Ontology, Epistemology, Teleology: Triangulating Geographic Information Science

Helen Couclelis

University of California, Santa Barbara, California, USA
cook@geog.ucsb.edu

Abstract

For the past several years ontology has enjoyed a robust regard within the geographic information science community. Ontology is however only one apex of a triangle of knowledge that also involves epistemology and the (long discredited) notion of teleology. Without epistemology we lack a systematic understanding of the nature of the correspondence between ontologies and the general or specific domain of inquiry each of them represents. Without teleology we miss the crucial distinction – essential especially in ontologies of change – between the outcomes of causal processes on the one hand, and the results of purposeful action by sentient actors or machines on the other. This paper argues that connecting current conceptions of ontology with these two other, complementary perspectives would allow new kinds of scientific questions to be addressed as well as to expand the scope of ontology itself in geographic information science. I briefly outline an ontological framework that builds on the epistemological notion of *information* and is guided by the teleological notion of *purpose*, and based on this sketch I suggest a possible way of completing the golden Greek triangle of geographic information science.

Was wir als Wirklichkeit wahrnehmen, ist unsere Erfindung[1]
(Heinz von Foerster)

[1] What we perceive as reality is our own invention. http://www.univie.ac.at/constructivism/HvF.htm

G. Navratil (eds.), *Research Trends in Geographic Information Science*,
Lecture Notes in Geoinformation and Cartography, DOI 10.1007/978-3-540-88244-2_1,

1 Introduction

Of the three pillars of Aristotle's philosophy, ontology alone enjoys a robust regard within geographic information science. What was not long ago the esoteric pursuit of a handful of philosophically inclined researchers has now become a mainstream subfield yielding tangible results. Ontology is however only one apex of a triangle of knowledge that also includes epistemology and teleology. While ontology deals with what exists in a given world, epistemology is concerned with the nature and scope of knowledge, and teleology with the *reasons* (not causes) why the world is as it is and why and how it is changing. Reasons derive from the beliefs, thoughts, hopes and desires that lead people to strive towards particular purposes or goals, whereas causes have effects regardless of any reference to human intentionality (Lyons 1995). The distinction may often boil down to a difference in perspective. You may correctly think that the rain caused me to open my umbrella, though from my perspective it is my desire not to get wet, along with my belief that a personally unpleasant state will result if I do get wet, that leads me to open my umbrella. In many (most?) cases the first, simpler account may be good enough, but clearly something is lost by leaving out the teleological explanation. This paper argues that linking current conceptions of ontology in geographic information science with teleology as well as with epistemology would allow new kinds of scientific questions to be addressed would expand the scope of ontology itself towards novel and fruitful directions.

In developing the argument for epistemology and teleology this paper explores the implications of basing ontology construction in geographic information science on the dual principles of *information* and *purpose*. Information, a fundamental epistemological notion, seems a natural choice for an *information science*, but there are additional advantages relevant to the task at hand. One advantage is that information is a relational rather than an absolute concept, expressing an intrinsic relationship between information source and recipient (Williamson 1994; Huchard et al. 2007). This establishes a basis for taking into account the interests of the user and thus for forging a link between ontology and teleology. Another advantage of using information as the central notion rather than concepts or linguistic terms more directly associated with the empirical world is precisely that it begs the question of the relationship between that empirical world and the ontology under consideration, thus making epistemology inescapable. Finally, since information comes in quanta, it facilitates a constructivist approach to ontology development, an approach that drives the framework briefly outlined in section 3.

Purpose, the hallmark of teleology, is not a notion emphasized in existing ontologies of geographic information science, and yet every geographic representation is developed for some purpose. In addition, many if not most of the empirical entities represented in these ontologies have also been created or modified by humans with specific purposes in mind: these are the 'artificial' entities that Simon (1969) writes about in his famous book '*The Sciences of the Artificial*'. This double observation provides an answer to the geospatial ontology builder's basic challenge, which is how best to represent geographic phenomena. In the case of socially produced geographic phenomena such as roads, land parcels and campgrounds the challenge is augmented by the necessity to draw a line between these tangible, physical entities and the rest of the social world. *Purpose* may be seen as the interface between observable geographical entities on the one hand, and social needs and wants on the other. Purpose is like a permeable membrane enveloping the geographical world that permits socially conditioned questions to traverse it one way, and socially meaningful interpretations to emerge in the other direction.

The ontological framework outlined below, which is anchored by the notions of information at one end and of purpose at the other, is populated by an ordered sequence of discrete domains of *information objects* that correspond to – but are logically different from – the more familiar types of empirical entities or concepts that are the focus of most other ontologies. Details of the framework summarized here are presented in a forthcoming article. This paper focuses on the triangle of knowledge of geographic information science that has ontology, epistemology and teleology as its apexes, and of which the interior is occupied by the foundational notions of information, (information) object, and purpose. The sides of that triangle are also meaningful, suggesting a number of research questions that are either new or are novel perspectives on familiar geographic information science questions. For example:

- *Ontology-Epistemology*: Given two arbitrary ontologies, how can we tell a priori to what extent these may be compatible? Given a specific ontology, how can we tell whether it is complete and internally consistent?
- *Ontology-Teleology*: How can we best represent artificial objects and purposeful change within the same ontological framework as natural objects and non-purposeful change? How can we seamlessly integrate the natural and the artificial in both static descriptions and representations of change?
- *Teleology-Epistemology*: How do we know that a proposed ontology is appropriate for particular user purposes? What is the role of intentional stance in helping decide among competing ontologies?

Ontology and epistemology have been considered together before from the perspective of geographic information science (Frank 2001) but the lowly status of teleology in traditional scientific thinking must have been a major reason why that third essential perspective on knowledge has not been a more prominent part of the field's agenda. Yet teleology has undergone a quiet renaissance since the beginning of the computer era in connection with the realization that some kinds of advanced machines are characterized by purposeful behavior (Rosenblueth et al. 1943). More recently the international conference series DEON (Conference on Deontic Logic in Computer Science, http://deon2008.uni.lu/cfp.htm) has brought teleology into mainstream computer science, highlighting the host of contemporary domains of application that can benefit from implementations of telic thinking. In my view geographic information science should be one of these domains.

The next section briefly discusses current notions of ontology in connection with related research in geographic information science. I then sketch out a hierarchical ontological framework based on the dual notions of information and purpose, arguing that (a), the systematic relationships between levels of that framework suggest answers to certain significant epistemological questions and (b), the relevance of teleology becomes evident at the highest levels of that hierarchy. Only the static case is discussed here, covering time-slice extensions but not processes, actions and dynamic events. Since the purpose of this paper is primarily to pose questions and to stimulate discussion, the conclusion is brief and speculative.

2 Ontologies, Artificial Worlds, and Cognitive Semantics

Small -'o' ontology is the description of a world – not 'The' World. The ontology of a domain of inquiry is the formal description of an artificial world (one of an infinity of possible small-'w' worlds) that gives rise to legitimate *representations* or models constructed within that domain. This view is in agreement with a widely accepted definition according to which an ontology is a formal and explicit specification of a shared conceptualization (Gruber 1993; Borst et al. 1999). Shared conceptualizations and their kin, descriptions, representations and models, are just as likely to be dynamic as static, yet existing geographic information ontologies tend to be strongly biased towards static categorizations and classifications. Beyond internalizing dynamics and process this definition also stresses the intersubjective and cognitive nature of ontologies. It is also compatible with a perspective on models from computer science, proposing that a model represents a microworld consisting not only of contents (things and their relationships) but also of spatial structure, temporal structure, 'physics' (processes allowed or rules of interaction and behavior), and rules of inference or logic (Smyth 1998; Couclelis 2002; see also Zeigler et al.

2001). To the extent that ontologies are models this view applies to them also, emphasizing their contingent nature which extends beyond contents and structure to process and to the fabric of space and time themselves.

The relevant ontologies for the framework sketched in this paper are the foundation ontologies, which purport to describe fundamental concepts and relations that are valid across domains. This is in contrast to the more specialized domain ontologies that are specifically tailored to the needs of particular areas of inquiry or application. Foundation ontologies may focus on real-world entities, on concepts or linguistic entities, or they may be mixed, integrating both 'external' and 'internal' representations (see Agarwal 2005 for a review). Still other ontologies strive to encompass the entire spectrum of empirical reality as seen from a spatial standpoint, including abstract aspects such as the social and experiential. These are usually hierarchical, consisting of sequences of 'levels', 'realities', 'worlds' or 'spaces', and they tend to be quite similar in principle. For example, Couclelis (1992) suggests a hierarchy consisting of mathematical space, physical space, socioeconomic space, behavioral space, and experiential space; Guarino's (1999) ontology of particulars includes a physical level, functional level, biological level, intentional level, and social level; and Frank's (2003) proposed tiers are: physical reality, observable reality, object world, social reality, and cognitive agents. These and several other empirically based ontologies may all be useful and intuitively plausible but they tend to lack a convincing justification for the designation, order and contents of the levels, as well as a systematic procedure for moving up and down the hierarchy.

Kuhn et al. (2007, p 7–8) propose a list of potential benefits for ontology engineering to be gained from cognitive semantics. These include:

- "*Grounding ontologies*, that is, establishing primitives that are both meaningful and suitable as building blocks for ontologies".
- "Moving space and time from their current status as application domains to become *foundational* aspects of ontology".
- "Reconciling *meaning and truth*".
- "Allowing for *perspectivalism* without giving in to relativism".
- "A cognitively plausible ….understanding and formalization of *conceptual mappings*".
- "*Personalizing* geospatial services" by taking into account "situational and personal context".

These desiderata are clearly epistemological while the call for perspectivalism and personalized geospatial services also hint at teleology in that they brings user needs, perspectives and context into the picture. While not explicitly emphasizing cognitive semantics, the framework outlined in the next section indicates one possible way of addressing these points in ontology engineering. One important question that this framework raises is precisely the connection between information, user purpose, and cognitive semantics. The very partial and tentative answer provided here will hopefully contribute to a much needed broader discussion on this issue.

3 Information, Information Objects, and Purposes: Sketch for an Ontological Framework

The ontological framework adumbrated here consists of an ordered sequence of seven systematically related hierarchical levels. The levels are differentiated by their degree of semantic richness, ranging from minimal to maximal semantic complexity. Like most hierarchies this framework may be approached from either end, from the bottom up or from the top down. A very important point concerns the distinction between the mode of generation and the mode of use of this hierarchy. While it is interpreted and used from the highest level down (from purpose to minimal necessary information: the *intentional* direction), it is more logically presented from the bottom up (from minimal elementary information building up to purpose: the *generative* direction). The generative direction, which helps explain the systematic procedure by which the levels are derived from each other, will not be discussed in this paper.

The idea underlying the construction of the hierarchy is the following. Like all information sciences, geographic information science is about *representations* of entities, not directly about the entities themselves. Representations are made up of *information* selected and organized for some *purpose*. Now, the possible ways of selecting and organizing information to represent any non-trivial geographical phenomenon are in principle indefinitely many. The reason why we come up with models that are 'use'-ful is that this process of selecting and organizing information is implicitly or explicitly guided by some practical purpose. The purpose of the framework outlined here is thus to present a systematic model of how representations of geographic entities relate to available information on the one hand, and to the purpose(s) for which such representations are constructed, on the other. Seven different semantic domains, corresponding to the seven levels of the hierarchy, are distinguished in this framework, though no claim can be made that seven levels are either necessary or sufficient. These semantic domains range from the most complex, populated by representations that fully correspond to their intended purposes, to the most sparse, where only the potential existence of information suitable for constructing a specific representation of interest is ascertained. In between the two ends lie five more levels that can be derived from each other either by adding purposefully selected semantic content (bottom up), or, conversely, by subtracting suitably selected semantic content (top down), so that the representations ('information objects') left behind are still meaningful though increasingly semantically impoverished.

The following is a brief outline of the levels of the hierarchy, while Table 1 provides an illustrative example of how the 'same' phenomenon is specified differently across the levels depending on purpose. Teleology thus motivates the construction of this entire ontological framework. At the same time, the suggested recursive decomposition procedure clarifies the epistemological relations among levels. Taking the top-down view, the levels are derived from each other by subtracting at each step suitably defined domains of semantic content until there is hardly anything left behind. Imagine an originally fully conscious intentional agent (a person, a group, or a society) becoming more and more semantically challenged as it descends the hierarchy– or perhaps 'Hal' the *Space Odyssey* computer as its modules are gradually being stripped away by the spaceship's frantic survivors (Clarke 1968).

Level 7: Purpose. Purpose is not itself a geospatial concept, but as mentioned earlier, it is the interface between the world of geospatial entities one the one hand, and the social world of intentional agents on the other. Purpose determines what spatial functions need to be represented, what distinct spatial entities belong together to form a complex object, how simple objects are named and categorized, what spatial patterns and measurable properties correspond to the entities of interest and how these should be analyzed, what sort of information is relevant, and finally, what spatio-temporal framework must underlie the representations appropriate for the purpose in question. Purposes thus *select* suitable information subsets out of a comprehensive domain of possible data and *construct* out of these the semantically appropriate (to that purpose) information objects.

Earlier we distinguished two different kinds of purposes relating to geographic representations: (i) their intrinsic purposes *qua* models built with an end use in mind (e.g., the representation of a weather front intended for navigation rather than for presentation on television), and (ii) the extrinsic (to the representation itself) purpose of any artificial entities (e.g., the purpose of a school or a bridge) that may need to be reflected in the data model. The illustrative example in Table 1 combines these two cases: here a map of roads *qua* representation serves two different purposes, in the first of which the main objects represented (roads) are approached as artificial entities endowed with their own purpose (transportation), whereas in the second case (ecological study) the purpose of the roads is irrelevant and only their emerging function as dangerous physical barriers to wildlife movements is of interest.

Level 6: Function. (i) Every representation is designed to function cognitively in particular ways so as to support the purposes for which it was developed. Moreover, (ii) in artificial entities and natural entities adapted for human purposes, function is the geospatial realization of these purposes.

Level 5: Complex objects. Entities made up of discrete or inhomogeneous parts are recognized as single objects to the extent required by the function(s) necessary to meet specific purposes.

Level 4: Simple objects. Spatially connected, homogeneous objects are categorized and named depending on their role in the context of complex objects or directly on their function. This is the lowest level at which information objects are identified as specific real-world entities.

Level 3: Classes. At this level spatio-temporal patterns and object attributes are analyzed and classified based on their measurable properties (e.g., as in automatic classification), though the available information is no longer sufficient to identify the resulting information objects with specific empirical entities.

Level 2: Observables. Crude information objects at this level only allow the qualitative knowledge that distinct kinds of relevant information exist at specific space-time points.

Level 1: Existence. By now the framework has been drained of all semantic content except for the notion that specific points of the spatio-temporal plenum are associated with information appropriate for the purposes specified at level 7.

4 Triangulating Geographic Information Science

We may now return to the questions posed in the introduction of this paper and sketch out some answers suggested by the ontological framework outlined in the previous section.

Table 1. Purpose in representations versus the purposes of artificial entities: contrasting examples.

	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 Complex objects	A road network	A wildlife corridor network
4 Simple objects	Places, freeways, arterials, collectors, intersections, ramps,	Roads, wildlife corridor segments, underpasses, culverts,

	roundabouts,…	high-conflict intersections,…
3 Classes	Information objects associated through location, geometry, topology, directionality, surface, flow etc. attributes	Information objects associated through data on incident frequency, barrier permeability, height above ground, width, density per unit area, soil characteristics, etc.
2 Observables	Hard, rough, green, brown, wet,…	Open, blocked, green, hard, kill, dry, wet…
1 Existence	"Road-map relevant information exists here now at such-and-such appropriate granularity"	"Wildlife-corridor relevant information exists here now at such-and-such appropriate granularity"

4.1 Ontology-Epistemology

Given two arbitrary ontologies, how can we tell a priori to what extent these may be compatible?

The contents of the different levels of the semantic hierarchy and especially the relations holding among levels suggest how alternative ontologies may be mapped into that structure. Category theory provides the tools for effectuating such mappings in a computer science as well as in a mathematical context (Peirce 1991). Most object-based ontologies will map primarily into Levels 4 (simple objects) and 5 (complex objects) though they will also have parts extending to the lower (usually) and higher (rarely) levels of the hierarchy. Given any two ontologies, the extent of overlap of these mappings may be interpreted as the degree to which the corresponding ontologies are compatible (interoperable).

Given a specific ontology, how can we tell whether it is complete and internally consistent?

Mapping a given ontology into the hierarchical structure may also be used to suggest internal inconsistencies and gaps as well as opportunities for broadening the scope of that ontology. Basically, a consistent ontology will extend across a number of consecutive levels (e.g., spanning levels 3, 4 and 5 is consistent but not 2, 4 and 5 since the latter involves a jump from raw observations to objects, bypassing issues of measurement). Conversely, an ontology whereby the information objects corresponding to a given level are less developed or numerous than the ones below manifests gaps that may be filled by exploiting the full range of available lower-level objects.

4.2 Ontology-Teleology

How can we best represent artificial objects and purposeful change within the same ontological framework as natural objects and causal change? How can we seamlessly integrate the natural and the artificial or purposeful in both static descriptions and representations of change?

Artificial objects have many material properties similar to those of natural objects yet their existence and structure are incomprehensible when viewed strictly from the perspective of natural science (Simon 1969). This is because the ontological essence of artificial objects is very different from that of natural objects, the former existing only as a result of human purpose, having been designed and built to serve a specific function or goal. Natural objects can also serve a purpose to the extent that they afford a needed function, e.g. while on a walk in the country I can sit on a rock of the right size and shape for the purpose of resting. Rocks and chairs have very different origins and geometrical properties (no natural process could produce an office chair, and no natural object has the clean geometry of an IKEA piece of furniture) yet seen from Level 7 of the ontological framework these differences are minimized through a potential common purpose of interest to the user. While the treatment of change is not discussed in this paper, an analogous distinction holds between natural processes and purposeful actions, in the sense that many natural processes may be harnessed and modified for a purpose and thus become agents in a purposeful process (e.g., wind-generated electricity).

4.3 Teleology-Epistemology

How do we know that a proposed domain ontology is appropriate for particular user purposes?

Indirectly albeit insistently, this paper has stressed the related issues of user needs and fitness for use of data, which are more fully treated elsewhere in this volume (Hunter et al. forthcoming). The present paper suggests a possible approach to these questions focusing on ontology rather than on database design. Indeed, an ontological framework culminating at the level of purpose immediately suggests how such questions might be tackled. One must first identify the information objects at the top levels of the hierarchy that correspond to the purpose or purposes of interest. Then, having mapped the domain ontology in question into the hierarchical framework, one follows the relevant branching paths downward to the highest level at which elements of the ontology under consideration can be found. If the branching paths from purpose to function to complex objects etc. intersect these elements, and the ontology is internally consistent (see above), then the ontology is appropriate for the purpose. This also suggests how the next, related question may be approached:

What is the role of cognitive stance in helping decide among competing ontologies?

We may venture that several choices are possible depending on the informational depth desired for, or required by specific applications. It may thus be sufficient in some cases to choose an ontology that describes what Bibby and Shepherd (2000) call the ‘brute, unproblematic GIS objects’ thoroughly and well, (Levels 4 and 5), while in other cases ontologies spanning the higher levels of semantic complexity at which function and purpose are made explicit may be necessary. This too is a purpose-oriented decision, and so, one way or another, teleology reaffirms itself.

5 Conclusion: From Triangles to Tetrahedra (perhaps) – and Beyond

The term ‘information’ in geographic information science makes it clear that the field is about constructing useful representations – models – of a particular kind of real-world phenomena, not about studying the phenomena themselves. Unlike geography (or, for that matter, geology, medicine, biology, chemistry, economics, and so on) geographic information science is not about describing and explaining the world, but rather about representing it in ways that are most useful to those who do the actual describing and explaining. This makes geographic information science a ‘meta-’ discipline, and like all information sciences dealing with representations it cannot escape philosophy (just think of the entanglement of computer science with the philosophy of mind, or the philosophical problems raised by the Church-Turing thesis). In this paper philosophy has manifested itself through the three basic questions: what (ontology), how (epistemology) and why (teleology) for geographic information science. The close relationships between these three broad fields are implicit in the manner the framework outlined in these pages was constructed, and the significance of these relationships for geographic information science was hinted at above. This short paper could not get into implementation issues but the framework generation process described is qualitatively similar to recursive decomposition and should thus be amenable to computational treatment.

To close, one definite conclusion that may be drawn from all the preceding is that there is significant foundational work yet to be done in the area of geographical ontologies. Recent emphases in ontology development that tend to privilege implementation, visualization, data mining and other more applied issues over conceptual exploration seem to suggest that the theoretician's job is now over and that we are squarely in the era of applying and refining what we have learned. I disagree. I think that there is still tremendous scope for the investigation of the more abstract and philosophical aspects of the subject, and that both the theoretical and applied lines of ontology research will greatly benefit from being more closely intertwined with each other. This essay focused on two rather neglected perspectives, arguing for the potential contributions of epistemology and teleology to geographic ontology development. There are many more such angles, that of cognitive semantics mentioned earlier being one. Constructivism also comes to mind, a philosophical tradition reflected in the framework presented in this paper and one with close connections to the University of Vienna (see the opening quote by Heinz von Foerster), to name just one more. There would be no better way to honor Dr. Andrew Frank, a pioneer in thinking about such issues, than for the papers in this volume to reaffirm their authors' commitment to pursuing further the fundamental questions relating to the representation of the geographical world.

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