5. Spatial Ontology: A Geographical Information Point of View

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Prima di essere ingegneri siete uomini!
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5.1. Introduction

The ancient philosophical discipline of ontology has been rediscovered for the purposes of artificial intelligence (Hayes, 1978; Hayes, 1985b). The importance of fixing exactly what is at the base of the things one talks about and of specifying how the different terms interact becomes evident when one attempts in a serious fashion to construct models of the real world. Above all, because in natural language different points of view are brought to bear, confusion and incompatibility can arise.

Ontology has been concerned with the properties of objects, with their modes of existence and with questions such as how they can be divided in parts and how they fill space (Smith, 1982). Ontology, topology and mereology (Simons, 1987) have thus been linked together (Smith, 1995). Recently an ontology of holes has been published (Casati and Varzi, 1994).

There is extensive literature proposing practical ontologies and discussing the finer points of difference between the schemes proposed by others (Hobbs and Moore, 1985). This literature is important in furthering the development of ontologies and it helps us to understand the consequences of different choices (Shaw, 1984). While some of my earlier papers can be understood as contributions to this tradition of proposing formal ontologies and exploring their properties (Frank and Kuhn, 1986; Frank, 1992a; Frank, 1994; Frank, 1996b; Frank, 1996a; Frank, 1996c), I would like here to proceed in a different direction by taking the position of a consumer of ontologies.

This assumes that there is a production of ontologies in the research literature and that these ontologies are useful and can be used. The chapter concentrates on the latter pair of issues, discussing a particular area of application, namely geographic information systems (GIS) (Maguire et al., 1991). It addresses how ontologies are used and how they can contribute to the building of better information systems (Kuhn, 1992; Mark et al., 1992). This is done mostly in relation to examples of problems that arise for the users due to the lack of a consistent ontology in the system (Kuhn, 1993; Kuhn, ress). Such problems become manifest at the user interface level, where the user is confused by two conflicting ontologies and has to learn when one and when the other applies.

The chapter concludes with a set of recommendations as to how ontologies can be made more useful and how the connection between the producers and consumers of an ontology can be structured to make the exchange of ideas more effective. I will also list a number of research directions and specific topics that I would think could provide a useful contribution both from a scientific and an engineering point of view.

This chapter is built on a simple *metaphor*: ontologies are products and are sold in the international *supermarket* of AI research. In this *supermarket* consumers with particular needs shop for ontologies. They must select a set of ontologies to describe the entities in their application domain, and these ontologies must form a consistent ensemble. Contradictions and other inconsistencies may later become apparent to the end-users of the information system. In consequence, the producers of ontologies need clear labels on the products, indicating the advantages and disadvantages of each ontology and potential conflicts with other ontologies. This is advocating truth in labeling for ontologies.

5.2. Geographic Information Systems Build on Ontologies

To make it easier to understand the focus of this chapter, it seems useful to clarify the position from which it starts. Geographic information systems (GIS) are systems that manage information about cities, rural areas, the environment for many different purposes (Antenucci et al., 1991; Laurini and Thompson, 1991). They integrate data about space collected from many sources and use computer technology for the processing, storage, and visualization of such data.

GIS have their origin in the analog method of overlaying different thematic maps to show combinations of features: if one map uses cross-hatching to indicate built-up areas, another uses hatching to indicate the areas zoned for residential buildings, and a third uses gray tone to mark

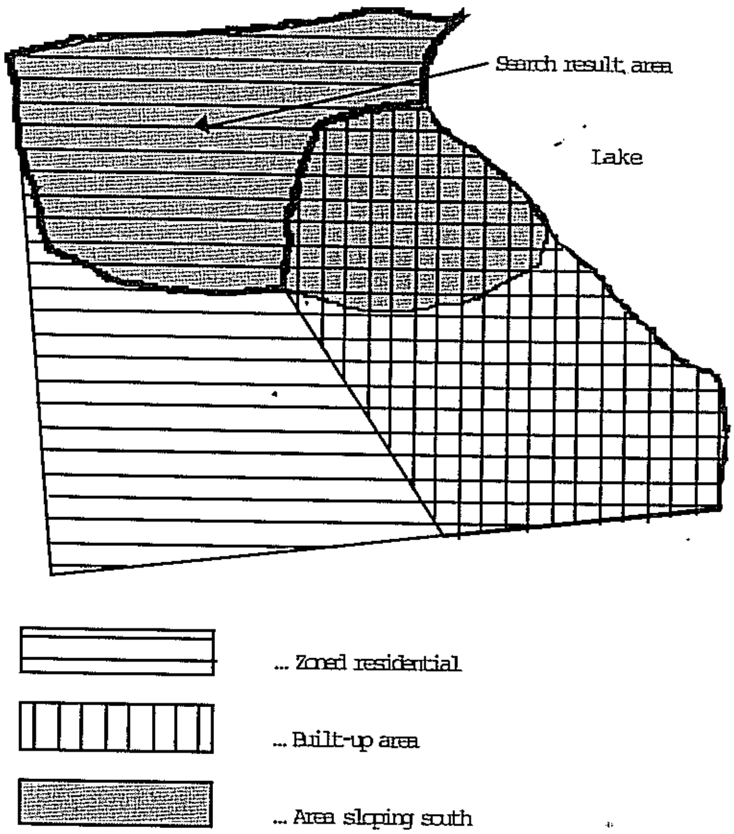

Figure 1. Overlay search for an area where one can build a new family home facing south

areas sloping south, then the combination makes it easy to spot areas where one could build a new family home facing south. It is necessary only to search for areas that are hatched and gray throughout (see Figures 1). In zones that are cross hatched and gray, one could search for homes that are for sale (Frank, 1987).

The traditional analog method points to a computer implementation and systems were constructed already in the 1960s (Schmidt and Zafft, 1975). The restrictions of the analog method (for example, only a few layers can be used at any given time) were eliminated. Tomlin proposed a closed algebra with a rich set of operators on maps (Tomlin, 1983a; Tomlin, 1983b; Tomlin, 1989).

Such systems are widely used in urban and regional planning, in the discussion of environmental problems, and for all geo sciences (see especially volume 2 in (Maguire et al., 1991)). They are useful but also limited as they are built around the map metaphor. In the analog system, human cartographers or planners drew the maps and interpreted the results. They applied their commonsense and professional understanding of the situation; They knew about the limitations of the process and separated the ontology of the process (map, color encoding, and so on) from the ontology of the application domain (land-use categories, soil types, and so on). They avoided unwarranted conclusions based on their understanding of the application domain.

Some of the limitations of the map algebra-based, layer, and overlay operations oriented systems are linked to the cartographic models from which they originate. In lieu of working with maps (graphical pictures of the world), a GIS attempts to construct a model of the world (Frank, 1984). Analytical functions can be applied to the model rather than graphical analysis applied to a graphical rendering stored in a computer. This approach was very fruitful, first and foremost for administrative systems, but then also for GIS used for scientific research and planning.

GIS today are widely used and their field of application is almost without limit: most human activities are linked to space and thus most administrative and political decisions are influenced and influence space. GIS are regularly used to plan political campaigns, to assess social disparities, to make regional and urban planning decisions, but also to study global change in climate. GIS software has a rapidly increasing market; for some regions of the world, rates of increase of 20 to 30% per year are currently observed.

The GIS industry is hindered by the capabilities of the software and its quality (Mark and Frank, 1991; Frank and Mark, 1991; Mark and Frank, 1996). This is similar to the state of affairs in other branches of the information technology industry (Joch, 1995), but the problems are more acute and thus better analyzed. In addition to the regular problems of software engineering and poor programming practice using current programming languages (Liskov and Guttag, 1986), a number of special issues can be detected that are directly linked to the ontologies used and thus of interest in the current discussion.

5.2.1. MODELS OF REALITY IN A GIS MODEL AN EXTERNAL INDEPENDENT REALITY

The GIS is built to present a model of some aspects of reality (Frank and Mark, 1991). This model must reflect observable properties of this reality, and the model is useless if there are substantial systematic deficiencies in the correspondence between observed reality and model.

This differentiates GIS and other reality-oriented information systems (such as systems designed for the steering of robots) from those administrative information systems where there is no other reality than the one created through the system so that the system is, by definition, correct. The stock example is banking, where the only operations possible are the ones built into the program, and there is no attempt to model connection to an independently existing external reality. The definition of a client of a bank is "a person listed in the database of bank clients". Systems that must correspond to some external reality are more difficult to build (Shaw, 1984). The most obvious consequence of modeling an exterior reality is that the closed-world assumption, which is at the foundation of any database query language, is not valid any more (Reiter, 1984).

5.2.2. A GIS IS A FORMAL SYSTEM.

Despite the fact that GIS are built following informal specifications and formal methods are not yet sufficiently developed to be used routinely for software development, the resulting set of programs is a formal system executed by the computer.

The formal properties of a GIS, which is a complex system of several million lines of code, are hidden in the mass of the programming code. It is difficult to see where different definitions are used and how they interact, but they will often interact in the most distracting manner, as an abundance of complaints from users demonstrate.

5.2.3. GIS MODEL SPACE

In GIS software some particular concepts for the representation of space are built in. The appropriate models for space have been central in much of the scientific discussion of GIS (especially the series of AutoCarto conferences and then Spatial Data Handling and Conference on Spatial Information Theory).

In GIS it is customary to use a three-level hierarchy of concepts for modeling space (Frank, 1992b; Goodchild, 1992):

- *Spatial concepts*, which reflect the *user's* conceptualization of space, can be informal and not directly implementable. Two fundamentally different views are necessary: a concept of space with attributes (commonly labeled as *raster GIS*) and one with objects that have spatial and non-spatial attributes (which is often called *vector GIS*). These two concepts can be traced back to ontological roots.
- *Spatial or geometric models* are implementable models of space with formal definitions. The major two contenders are models that model space using a raster and others that support geometric constructions based on points, lines, and areas.
- *Spatial data structures* implement geometric models in computer code, achieving optimal performance.

These three levels are comparable to the AI division in concept, knowledge, and data.

5.2.4. GIS ARE USED FOR HUMAN ACTIVITIES.

The results yielded by GIS are used in administrative and political processes, where they are the input in human decision-making processes. ¿From this it follows that the interpretation of output by humans matters. The goal is not primarily an objective scientific truth, but a commitment to consider human cognitive processes.

There is first and most obviously an effort to be made to produce output in a format human beings can digest, thus leading to efforts to visualize in graphical form but also using other media that are effective and easy to interpret by the application specialist.

There is also an effort necessary to construct user interfaces in the broadest sense that correspond to the abilities and concepts of the users to reduce the effort to learn to use the system. This is particularly important as today more than half of the cost of acquiring GIS software goes for efforts to train the user to use the system effectively.

5.2.5. GIS INTEGRATE DATA FROM DIFFERENT SOURCES BASED ON DIFFERENT CONCEPTS.

The fundamental tenet of GIS is the idea of integrating data from different sources with respect to spatial location. This reflects the human experience that different factors affect locations, from natural phenomena like southern exposure and soil type to factors created by human beings: distance from a railway station, noise effects from an airport, building zones, south-exposed slope, and so on.

Different data originate with different organizations and reflect different scientific backgrounds. It is surprising how the spatial concepts of different sciences differ. Scientific disciplines are often distinguished by the scale of spatial or temporal phenomena they consider: resolution of time for a geologist is in thousand-year units, whereas a wildlife biologist studies movement of animals during a day. Similar differences apply in the spatial scale.

Spatial concepts can be two-dimensional (possibly embedded in a three-dimensional space), three-dimensional, continuous or divided in discrete units, or restricted to a graph (as is typical for traffic and other communication studies). Despite several years of research effort, it has not been possible to find a single, unifying concept of space to which all the others can be reduced; the question of whether this is possible in principle is still open.

5.2.6. DIFFERENT CULTURAL GROUPS ARE INVOLVED IN PRODUCING AND USING A GIS.

GIS software is used to model many different kinds of geographic information. It is used in different circumstances and different countries (Campari, 1991). GIS users speak different languages (Campari, 1994). Differences in the concepts of land, ownership, nature, and the environment are easily detected (Campari, 1992). A less evident issue is caused by the fact that the designers and programmers of GIS software are predominantly from the United States and assume typical U.S. attitudes toward planning, land use,and so on (Guttenberg, 1992; Guttenberg, 1993), attitudes that rest on concepts distinct from those used in many other countries where GIS is used (Campari and Frank, 1994).

5.3. Problems with Ad-Hoc Ontologies in GIS

GIS are a typical, advanced, and demanding case of a complex information system about the spatial environment. They point to a number of difficulties in building such systems, difficulties that are, however, not unique. Observations made today in building GIS software can be generalized and applied to other fields. It is thus important to observe how such systems are advanced by the use of properly developed ontologies.

GIS are based on ontologies about objects, space, time, and many categories from law, technologies, and social structures. Until recently, these were mostly ad hoc or based on well-known mathematical abstractions like topology, Euclidean geometry and set theory.

Problems can be observed in today's use of GIS that can be traced back to the unsystematic use of ontologies (Guevara, 1985). The problem was not so much a lack of systems but rather a multiplicity of alternative systems combined with a neglect of serious work in the subject until around 1890 and then again between 1920 and 1980 (Smith, 1982; Simons, 1987).

5.3.1. INCONSISTENCY BETWEEN ONTOLOGIES BUILT INTO A GIS

The ad hoc construction of the ontology of a GIS will invariably lead to some choices that will not be compatible with each other. Galton discusses possible inconsistencies for time and motion (Galton, 1995c); in the rich domain on which GIS are based, many more inconsistencies are possible. The legal definition of a parcel in common law uses a *general boundary* concept, which is a fuzzy area not belonging exclusively to any of the two parcels. The GIS typically represents such a boundary area by a sharp line (which is the dominant legal concept in the European cadastres).

5.3.2. CONFLICT BETWEEN THE ONTOLOGICAL CONCEPTS AND THE IMPLEMENTATION

GIS software is often assuming continuous space and, if included, continuous time. The user interface is designed in these terms, and much of the code is written based on concepts of continuous space. The implementation, of course, must use finite representations for coordinate values and thus cannot truly manage continuous space. For at least fifteen years, GIS software was plagued with simple conflicts between geometric computations done with floating point numbers approximating real coordinate values and rules from topology: overlay computations produced erroneous values for regular input or could not complete a computation. After many years of gradual improvement, a consistent theory is available (Greene and Yao, 1986), and an ontology-like description of a consistent geometry that can be implemented is known (Gueting and Schneider, 1992).

5.3.3. CONFLICTS BETWEEN THE COMMONSENSE ONTOLOGY OF THE USER AND THE MATHEMATICAL CONCEPTS IN THE SOFTWARE

The concepts used by the different users of a GIS are often closer to commonsense theories than to objective scientific (physics-based) theories. Administrative rules and law, everyday ethics, and everyday planning decisions embody ontologies that which with scientific ideas but are highly useful nonetheless.

The difference between commonsense ontologies and the ones used in physics are surprisingly large. Equally surprising is the observation of how little the construction of our material technology (buildings, machines, cars, and so on) is based on strict physical laws. It was found that systems to diagnose real machines must use so-called naive physics that permits logical, often qualitative, but not strictly quantitative physical modeling of simple physical mechanism. Egenhofer and Mark (1995) apply similar ideas to geographic information.

5.4. Use of Ontologies in GIS and Similar Information Systems

Building application programs in this context means constructing an ontology for the application domain. This is normally done by the analyst in assimilating the ontology underlying the description given by the application specialist.

This partial information is then transformed in an abstract ontology by the software designer, usually relating it to standard mathematical concepts. These do not precisely capture the application notion; hence, they are then modified, and inconsistencies result. Sometimes it is not possible to implement these mathematical categories exactly, and approximations are used, again leading to inconsistencies.

A GIS uses quite a few ontologies, each of which poses serious problems, most of them have occasionally appeared in the literature. A survey of a few issues follows.

5.4.1. ONTOLOGY OF ENTITIES

What does it mean to be an entity? When are entities created, when do they end (Al-Taha and Barrera, 1994)? When does a piece of land become an entity in its own right? A typical example is provided by the legal system, which deals with land parcels: they are created and cease to exist, despite the fact that land can neither be created nor destroyed. New parcels emerge when previously existing ones are divided and cease to exist when merged with another one (Casati and Varzi, 1994).

5.4.2. ONTOLOGY OF SPACE

Space in today's GIS is always seen as Euclidean space, represented with Cartesian coordinates. To deal with the spherical surface of the earth (which is not a Euclidean plane) is often not necessary. But when it is necessary, for example, to construct a spatial sampling method that gives equal probability for any point of the sphere to be included, no good solutions exist (Goodchild and Shiren, 1990).

Data that are not related to a point with given position cannot be entered in a GIS. This limits the use of GIS for combining verbal reports about events, such as accidents. "The fire is on the left bank of the river", "The fire is north of the railway bridge", and "The fire is on route 451" together describe a precise location, but neither of the three pieces of information can be entered in a GIS independently (Frank, 1992a).

A separate issue is the representation of nonpoint data, for example, the representation of diffuse chemical contamination of an area. Either space is seen as a continuum, so that for each point (in principle) an attribute value gives the local concentration, which is then discretized to a regular raster. Alternatively, space is seen as consisting of a collection of spatial objects with uniform raster and proper boundaries. In some applications, these objects must form a partition and together constitute the space. In other applications, different objects may coexist at the same location, that is, objects may overlap. In both cases, space is modeled as a collection of spatial objects that describe the boundaries of these objects (Corbett, 1979).

A new idea is the use of constraints, which, in the simplest form, describe a semi plane but can be combined to limit the infinite set of points to the desired area. This represents the infinite number of points in an area by inequalities, that is, an infinity of coordinate pairs.

5.4.3. ONTOLOGY OF TIME

Most GIS do not include concepts of time; they describe an instantaneous picture. Indeed, they often give the data valid for different instants, depending when the last update for an area was made. Administrative uses demand at least that the date for which the data were valid is recorded, to avoid inconsistencies due to the comparison of data from different times. Often there is a legal need to record not only the current situation but also previous situations so that a complete documentation of all previous states, and of all the operations that led to the current state, can be reconstructed. This is typically the case for cadastral applications (Al-Taha, 1992) but will be increasingly included in others. For example, a commercial distributor of a road atlas in digital form documents all changes to his road databases to avert liability cases.

Natural sciences often study theories that describe change. GIS for scientific uses thus must deal with time series (instantaneous data related to regularly spaced moments in time). The national statistical bureaus collect and distribute snapshot data, collected in regular intervals (typically every ten years).

Not all models of time in science follow the familiar arrow concept: natural phenomena are often repetitive and thus their description is cyclic also (Frank, 1996a).

5.4.4. MEREOLOGY

The entities in a GIS appear single and uniform at one level of description, but they can be divided and further divided; each of these parts can again be an entity in the GIS. They seem to form hierarchies (such as the division of a country in smaller units), but often the relations are more complex and form a lattice. The prototypical case of hierarchies of two-dimensional areas form a part of hierarchy; but there are special cases. For example the *Gemeinden* (communes, counties) in Switzerland do not form a partition. There are areas that are jointly governed by two Gemeinden and there are others that are not in any Gemeinde.

Hierachies in linear networks are not built on a part of or inclusion relation, and a consistent ontology is an open problem (Car and Frank, 1994; Timpf et al., 1992). Considering maps of different scales, objects from the small-scale map are shown with more detail, more parts, on the larger scale-map. A detailed analysis of this relation is necessary to build comprehensive, multiscale cartographic databases (Frank and Timpf, 1994; Timpf et al., 1994; Timpf and Frank, 1995).

5.5. Two Different Types of Uses for Ontologies

The above list documents questions thta are typically dealt with in ontology and mereology, but current GIS use ad hoc solutions. The few cases where useful ontologies have been proposed in the literature demonstrate that formal ontologies, if applicable, are quickly assimilated by the GIS designers and built into the software. For example, Allen's time intervals (Allen, 1983) were generalized to two dimensions by Egenhofer (Egenhofer, 1989) to construct a classification scheme for topological relations. This scheme is implemented in GIS software, mostly in order to achieve formal semantics for spatial query languages.

5.5.1. CONSTRUCTION OF SOFTWARE

Ontologies are useful for the construction of software. Indeed, they are indispensable, and all application software contains some ontology of the domain it is applied to. Too often, however, these ontologies are not intentionally designed and are constructed in an ad hoc fashion. Tools exist today to describe ontologies formally and to check their consistency (Guttag et al., 1985; Frank et al., 1986; Frank, 1994).

5.5.2. CONSTRUCTION OF TESTABLE HYPOTHESIS ABOUT

COMMONSENSE THEORIES

Understanding the commonsense theories is very difficult, and several large-scale projects are underway (Lenat et al., 1990). Formal theories help to identify possible alternative theories, to construct alternative hypotheses, and to develop the experiments to decide the question (Stevens and Coupe, 1978; Mark, 1992).

5.6. How to Make Ontologies Usable

For a software engineer building basic GIS software, ontologies would be very helpful if they were ready made for use. What properties are important to make an ontology useful? Here, properties of the ontology and then properties of the presentation, which make the ontology easier to implement, are discussed.

5.6.1. SMALL THEORIES TO COMBINE

The guiding assumption here is that no single ontology can capture all aspects of reality but that we can build particular ontologies for specific aspects of physical, cognitive, administrative or legal reality. For example, in Frank (1994) different models for time from cognitive, natural science, and administrative points of view are presented. These small theories can be formally documented and must be described in a form that makes it possible to combine them with other similar small theories.

5.6.2. TYPED ONTOLOGIES

Combining small theories is likely aided by using a typed logic for their formalization. Typed logic avoids paradoxes and helps understanding. Most programming languages used today for GIS are typed, and thus the translation effort for the software engineer is reduced.

5.6.3. PRESENTATION FORMAT

Software engineers are at best fluent in first-order predicate calculus using standard notation. Any deviation from this *lingua franca* increases the effort necessary to understand. Indeed, other formalism makes a text nearly incomprehensible for the software engineer, and thus the ontology described is not consumable. I understand the reasons for continuing with the notational standards of traditional ontological research (Simons, 1987), but these must be weighted against the limitations of the potential users.

5.6.4. REVIEW OF FORMALLY DESCRIBED ONTOLOGIES IN A COMPARABLE FORMAT

The literature contains a large number of ontologies with some differences; these differences can be important for some applications or then can make certain combinations possible and rule out others. A systematic review, with identification of common parts, would be useful. In particular, a formal description perhaps in the form of a lattice of types, with inheritance relations and dependencies indicated would be most useful for software designers. Catalogs of "reusable parts" (Booch, 1987) were very successful in software engineering and have substantively influenced current practice.

5.6.5. ONTOLOGIES THAT ADMIT A FINITARY REPRESENTATION

Computers can deal only with finitary representations. Ontologies that assume a continuum are difficult to simulate on a finite machine. Users will detect effects of the approximations and in consequence be confused in their understanding of the operation of the GIS software.

The translation from an ontology using an unbounded continuum to one that is based on a bounded and finite set, which can be represented in a computer, is non trivial and not purely an implementation problem but part of the problem of ontology construction.

5.6.6. COMPUTATIONALLY EFFECTIVE

The models must be computational and should lead to good practice. Models built or translated in constructive logic or even easily implementable subsets of logic (such as Horn clauses) are more easily assimilated by the designers of GIS.

5.7. Open Questions for Ontologies for GIS

In this section a number of questions for ontologists are posed from a GIS perspective. They are based on observation of current research in spatial information theory and point to areas where fundamental work at the level of ontologies would make a useful contribution.

5.7.1. ATOM-BASED THEORIES

There are good reasons to assume continuous space and time, but in many cases, reality presents itself as consisting of discrete pieces. The human senses do not allow us to differentiate spatial position when objects are less than 1/10 mm apart or events in time when events occur less than 1/30 sec after each other: a piece of paper cannot be torn in infinitely many pieces, and so on. There are limits to the subdivisions, but in practical experience we hardly ever reach that point: after cutting the paper into twenty pieces, further subdivisions are not attempted. Parcels of land are often subdivided beyond what is reasonable to allow economical exploitation, but they still remain at least several square meters large. Distances between boundary points of less than one meter would show the influence of measurement errors in cadastral surveying even to the layperson!

5.7.2. ONTOLOGIES THAT CAN COPE WITH IMPRECISION AND UNCERTAINTY

The common experience of all observation of reality demonstrates the presence of errors, imprecision, and uncertainty in the results. There are various reasons for these limitations of the observation process (physical, technical, and cognitive) but they are fundamental, and nearly nothing can be measured with absolute accuracy. Constructing ontologies that allow for these limitations of the perception of reality would be most helpful (Burrough and Frank, 1996).

5.7.3. DIFFERENT TYPES OF BOUNDARIES

Boundaries come in different kinds: some are sharp and well defined physically; others are undefined. There are several kinds, each with its own properties (Burrough and Frank, 1996). A family of consistent ontologies of boundaries and related phenomena would be most useful.

Human cognition has a tendency to move boundaries to areas where few difficult cases may appear: the boundary between Austria and Italy generally follows mountain ridges, where economic interest in land is extremely low and nothing hardly ever happens. This becomes apparent when something happens there; for example a mummified body of a Stone Age man is found, and the two countries become involved in a dispute of scientific ownership. Other boundaries are in the middle of lakes or rivers, where there is no land to discuss the ownership of. Similarly, boundaries between cognitive categories are such that few dubious cases arise: there are no questionable animals between dogs and cats, between fish and others (and the efforts of biologists to confuse us with the classification of sharks or whales do not constitute important cognitive counterexamples in this respect).

5.7.4. HIERARCHICAL STRUCTURES

Cognitive structures are often arranged in such a way that wide concepts are subdivided into more narrow ones, if necessary. At first, they seem to follow a hierarchical structure, where the elements of the upper level are subdivided in smaller ones, such that a group of smaller ones makes up exactly one unit at the higher level. But this is not necessarily the case, and in general a directed acyclic graph can be observed, sometimes forming a lattice or a structure that can be easily completed to form a lattice.

This can be observed for spatial areas (such as the political subdivision of a country in regions, provinces, and counties, but also others, for example, the subdivision in water catchment areas). It can be conceptual classification (e.g. the subdivision of plants according to the Linnaean system). It can be a division of a task in a subtask (driving from A to B consists of tasks like entering the car, starting the engine, and so on).

This is a particular case of a part-whole structure, where the parts do not have the same level in the genus-species tree (Smith, 1982). There is sufficient generality to warrant a systematic investigation.

5.8. Using Ontologies: Merging Multiple Theories

Assuming that ontologies are small theories with few axioms and few predicates (for example the RCC theory of Randell and Cohn, 1989 and Randell, Cui, and Cohn, 1992), how do we arrive from these small theories capable of modeling reality, as is required for an application? Assume that there are ontologies for solids, space, living things, persons, and buildings: how can we build from these the ontological base for a legal ontology (Frank, 1996c)?

It seems possible to build the prototypical case from the concrete classes of the physical world. The adaptations reflect metaphorical mappings in the sense of Lakoff and Johnson (Lakoff and Johnson, 1980; Johnson, 1987). From the simple case the more complex cases are then constructed through specialization of the classes in *is_a* hierarchies.

A difficulty stems from different viewpoints: we generally assume that the theories are treating different things, that is, an entity is either a person, a piece of land, or a building, with an "exclusive or", and follows the rules of the corresponding theory. But theories must also be combined if they consist of different viewpoints: a piece of land can be at the same time a parcel, a census track, a wildlife habitat, and so on. A person is owner of the parcel, is employee of the bank granting a mortgage on the parcel, and so on.

Last, but not least, the theories can be different in their approach: a legal (commonsense) theory of land applies at the same time as a physical theory of space or a technical construction based on Euclidean geometry. However, they may differ in the uncertainties or errors considered.

5.9. Research Topics

The previous list of major open questions indicates issues where concerted, multiyear efforts seem appropriate. In this section, a few questions are listed, to which interesting and useful results could be achieved with limited efforts, perhaps a single Ph.D. thesis.

The approaches proposed here are all case based. This stems from the conviction that the past years have developed all the results that can be found by theoretically considering and reconsidering the same general topics. New insight can be gained from detailed investigations in particular cases; the more concrete, the better. Later generalizations, if the same observations are made several times, can then lead to a better general theory.

5.9.1. LEGAL ONTOLOGIES

The law assumes ontologies for various things, from human beings to land parcels. The ontological bases of a specific national law would be a worthwhile project, but it seems also possible to build ontologies for certain legal areas, independent of specific national legislation. Different legislations must resolve the same problems, and thus the ontologies are likely similar, will reveal more about the problem area, and separate this from specific legal solutions. There is currently a need for such analyses for the new countries in Eastern Europe and Asia, which all must rebuild their legal systems and need, for example, legislation for land ownership.

5.9.2. ONTOLOGIES FOR TRADITIONAL GAMES

The traditional games are valuable artifacts that embody in an abstract and reduced form substantial parts of human cognition. Many of the board games (such as chess and go) include a spatial abstraction. To formalize these notions and to understand the differences in the concepts of motion, for example, in these games, would be useful and advance the understanding of the prototypical cases of human cognition.

5.9.3. SPATIAL ONTOLOGY FOR A SPECIAL CASE

The spatial situation of a town can be abstracted to an atomic theory of space, where the spatial atoms are much smaller than the objects to be modeled: buildings do have certain sizes (a building in Vienna holds the international record: it is less than 2 m wide!). Between-building spaces are left, again, with some minimal sizes, otherwise they could not function as roads or pathways. The basic ontology could abstract the gaps between buildings to a graph and consider the relations between buildings and roads (for example, access) (Campari, 1996).

5.9.4. SPATIAL ONTOLOGY FOR LANGUAGE

What are the basic spatial notions apparent in language? What are the categories used in the explanation of language? As a starting point, I would select the spatial image schemes from the list by Johnson (1987) and use the detailed analysis of Herskovits (Chapter 6).

5.9.5. ONTOLOGICAL PROBLEMS OF DATABASES

In current applications of database technology two (at least two) fundamental ontological problems appear as real and vexing problems:

- How do entities assume a role? How do we separate between objects and the roles they assume?
- How long does an object remain the same? When does it become a new one?
- How to determine when the normal closed-world assumption applies to application domains and when it does not?

5.10. Conclusions

This chapter lists a smörgåsbord of problems for which I see links with the standard ontological and mereological questions. I have listed some examples where I sense that current GIS technology is hindered by a lack of clear ontological bases, following the tradition of a study in 1983, which already pointed to the connection between the lack of theory and the difficulties encountered in the practical application (Smith et al., 1983).

What a software engineer building a GIS or any other information system would expect is a set of small theories capturing the behavior of certain parts of reality. The software technology to combine reusable pieces of code is spreading rapidly with names like rapid application development (RAD), OLE, and applets. What is missing is the theoretical (ontological) foundation for these coded objects.

To make such small theories usable, there must exist a method to combine them and to predict their interaction. Combinable theories should be available for the same parts of reality, seen from a physical or engineering point of view, and also considering a cognitive aspect or sociocultural perspective. The engineering point of view is necessary to integrate engineering knowledge in the system; the cognitive position is necessary to make it understandable to the user at the interface. Finally, the third, the sociocultural perspective, serves to achieve integration with the social and cultural systems, such as the law and administrative tradition, which are more based on folk theories or commonsense reasoning.

The current literature fulfills this requirement only partially. To be useful for software engineers, contributions must be in a format corresponding to standard software engineering practice. In particular, formalisms must use modern symbolism and terminology (engineers do not appreciate being confused with the Aristotelian senses of substance or accident). Engineers have very little interest in reviews of historical development of an idea: only the "correct" solution warrants much attention. Consequently, there is hardly any discussion of historic development in engineering. The difference in discussion style between ontology as a philosophy-influenced discipline and mathematics documents this aspect: historical development is at best reduced to footnotes, and the history of mathematics is a subdiscipline with very few disciples. To make a contribution useful for an engineer does not only exclude a lengthy historical treaty but also requires a view toward the consistent part, not the differences between views: the search is for a "useful piece", not discrimination between different people's contribution. To allow effective cooperation and transfer of knowledge from ontologists to software engineers these differences of attitude need to be respected.

Efforts to build a single, unified, and encompassing ontology (the grand, unifying theory) appear to be impractical. Understanding the differences in the ontologies of different applications is more important.

A goal could be a standard catalog of ontologies, with a corresponding taxonomy, with description of assumptions and pointers to possible interaction with incompatible assumptions that other theories may make. In software engineering, such catalogs have been produced for data structures (Booch, 1987). They are useful and have led to standard implementations as software libraries after the necessary changes were included in programming languages and software engineering practice.

Acknowledgments

I wish to thank the organizers of this symposium for the opportunity they provided. They have shown a broad concern, which goes substantially beyond the usual scientific disciplinary point of view, and the resulting discussion has demonstrated, once again, the potential of interdisciplinary discussion to transcend the ordinary course of science. It has also led to new insight not only in particular ontologies, but also in the methods different researchers have used, in the different types of problems posed and the limitations of the results achieved.

It is a pleasure to acknowledge the numerous and profound discussions with Barry Smith. He made extensive comments on an earlier draft of the manuscript, which contributed enormously to the clarity of the exposition of these ideas here. I further appreciate Mag. Roswitha Markwart's efforts to make my presentation clear and easy to read.

Spatial and Temporal Reasoning

edited by

Oliviero Stock
IRST, Italy

KLUWER ACADEMIC PUBLISHERS
DORDRECHT / BOSTON / LONDON

A C.I.P. Catalogue record for this book is available from the Library of Congress

ISBN 0-7923-4644-0

Published by Kluwer Academic Publishers,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Sold and distributed in the U.S.A. and Canada
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

Printed on acid-free paper

Printed in the Netherlands