogy, the raw measurements and their formalizations (view 1) correspond to the context-free and semantics-free *syntactic* aspects of information (something along the lines of Shannon's information), view (2) represents the *semantic* aspects, and the *pragmatics* view (3) helps define the specific context of each micro-ontology. In this model, the previously developed ontological framework (Couclelis 2010) is now the *semantics* view. The new model represents the necessary parts for the derivation of internally (and to some extent mutually: see section "The Syntactics and Pragmatics Views") consistent micro-ontologies in a universal-to-particular relationship. The role of the earlier framework as the semantics part of a "micro-ontology generation engine" is thus new to this paper. The relevant aspects of that earlier framework are outlined in section "Ontologies of Geographic Information: An Overview". In section "Purpose and Function in Micro-ontology Design", several hypothetical geographic examples are presented that tentatively illustrate how the model could be put to work. Section "Towards Implementing User-Centred Micro-ontologies" provides indications as to how it could be implemented, focusing on the model's connections with the literature and a few other potentially relevant aspects. The conclusion recapitulates the chapter's contributions and shortcomings and considers certain promising avenues for future research.

Ontologies of Geographic Information: An Overview

The framework presented in the paper with the above title (Couclelis 2010) is at the heart of the new model of information presented here. Note that the three parts of this new model are called "views", whereas the previously developed framework that now forms the semantic view is composed or "layers" or "levels"; also that the term "framework" is reserved for the earlier work. The new conceptual structure is called "model." This section summarizes three key principles of the framework that continue to be relevant in the new model. The main modifications that were made in the current project are indicated below and at the end of this section, and in the following.

Three Key Principles

Three aspects of the framework that are also a major part of the new model are presented here. These aspects are as follows: (a) The foregrounding of the perspective or motivation of the *user*; (b) the ability to distinguish a nested sequence of representational layers of varying degrees of *semantic richness*; and (c) the principle of *data filtering* through criteria resulting from the users' purpose-oriented semantic choices. While maintaining these key aspects of the framework, the new model introduces two major modifications. First, it treats the earlier unitary framework as one of three "views"—the *semantics* view—flanked by the views of *measurements* on the one hand, and of the *context* of information interpretation and use on the other. Second, it assigns special roles to the two layers of the semantics view that most directly ground the model: the "classification" layer on the one hand, which now serves as the bridge between the semantics and measurement views, and the "purpose" layer on the other, which now serves as the main connection between the semantics and context views (Fig. 1.1). To pursue the earlier linguistic analogy, the semantics, syntactics, and pragmatics of the representation interact with one another, as they do in language. The aspects of the framework relevant to the new model are as follows.

First, the framework is anchored at one end on the notion of the perspective or intention of the *user* of the information, since information is a binary concept that involves not only a source or sender but also an active receiver able to decode and use it. The user may be an individual, a community, or an institution, as determined by a particular requirement or kind of task, set in the context of specific societal interests and understandings, and subject to particular resources and constraints. For example, there may be many possible perspectives on the same transportation network as a real-world phenomenon, from that of the transportation engineer concerned about the flow of traffic to that of the biologist studying wildlife movement barriers and road casualties on segments of the network. The user perspective or purpose or more generally, intentionality (Searle 1983) as relating to the task at hand is molded by the context against which the relevance of a particular representation is defined, entailing a suitable interpretation, selection, and reification of available information (Adams and Janowicz 2011; Gangemi and Mika 2003; Scheider et al. 2010). Because user purposes as well as the phenomena of interest vary with time, the framework is inherently spatiotemporal, though only the basic static version is discussed here.

Second, the framework is a structure consisting of a number of nested layers representing cumulative degrees of "decoder capabilities"[1], which range from the full capabilities of a human observer to brute awareness. Just as we can build a hierarchy of descriptions based on decreasing spatiotemporal and attribute detail (*quantity* of available information), we can also envision a hierarchy based on decreasing semantic richness (*variety* of types of available information). For example, given a set of polygons geocoded with high accuracy, and the same set of polygons in rough outline along with the knowledge that it represents a college campus, the latter is considered to be semantically richer. Formally, the principle is somewhat analogous to the notion of "reduction" in rough set theory, iterated over seven levels (Pawlak and Skowron 2007).

Table 1.1 summarizes the basic version of the structure and indicates the names of the levels and of the key decoder capability that may be associated with each. In geographic information science, the most often studied transition is the one from L4 to L3—though it is more commonly treated in the opposite direction, from L3 to L4 (from data classifications to named objects)[2]—but most other transitions may be just as significant. For example, the move from L6 to L5 loses the ability to represent the notion of spatial *function* even though it is still possible to recognize and model relations among spatially disconnected or otherwise distinct objects. Think of the difference between—say—knowing that certain configurations of buildings and other installations constitute a water treatment plant, versus also understanding how that particular configuration relates to the actual functioning of the plant. The

Table 1.1 The expressivity of representations is gradually collapsed over levels 7–1 of the hierarchy as the semantic richness of the system contracts from top to bottom (principle of semantic contraction). Each level is associated with a characteristic property domain and also includes those at the levels below it (Adapted from Couclelis 2010)

Semantic resolution levels	Decoder capabilities	Forms of representation
7 Purpose	Intentionality	Objects
6 Function	Instrumentality	
5 Composite objects	Association	
4 Simple objects	Categorization	
3 Classes	Classification	Fields
2 Observables	Perception	
1 Existence in space-time	Awareness	

---

[1] This expression is used to avoid suggesting that the sequence described here has empirically established cognitive/psychological validity (although it may), or that human cognition is not relevant to ontology development (which of course it is).

[2] Fields and object are the two fundamental forms of representation in geographic information science. Much attention has been directed towards clarifying their logical relationships and formalizing their integration (Couclelis 1992; Galton 2001; Goodchild et al. 2007; Kjenstad 2006; Voudouris 2010). Note that the distinction between fields and objects qua representation forms is entirely a semantic issue. Raw measurements do not support one or the other interpretation.

third column marks the *reification* step that occurs between levels 4 and 3 and is usually considered the most critical.

The third important point results from the combination of the above two. The context of the representation problem, consisting of the fundamental duality of user perspective and phenomenon of interest, plus any pragmatics relating to data issues, time or resource constraints, and other situational factors, governs the selection of information at each level, based on the criterion of *relevance* to the task at hand. Thus, for the same phenomenon, different paths across the hierarchy will be traversed by different user selections. Similar paths will result in closely related representations, while very dissimilar paths will result in markedly different ones (Table 1.2). All paths end with the selection of the spatiotemporal framework (including geographic scale, granularity, extent, etc.) most appropriate for the task at hand. Note that the spatiotemporal framework must be discrete, since information is collected in discrete units at discrete locations, and the point analogues must be extended spatiotemporal "granules."

Table 1.2 Two different perspectives on a "road network" (Adapted from Couclelis 2010)

	A road map of region X	A map of roads in region X
7 Purpose	Facilitate vehicular travel planning and navigation	Identify and mitigate barriers to wildlife movements
6 Function	Represent possible routes from place A to place B	Represent the locations where wildlife corridors intersect with roads
5 Composite objects	A road network	A wildlife corridor network intersecting with a road network
4 Simple objects	Places, freeways, arterials, collectors, intersections, ramps, roundabouts, …	Roads, wildlife corridor segments, underpasses, culverts, high-conflict intersections, …
3 Classes	Fields of properties (corresponding to surface material, slope, network structure, …) aggregated in diverse geometrical patterns	Fields of properties (corresponding to incident frequency, barrier permeability, height, width …) aggregated in diverse geometrical patterns
2 Observables	Hard, rough, green, brown, wet, …	Open, blocked, green, hard, kill, dry, wet …
1 Space-time exist	"Task-relevant information exists here-now at such-and-such appropriate granularity"	"Task-relevant information exists here- now at such-and-such appropriate granularity"

Semantic Contraction and Geographic Information Constructs (GIC)

Unlike other stratified ontology models, the framework in Couclelis (2010) is not a taxonomy of aspects of reality (Frank 2003). Rather, it is a cumulative structure that may be systematically decomposed into simpler but still logically coherent substructures. Observed from the top down, the layers correspond to successively narrower domains of semantic content, as described in section "The Semantic Hierarchy". Each level includes its own characteristic domain of properties plus those of all the ones below it, so that internally consistent spatiotemporal representations may be obtained by merging information *from any level down*. One may imagine gradually draining the structure of semantic content by peeling away successive layers, until nothing is left but the idea of a spatiotemporal frame with information. This notion of step-wise semantic reduction of the structure is called "semantic contraction."

Semantic contraction thus results in truncated structures that may reach no higher than levels 3, 4 or 5. These are called here "geographic information constructs" ($\boldsymbol{GIC}_\mathbf{i}$, i = 1–6) to allow differentiation from representations that span all seven levels. Table 1.3 indicates the relationship between a fully developed, 7-level representation, and a truncated one that reaches only to level 4 ($\boldsymbol{GIC}_\mathbf{4}$). The table may be seen as an accounting sheet that registers the presence or absence of property domains, and of quantitative changes in property values within property domains. It is subdivided into seven primary columns corresponding to the seven levels of the hierarchy. Each of these columns is headed by one of the domains of properties $\{p_n\} \subset P$ that characterize the corresponding level over and above the properties at the next level down, and is further subdivided into as many columns as there are properties in that set, and then again, to whatever degree of detail is needed. The primary rows are

Table 1.3 The semantic information system. The full table represents a geographic information construct, $\boldsymbol{GIC}_\mathbf{7}$, occupying topons $\mathbf{g_1}$–$\mathbf{g_m}$ at chronon $\mathbf{x_t}$, complete through level 7. Columns $\{p_n\}$ may be removed sequentially from right to left to yield reduced but internally consistent representations of the original *GIC*. The white area represents a GIC reaching only to level 4 ($\boldsymbol{GIC}_\mathbf{4}$). The *profile* of each topon *g* for a given chronon *x* is represented as a code (here: binary) extending across n ≤ 7 hierarchical levels. (Adapted from Couclelis 2010)

	$\mathbf{x_t}$		$P = \{p_7\} + \{p_6\} + \ldots + \{p_1\}$				
		$\{p_1\}$	$\{p_2\}$	$\{p_3\}$	$\{p_4\}$	….	$\{p_7\}$
		p_1	$p_{21}, p_{22}, \ldots\ p_{2k}$	$p_{31}, p_{32}, \ldots\ p_{2j}$	$p_{21}, p_{22}, \ldots\ p_{2n}$	….	$p_{71}, p_{72}, \ldots\ p_{7i}$
	g_1	1	1 0 … 1	1 0 … 0	1 1 … 1	….	1 1 … 0
GIC_i	g_2	1	1 1 … 1	0 1 … 1	1 1 0	….	1 1 … 1
	…	….	….	….	….	….	….
	g_m	1	0 1 … 0	1 1 0	1 1 0	….	1 1 0

labeled for the *GICs* of interest. Each primary row is subdivided into further rows, one for every granule of the space $g_1, g_2, g_3, \ldots g_i \in G$ that the corresponding GIC occupies at a specific (discrete) time granule.

As will be seen in the following, neither the spatial nor the temporal granules can be geometrically specified in advance independently of the highest semantic level at which a GIC is considered. To differentiate these extended atoms of space and time from ordinary spatiotemporal coordinates, they are given the names of *topons* and *chronons*, respectively. A topon (from the Greek τοπος, place) is thus the smallest 2- or 3-dimensional chunk of space over which properties of interest (from the perspective of a particular user purpose) may be measured. A chronon (from the Greek χρονος, time) is the smallest interval of time over which a change in some property of interest to the user may be observed. Spatial and temporal atoms are treated separately because the properties of time and space are not necessarily parallel at all levels. A cell C_{ij} of Table 1.3 thus records whether, for chronon x, topon g has been observed to have property p. The entry will be binary (yes/no, the property is or is not present) in the simplest case but generally it may be any value within the appropriate range. The table is read from right to left, in the direction of semantic contraction, beginning with the most semantically rich level 7, where all the property domains are available that are necessary for describing the relevant aspects, functions and purposes of any specific GIC. Reading across the rows we find ordered descriptions of what properties and values exist at each topon, and the corresponding vectors, or *profiles*, get shorter with every domain of properties being removed. These vectors represent the "paths" across the layers mentioned above.

Truncated GICs can be practically useful when the representational problem is fairly familiar and uncontroversial so that the explicit representation of the upper levels would be redundant. They are also theoretically significant because of the connection made in section "The Syntactics and Pragmatics Views" with the notion of geo-atom developed in Goodchild et al. (2007).

The Semantic Hierarchy

Very briefly, the characteristic properties of each level are as follows. Moving from level 7 downwards, the *semantics* of each level are built on its own level specific properties plus those of all the levels below it. The *purpose* of the representation serves as a filter providing for each level specific criteria that restrict what can (should, needs to) be expressed at that level. Terminating at level 1, the procedure picks the spatiotemporal frame (discrete-continuous, granularity, extent, etc.) most appropriate for the purpose-specific micro-ontology being generated.

- L7: *Purpose*. Purpose (more generally: intentionality, perspective, interest, and so on) is not a spatiotemporal concept but it is the interface between this spatiotemporal ontology framework on the one hand and the societal context motivating these purposes on the other. Purposes may be research-oriented, professional, institutional, governmental, etc.

- L6: *Function*. Function and purpose are tied together in a close means-ends relation. This relation is characteristic of the *design* perspective. Representations (models) must be designed such as to meet corresponding purposes (e.g., weather maps designed for scientific and TV presentation uses will be very different). Note that in addition to the purpose and function of the representation itself, many represented spatiotemporal phenomena such as cities, farms, transportation networks and harbors are *artifacts* with purposes and functions of their own, aspects of which may need to be explicitly represented for some uses. In this latter case, "function" also encompasses agency and action, both of which are teleological notions (doing something "in order to_").
- L5: *Composite objects*. Many objects in the world, both natural and artificial, are composed of spatially disconnected or otherwise heterogeneous parts. Recognizing that—say—a number of chairs and tables in specific spatial relations to each other are part of an office rather than a storage room, or that a large Christmas tree nursery is not a small pine forest, requires more "intelligence" than recognizing the constituent parts.
- L4: *Simple objects*. As the semantic contraction continues, descriptions have now reached the last level at which discrete objects may be recognized, categorized and named. How these objects are named (and understood) depends on the observer's perspective-specific criteria as these result from levels 7–5. As certain popular cartoons remind us, one person's playing field is another's building lot, and one person's fishing grounds is another's marine preserve. Different perspectives, and thus criteria, may also result in different object boundaries, e.g., the cartographer's valley may be different from the cyclist's or from of the Valley Hotel manager's.
- L3: *Classes*. This is the level of "pure" data. Here, objects have given way to corresponding classes of properties represented as (uninterpreted) fields of measurements. All data manipulations and analytic operations are in principle enabled here, as well as the aggregation of similar values into 0- to 3-dimensional geometries. Criteria specific to each user purpose, as derived from levels 7-4, restrict measurement specifics, manipulations, and operations to those suitable to the particular representation being generated. These same criteria also yield the *classifications* that are the semantic precursors of the simple objects of level 4.
- L2: *Observables*. This level serves to distinguish the necessary kinds of variables from the values these may take on (Goodchild et al. 2007; Probst 2007). It is the level of qualia, where spatial variation may be observed but not yet measured and communicated, let alone named. Levels 2 and 3 are as closely bound up with each other as levels 6 and 7 are at the top of the hierarchy.
- L1: *Spatiotemporal existence*. In and of themselves, the vanishing semantics of level 1 just barely suggest the existence of some spatiotemporal frame that may contain information relevant for some purpose. This extreme vagueness is resolved by the filtering procedure that started at level 7, which restricts possibilities to just the kind of spatiotemporal frame entailed by the original user perspective.

Thus the hierarchy is anchored at one end by the notion of a spatiotemporal framework to be specified by choices made at all the preceding levels, and at the other end, by the purpose of the representation, itself deriving from any number of societal influences and needs, which may be professional, institutional, socioeconomic, personal, educational, and so on.

In the new model, three modifications are made to the framework as described in Couclelis (2010) and summarized in this section. (a) As mentioned in the Introduction, the fundamental modification is the development of a model comprising three distinct views—syntactic, semantic, and pragmatic—of which the framework is now the *semantic* view. Also (b), there is a switch in the order of levels 2 and 3 in the semantic hierarchy, whereby the observables (required types of variables) are now picked up before the corresponding values. And (c), the two kinds of purpose-function pairs: of the representation itself, and of the entity represented (in the case of artificial entities, or more generally entities used to support some function), will be clearly distinguished in the following as type A and type B, respectively. Section “Purpose and Function in Micro-ontology Design” provides examples of these changes while focusing on the semantic view. The latter is discussed further in section “Towards Implementing User-Centred Micro-ontologies”, along with the syntactic and pragmatic views.

Purpose and Function in Micro-ontology Design

Representing Natural, Artificial, and Abstract Entities

Representation is the basic underlying notion in all modeling, including the construction of ontologies seen as meta-models or templates for deriving particular kinds of models corresponding to specific requirements. The class of models of special interest in this research is that of the lightweight or micro-ontologies, seen as use-specific realizations of the conceptualization illustrated in Fig. 1.1. From an engineering perspective, all models are artifacts designed for particular purposes (clarifying, explaining, illustrating, supporting, facilitating, problem-solving, restricting meaning, etc.) and must function in ways that support these purposes. As such they share the general properties of designs as abstract or material tools developed for addressing the requirements of particular uses or users. According to Simon’s seminal work on the design sciences (Simon 1969), artifacts constitute a separate ontological category from other things in the world because they would not have existed but for an agent’s intentional action towards serving some purpose. Thus, models, ontologies, and micro-ontologies have purposes and functions irrespective of whether they represent natural entities such as mountains and rivers, or artificial entities such as road networks and college campuses, which of course have purposes and functions of their own. In the following, we will use the notation “A” for the purposes and functions of the representation itself, which are always present, and “B” for those of an artificial entity that may be the object of a given representation. In the latter case, the fact that the entity is artificial as opposed to natural may or may not be relevant depending on the purpose (A) of the representation. The example in Table 1.2 above (Sect. 2.1.1) along with two additional ones in this section will help clarify this point.

The examples below are selected to illustrate a number of different cases that may be distinguished, concerning: (1) artificial physical entities (section "Road network"), (2) artificial abstract entities (section "State"), and (3) natural entities (section "River"). In addition, it is shown that in all three cases very different representations (micro-ontologies) result depending on whether or not user needs call for the representation of the purpose and function of the artificial entity represented (examples “road network” and “state”), and whether or not user needs require that function be imputed to a natural entity (example: “river”) that may be viewed, in this case, either as natural phenomenon or as transportation infrastructure.

“Road Network”

Table 1.2 illustrates a situation where a cartographer designs two different maps of the same region and phenomenon for two different purposes (type A): the first one for use in a road atlas, and the other for use by biologists studying wildlife road casualties. In the first case, the road network is approached as an artificial entity designed to facilitate movement between places, and these properties (type B) of the network are the ones of primary interest in the design of the map. In the second case, the network is treated as a collection of physical barriers and high-impact locations. The table indicates how these two different perspectives lead to very different selections of information across the hierarchy. Given appropriate data, possible queries include:

(a) Road map:

- Show me the two shortest routes from Goleta to North Fork
- Show me a route between Ventura and Mammoth with no grade above 7%
- Show me the average driving time between Corvallis, OR and San Francisco, CA on a summer weekend.

(b) Map of roads for use by wildlife biologist

- Show me the 10 road segments with the most wildlife fatalities in 2011
- Show me mountain lion casualties by year on the stretch from X to Y
- Show me where topography might allow wildlife passes under dangerous road segments.

Below I briefly outline two additional cases, the first concerning the concept of “State” (an abstract artificial entity), and the second is that of “river” (a natural entity).

"State"

What is a "state," or "country"? Do these two notions actually designate the same thing? The practical significance of these questions is highlighted in an article in *The Economist* (2010), which laments the difficulty of deciding how many states (or countries) there are in the world in the face of name ambiguities, disputed borders, rogue states, states with partial or no international recognition, stateless nations, states whose citizens use passports from another state, states made up of "just two nice buildings," and so on. As is the case with most complex concepts, the "best" definition of *state* or *country* depends to a large extent on who is asking: is it the United Nations (whose dilemma prompted the *Economist* article), is it a particular national government, is it a tourist agency, is it a cartographer, is it a political scientist or a historian, or is it an international immigrant seeking asylum in a foreign state?

The abstract concept of "state" has been discussed in the ontology literature and has been the topic of a debate as to whether, for example, a state is an organization or a legal person (Robinson 2010). The framework presented here suggests that a state can be both of these things or neither, and it may be many other things as well, depending on the purpose of the micro-theory being developed.

Let us take just two contrasting cases: that of a national state, and that of a stateless nation, both wishing to promote their interests in international negotiations. To be more specific, let us assume in addition that the national state is undergoing a severe economic recession, and that the stateless nation may be that of the Palestinians. In the latter case, the entity in question is not only abstract but also, at this point in time, hypothetical. In both cases, the main purposes and functions will be those of the representation (type A), and we will ignore in the first case the fact that states *qua* artificial entities also have purposes and functions of their own (type B), such as safeguarding the welfare of their populations and developing the institutional structures needed to do so. These aspects are however relevant for the second example, that of the stateless nation. With few exceptions, only spatial aspects are mentioned in these brief sketches.

a. National state:

- *Purpose*: highlight contributions of recent aid packages to regional progress, and point to remaining problems in order to help win further international economic and political support
- *Function*: emphasize factors that led to regional growth and/or decline, possibly using outputs from regional development models
- *Composite objects*: successful regions; backward regions; regions on the cusp of becoming successful; transportation networks; fast-developing communities
- *Simple objects*: infrastructure units, productive installations, productive land, tourist installations, rural and urban communities, border segments under immigration pressure, etc.
- *Observations*: required types of spatiotemporal information for describing the above objects, reflecting their relationships with growth, stagnation, and decline
- *Classification*s: classed values for the variables identified above

- *Spatiotemporal frame*: multi-scale (national, regional, and local as needed); temporal scale: 3–6 years (since time of last major international loan).

Given appropriate data, possible queries include:

- Show productive units in region X that benefited from earlier loan
- Show growth statistics for coastal communities that received tourism subsidies AND growth statistics for similar communities that did not receive such subsidies
- Show adjacent regions with contrasting ("high"-"low") levels of transportation infrastructure.

b. Stateless nation:

- *Purpose*: advance the cause of establishing a new sovereign state; argue for the feasibility of the desired territorial state; dramatize the consequences of failure
- *Function*: highlight and magnify the contradictions and conflicts resulting from the current spatial fragmentation of populations
- *Composite objects*: fragmented ethnic territories, adjacencies and overlaps with territories of other nations, disrupted transportation and supply corridors, regional urban distributions, regions of ethnic lands under foreign occupation, trans-border ethnic continuities, historic ethnic territorial distributions, etc.
- *Simple objects*: proposed national territory (–ies) covering all or most ethnic fragments, corresponding border(s); elements of the above composite objects; alternative proposed country borders
- *Observations*: types of variables required for representing and supporting alternative border proposals; evidence supporting the claim that proposals would lead to the eventual resolution of conflicts at current geographical hotspots;
- *Classifications*: values for the above variables
- *Spatiotemporal frame*: multiscale, emphasis on local. Temporal scale: short to medium term; ill-defined

Possible queries include:

- Show the locations with the most incidents resulting in casualties between 2009 and 2012
- Show the major routes where communications were disrupted by incidents since 2008, by duration and incident type
- Show the 20 most overpopulated ethnic areas and statistics on unemployment and building conditions
- Show alternative regions that enclose at least 90% of the ethnic areas OR at least 85% of the ethnic population.

Note that while no actual geocoded data exist for the focal point of this negotiation effort—the hoped-for national territory and its borders—hypothetical boundaries and any other relevant features may be indicated and geocoded on maps. While lacking physical reality, the potential new state is a (conceptual) artifact that implies (type B) purposes and functions, such as providing a permanent and safe home for people belonging to the stateless nation, and meeting minimal prerequisites of compactness, area, spatial organization, and infrastructure for proper functioning as a country.

"River"

Rivers are natural entities that, unlike artifacts such as roads and states, do not have their own intrinsic (type B) purposes and functions. Yet useful micro-ontologies representing rivers almost always reflect the purposes and functions of interest to their users. We may consider very briefly the contrasting cases of (a) a research hydrologist monitoring the discharge of a river over a multiyear period, and of (b) a company operating a fleet of tourist riverboats on that same river. The purpose of the research hydrologist's micro-ontology is to provide support in identifying relevant changes and trends in the river's quantity and quality of discharge, and their relationships with other physical factors such as rainfall and temperatures. The tourist boat agency, on the other hand, is interested in providing a positive client experience within given cost margins, and would want to know about water levels and river traffic at different times of the year, about distances between scenic stretches of the river, visual water quality, the quality and availability of shore facilities and landing areas, possibilities for shore excursions, the schedules of the competition, alternatives for very dry or very wet seasons, and so on. In other words—and avoiding the tedium of further analysis—these two perspectives on the same natural entity: the river as channel and water flow, and the river as transportation infrastructure, will likely have quite limited overlap. So will, of course, the corresponding micro-ontologies.

Towards Implementing User-Centered Micro-Ontologies

The model presented in this paper is conceptual and exploratory. Undoubtedly formalizing and implementing it will be challenging. However, some degree of optimism is justified considering certain marked affinities with research in ontology engineering and other areas in geographic information science. At this stage, such connections help provide an indirect evaluation of the work, by indicating how it may fit within the broader nexus of the literature.

From this angle, this section discusses the prospects of implementing the model. The previous section focused on semantics, aiming to demonstrate the effect of different user perspectives on representations of the same kind of entity. However, semantics is only one of three views of the new model, next to those of measurements and formal operations (syntactics view) and contexts (pragmatics view). All three views must eventually be implemented in a consistent manner for the model to be of use. Here, I indicate certain encouraging connections with the literature and then address a few broader aspects of the model.

The Semantics, Syntactics, and Pragmatics Views

The Semantics View

Possibly closest in spirit to the work presented here, though deriving from a very different perspective, is the paper by Gangemi and Mika (2003) on Descriptions and Situations (D&S). Having discussed the need for lightweight ontologies as the preferred way to harness the power of the semantic web, these authors propose the D&S ontology as a plug-in to DOLCE (Borgo and Masolo 2010). The D&S ontology makes a clear distinction between "Situations" S, which are uninterpreted data configurations, and "Descriptions" D, which provide the agents' conceptualizations or interpretations of the Situations "*based on a nonphysical context*" (p. 690, original emphasis). The Situations themselves are derived from "States of Affairs" (SoA), defined as non-empty sets of assertions that are constituted by statements about the world. The authors indicate that notions cognate to SoA are "flux, unstructured world, or data" (p. 694). The D&S strategy achieves the goal of providing the needed flexibility for supporting multiple conceptualizations of the same situation without lapsing into relativism, as it is built on top of the DOLCE foundation ontology.

The model proposed here has several aspects in common with the D&S ontology. Here too, the agents' alternative interpretations or conceptualizations are clearly distinguished from the empirical data being interpreted. Indeed, the entire semantic view in the model presented here corresponds to the Descriptions (conceptualizations, interpretations) aspect of D&S in Gangemi and Mika (2003), with the semantic hierarchy representing discrete degrees of sophistication ("intelligence") in these conceptualizations. Moreover, in both cases, these interpretations are "based on a nonphysical context" in the form of the agents' intentionality. However, the present model also recognizes low levels of semantic content in the uninterpreted data (Levels 1–3), distinguishing, between, on the one hand, "States of Affairs," which are about "flux" and "unstructured world" (Level 1), and on the other hand, Situations, which are about "Gestalt" and "Setting" (Level 3) and "configuration or structure" (Level 2). Also, in both Gangemi and Mika (2003) and in the present model, the key generative mechanism is reification (Adams and Janowicz 2011; Scheider et al. 2010).

Note that what is proposed here is very different from traditional AI work on goal-oriented knowledge representation, which tends to be concerned with the knowledge necessary for solving a specific problem or for carrying out a specific practical task. The limitations of these ad hoc structures were part of the motivation for the development of coherent foundational ontologies to represent general knowledge (Guarino 1995). Here, the task-specific, purpose-oriented representations are systematically derived from a unified framework that is closer to foundational ontologies in structure, if not in philosophy and content. The central role played in the model by the semantic view and the semantic contraction procedure (section "Semantic Contraction and Geographic Information Constructs (GIC)") should contribute to the internal semantic consistency of micro-ontologies developed on its basis.

The Syntactics and Pragmatics Views

In the model, the measurements provided by the empirical world are gathered in the *syntactics* view. It is called "syntactic" because all formal manipulations that may be performed on quantities are possible in this view, regardless of any interpretations. At least one approach from the geographic information science literature appears very suitable for formalizing the syntactics view of the model presented here. This is the "General theory of geographic representation" proposed by Goodchild et al. (2007), and in particular the notion of "geo-atom." A geo-atom is "a tuple <x, Z, z(x)> where x defines a point in space-time, Z identifies a property, and z(x) defines the particular value of that property at that point."(p. 243). This is analogous to the definition of the *topon* ***g*** in the present study (see section "Semantic Contraction and Geographic Information Constructs (GIC)" and Table 1.3). Indeed, the topon may be written as a tuple $<g, P_n, \{p_n\}(g)>$ where g is a granule of 1, 2, or 3d space at time (*chronon*) x_t, P_n is the cumulative set of properties from level n down to level 1, and $\{p_n\}(g)$ is a vector of values for these properties at that topon and chronon. Note that unlike in Goodchild et al. (2007), time is here treated separately from space because of qualitative differences in temporal behaviour from level to level in the dynamic version of the model.

Further connections exist between this framework and the work in Bouquet et al. (2003) on *context* in knowledge representation and reasoning. These authors distinguish two kinds of theories of context that they call *divide-and-conquer* and *compose-and-conquer*. The former implicitly assume some kind of a "global theory of the world" that is subdivided into collections of contexts. The latter assume only local theories, each of which represents a view point of the world. Neighboring local theories are partially compatible but there is no expectation of global consistency. The *pragmatics* view of the model presented here is closely related to just this kind of local theories ("microtheories") and user-oriented viewpoints of the world. While the parallel may not be perfect, the complete, 3-part model appears to synthesize the two contrasting perspectives in Bouquet et al. (2003). It serves as a "global theory" from which specific applications may be derived, while the microtheories generated against the specific context provided by the "pragmatics" view, and realized with information and operations from the syntactic view, may be seen as the local theories. Similar ones will appear in clusters, and others will be far apart, forming a network floating against an unstructured, multidimensional space of professional and broader societal purposes and understandings (Fig. 1.2). It is evident that the relative positions of the microtheories in that space are largely a function of user perspective, which determines what constitutes relevant similarity by selecting the properties of interest in the context of each specific application.

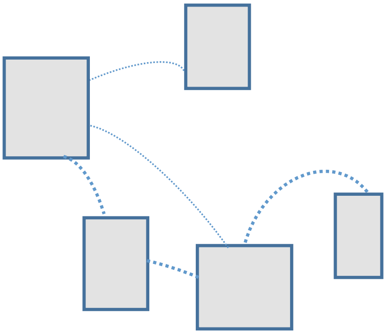

Fig. 1.2 Micro-ontologies as local theories of context (adapted from Bouquet et al. 2003). Distances among micro-ontologies correspond to degrees of similarity, and are a function of user interests

Broadening the Perspective

Micro-ontologies as Designs

A further characteristic of the model is the integration of at least five different semantic "zones," from the stage "of an animal at the vanishing point of intelligence" (Peirce 1878/1998), (L1), to the point where full-fledged mathematical spatial analysis may be conducted (L2 and L3), to declarative knowledge of spatiotemporal entities (L4 and L5), to design (L6 and L7), up to the often unacknowledged influences of societal factors as the source of user motivations (L7). Practical implications for the development of micro-ontologies may derive from the connections established in the model between (scientific) analysis and design, since these two complementary approaches to the world are often contrasted as opposites that are difficult to reconcile (Couclelis 2009b).

Viewing micro-ontologies as engineered (designed) artifacts implies that these must always express their intended users' purposes and functions. By integrating (a) the design perspective, characterized by goals, objectives, and a synthetic, problem-solving stance, with (b) the analytic perspective of science focused on observation, analysis, and representation, the model presented in this paper suggests the broad outlines of a procedure for generating task-appropriate micro-ontologies. The steps below, which correspond to the layers of the semantic core of the model, are along the lines of the design process in general.

- Clarify the purpose of the representation relative to the entity of interest
- Decide on a function or functions for the representation (type A)

  If the entity of interest is artificial, determine which aspects of its own purpose and function (type B) should be included in the representation

- Using function as a selection criterion, identify which configuration of (spatial) parts and relations should be represented
- List and name the individual parts and relations of the above configuration

- Determine what information (types of variables) is needed for representing the above in ways appropriate for the chosen function
- Obtain data of appropriate quality, quantity, format, and resolution

  If certain necessary data are not available, revise the design

- Represent in the appropriate geometry
- In practice of course the design process is not linear, and there may be several feedbacks among layers.

Looking Forward

Beyond the reassuring connections with other work, the model has a number of desirable properties. First, it makes little distinction between physical and abstract, natural and artificial, and even between actual and unrealized or imaginary entities to the extent that these are part of purposefully developed representations. This helps avoid several philosophical problems bound to arise in ontologies that purport to directly model the real world. Second, in its role as "micro-ontology generating engine," the model provides one type of answer to the concern that a proliferation of micro-ontologies lacking a common core would lead to knowledge fragmentation. Further implications being investigated concern the notions of time and uncertainty, since these manifest themselves differently on each layer of the semantics view.

Next to these welcome properties there are some major questions. Unlike the D&S theory in Gangemi and Mika (2003), the model does not have the backing of some traditional foundational ontology, and indeed it may not need to. It is not clear at this point what might be required instead for implementation purposes. Partial solutions come to mind. Domain ontologies come close to the "formal, explicit specification of a shared conceptualization" required by Gruber's (1993) definition, though it is clear that "shared conceptualization" can be quite a relative notion even within well-defined scientific or professional communities (Adams and Janowicz 2011). Also, most future users of the semantic web will likely not belong to well-defined professional communities. Similarly, an expanding library of ontology design patterns (Gangemi 2005, Gangemi and Presutti 2010) seems achievable and desirable for addressing the very large number of phenomena whose representation should be more or less uncontroversial. These could be matched to the levels of the framework and expanded or adjusted as needed while retaining internal consistency. Or perhaps the semantic web itself, as a repository of mostly common-sense knowledge, could take the place of a foundational ontology. Recent work on non-axiomatic logic (Wang 2013) might help make such a prospect realistic. Interestingly, the same "compose-and-conquer" imagery (Bouquet et al. 2003) mentioned above for its parallels with the model discussed here, also appears to apply to the semantic web: locally consistent, globally not.

The model's complement could also turn out to be some combination of other theoretical work in geographic information science, such as the data-oriented general theory of geographic information in Goodchild et al. (2007), as briefly discussed above, or the linguistics- and cognition-oriented perspectives in Kuhn (2003), (2009), Scheider (2011), and Scheider and Kuhn (2011). The latter two lines of research are especially promising since they correspond to two of the three layers where the model presented here is most clearly grounded in the empirical world: the layer of data (L2), and the layer of objects that can be identified and named (L4). Some other work, possibly from logic or philosophy, may be found to support the third such empirical layer, that of intentionality or purpose (L7).

Conclusion

This paper presented a new conceptual model that may be suitable for the generation of lightweight ontologies for GIS and other fields, capable of expressing a broad range of different user needs. That model supersedes the framework in Couclelis (2010), which, from the perspective of the current work, was developed exclusively around the semantics of geographic information, and addressed neither the question of the context of ontology use, nor that of measurements and related operations. In its new role as semantic view, the older framework mediates between the measurements provided by the empirical world on the one hand, and the possible context-dependent representations and interpretations of that world, on the other. From within the latter, different agents' perspectives act as filters to select, interpret, manipulate, and reify the information that is relevant to the task at hand, thus generating micro-ontologies or lightweight ontologies.

A basic premise of this research is that ontologies are not about representing the real world, but instead, about enabling the construction of useful and internally consistent representations of the *information about* that world: they are, in effect, meta-theories for the derivation of empirical models in the broad sense, or micro-ontologies in the case of this research. The strategy adopted in this study is thus to focus primarily not on real-world entities and data, but on the realm of purposes and interpretations relating to entities, and the representational and informational requirements resulting from these. Indeed, while the empirical world may be one, models are built through the lenses of a myriad different perspectives. The users' intentionality is treated as the main generator of microtheories tailored to specific professional, scientific, institutional, and other kinds of interests. A procedure here called "semantic contraction" generates seven nesting, semantically distinct levels of representation, starting with user purpose and ending with a vague notion of a space-time, to be clarified in the context of each specific application as a function of each user's representational needs. The approach has several properties, such as: the avoidance of a number of philosophical problems that affect attempts to represent the real world directly; the ability to handle physical, abstract, artificial, natural, and hypothetical entities as needed; an integrated approach to analysis and design; and evidence of connections with formal theories developed in related areas.

This being work in progress, a host of issues remain, among which the questions relating to implementation are the most pressing. The indications of multiple connections with other work in related fields are encouraging. Even more promising is the evidence of convergent thinking among researchers departing from quite different premises, as in Gangemi and Mika (2003), or in Kuhn (2003), (p. 407), where we read: "…how can we reasonably decide on the contents [of information sources], let alone the representations, before specifying their use? … What conceptualisations occur in an application? … How can a common ontology be constructed for them?"

The democratization of the web that accompanied recent major developments in cyber-infrastructure has often been understood in terms of technical user-friendliness: easy to find, easy to download, easy to upload, easy to change, easy to carry around, easy to probe, easy to update, easy to annotate, easy to share. Less attention has been paid to the fact that the momentous broadening (and deepening) of the user base for online resources also calls for greater *conceptual* user-friendliness, that is, for better adaptability of informational resources to the vast array of new needs and perspectives that these resources could potentially serve. The recent growing interest in lightweight ontologies, especially when seen as tools for mining the semantic web from any desired angle, is a major step towards greater web content usability. It is also a major research challenge, calling for new approaches from the ground up, ranging from the very practical to the philosophical. This paper contributes to the discussion towards that goal.

References

Adams BJ, Janowicz K (2011) Constructing geo-ontologies by reification of observation data. ACM SIGSPATIAL GIS. ACM Press, Chicago, pp 309–318

Borgo S, Masolo C (2010) Ontological foundations of DOLCE. In: Poli R, Healy M, Kameas A (eds) Theory and applications of ontology: computer applications. Springer, Dordrecht, pp 279–295

Bouquet P, Ghidini C, Giunchiglia F, Blanzieri E (2003) Theories and uses of context in knowledge representation and reasoning. J Pragmat 35(3):455–484

Couclelis H (1992) People manipulate objects (but cultivate fields): beyond the raster-vector debate in GIS. In: Frank AU, Campari I, Formentini U (eds) Theories and methods of spatio-temporal reasoning in geographic space. Springer, Berlin, pp 65–77

Couclelis H (2009a) Ontology, epistemology, teleology: triangulating geographic information science. In: Navratil G (ed) Research trends in geographic information science. Springer, Berlin, pp 3–16

Couclelis H (2009b) The abduction of geographic information science: transporting spatial reasoning to the realm of purpose and design. In Stewart Hornsby K, Claramunt C, Denis M, Ligozat G (eds), Spatial information theory, 9th international conference COSIT'09, pp 342–356. Springer, Berlin

Couclelis H (2010) Ontologies of geographic information. Int J Geogr Inf Sci 24(12):1785–1809

Frank AU (2003) Ontology for spatio-temporal databases. In: Koubarakis M, Sellis T (eds) Spatio-Temporal databases: the CHOROCHRONOS approach. Springer, Berlin, pp 9–77

Galton A (2001) A formal theory of objects and fields. In: Montello DR (ed) Proceedings, international conference COSIT 2001. Springer, Berlin, pp 458–473

Gangemi A (2005) Ontology design patterns for semantic web content. In: Gil Y, Motta E, Benjamins VR, Musen MA (eds) The semantic web. Springer, Berlin, pp 262–276

Gangemi A, Mika P (2003) Understanding the semantic web through descriptions and situations. In Meersman R, Tari Z, Schmidt D (eds), On the move to meaningful internet systems 2003: CoopIS, DOA, and ODBASE. OTM 2003, pp 689–706. Springer, Berlin

Gangemi A, Presutti V (2010) Towards a pattern science for the semantic web. Semant Web J 0:1–7

Goodchild MF, Yuan M, Cova T (2007) Towards a general theory of geographic representation in GIS. Int J Geogr Inf Sci 21(3):239–260

Gruber TR (1993) A translational approach to portable ontology specifications. Knowl Acquis 5(2):199–220

Guarino N (1995) Formal ontology, conceptual analysis and knowledge representation. Int J Hum Comput Stud 43(5–6):625–640

Janowicz K, Hitzler P (2012) The digital earth as knowledge engine. Editorial. Semant Web 1(1):1–10

Kavouras M, Kokla M (2008) Theories of geographic concepts: ontological approaches to semantic integration. CRC Press, Boca Raton

Kavouras M, Kokla M (2011) Geographic ontologies and society. In: Nyerges TL, Couclelis H, McMaster R (eds) The SAGE handbook of GIS and society. SAGE, London, pp 46–66

Kjenstad K (2006) On the integration of object-based models and field-based model in GIS. Int J Geogr Inf Sci 20(5):491–509

Kuhn W (2003) Semantic reference systems. Int J Geogr Inf Sci 17(5):405–409

Kuhn W (2009) Semantic engineering. In: Navratil G (ed) Research trends in geographic information science. Springer, Berlin, pp 63–76

Pawlak Z, Skowron A (2007) Rudiments of rough sets. Inf Sci 177:3–17

Peirce CS (1878/1998). The order of nature. Pop Sci (1878). Reprinted in Cohen MR (ed.) Chance, love, and logic: philosophical essays, Charles Sander Peirce. University of Nebraska Press, Lincoln

Probst F (2007) Semantic reference systems for observations and measurements. PhD thesis, University of Münster

Robinson EH (2010) An ontological analysis of states: organizations versus legal persons. Appl Ontol 5(2):109–125

Scheider S (2011) Grounding geographic information in perceptual operations. PhD thesis, University of Münster

Scheider S, Kuhn W (2011) Finite relativistic geometry grounded in perceptual operations. In: Egenhofer MJ, Giudice NA, Moratz R, Worboys MF (eds) Proceedings of 11th international conference COSIT'11. Springer, Berlin, pp 371–390

Scheider S, Probst F, Janowicz K (2010) Constructing bodies and their qualities from observations. In AM. Galton and R. Mizoguchi (eds) *Formal Ontology in Information Systems* (pp 131–144): Proceedings of the Sixth International Conference, FOIS 2010

Searle JR (1983) Intentionality: an essay in the philosophy of mind. Cambridge University Press, Cambridge

Simon HA (1969) The sciences of the artificial. The MIT Press, Cambridge

Smith B (2010) Ontological realism: a methodology for coordinated evolution of scientific ontologies. Appl Ontol 5(3–4):139–188

The Economist (2010) In quite a state: defining what makes a country. Print edition, 62–63 Apr 2010

Voudouris V (2010) Towards a unifying formalisation of geospatial representation: the object-field model with uncertainty and semantics. Int J Geogr Inf Sci 24(12):1811–1828

Wang Pei (2013) Non-axiomatic logic: a model of intelligent reasoning. World Scientific, Singapore