View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by PhilPapers

The Ontology of Fields

Report of a Specialist Meeting Held under the Auspices of the Varenius Project

Panel on Computational Implementations of Geographic Concepts

Talks and Discussions at the Specialist Meeting

Bar Harbor, Maine

June 11-13 1998

By

Donna Peuquet[1], Barry Smith[2], and Berit Brogaard[2]

[1]Department of Geography, Pennsylvania State University

[2]Department of Philosophy, State University of New York at Buffalo.

Table of Contents

1. Preface

This report describes the results of the Specialist Meeting of the National Center for Geographic Information and Analysis (NCGIA) on the topic of "The Ontology of Fields." The meeting was held in Bar Harbor, Maine, June 11-13, 1998. The main purpose of the meeting was to examine the ontology and conceptualizations of geographic phenomena in terms of spatially continuous fields. The concept of field is widely used in a variety of scientific contexts, most notably in mathematical physics, and many geographically distributed variables (e.g., elevation and temperature) are conceptualized as single-valued functions of location.

Some of the questions discussed during the meeting were: What *is* the ontology of fields? Is human cognition less accommodating to field conceptions than to object-based conceptions? What are the interrelationships between object and field types of representations in human cognition? How can the cognitive interrelationships between these two types of representation be operationalized, and how can field representations be accommodated within contemporary paradigms of computing? How are the representations of the mathematical modeling communities in various domains to be related to cognitive categorizations? What options exist for representing uncertainty and indeterminacy in fields, and are they meaningful from a cognitive perspective?

This Report on the Specialist Meeting serves to document some of the answers to these questions and some of the discussions held during the meeting. It includes also a set of researchable questions, which arose during these discussions.

2. Acknowledgments

This research has been supported by the National Science Foundation under Award No. SBR– s Project to Advance Geographic Information Science.” The Co-Leaders of this initiative are Barry Smith, Research Scientist of the NCGIA and Professor of Philosophy and member of the Center for Cognitive Science at State University of New York at Buffalo and Donna Peuquet, Professor of Geography at Pennsylvania State University with the assistance of Paul van Zuyle of NCGIA, Santa Barbara. They have provided intellectual oversight and management, in consultation with a Steering Committee, which included Barry Smith, Donna Peuquet, Nicholas Asher, Kate Beard, Mike Hutchinson, Helen Couclelis and Barbary Tversky. Kathleen Hornsby, Violet Gray, Anthony Chemero, and Berit Brogaard acted as rapporteurs. LaNell Lucius of NCGIA Santa Barbara and Blane Shaw of NCGIA Maine assisted with meeting arrangements. Pat Shyhalla from the Geography Department at State University of New York at Buffalo assisted with information for this report. Roberto Casati commented on earlier drafts of the report. The help of all these people and organizations is gratefully acknowledged.

3. Introduction

3.1 The Project “The Ontology of Fields”

The Ontology of Fields venture is a project under the research area Geographic Information and Analysis identified by the National Science Foundation in the late 1980s when the National Center for Geographic Information and Analysis (NCGIA) was established. Under the NCGIA’s Varenius project (http://www.ncgia.org/varenius), Ontology of Fields is one of three specialist meetings held under the panel on Computational Implementations of Geographic Concepts (Panel Chair: Max Egenhofer, University of Maine). Geographic information science is the research field that attempts to formalize geographic concepts and their use, particularly within a computing context. Geographic concepts are the primitive units of all cognitive operations relating to geographic space. In the original project description, geographic concepts were divided into three groups: First, there is the group of common-sense geographic concepts which are the concepts that people use in everyday life, such as *valley*, *lake*, *pond*, *uphill*, *leeward*, and so forth. Second, there is the group of abstract spatial concepts which are derived from mathematical formalization. These include concepts pertaining to coordinate systems (e.g., Cartesian coordinates), and to cartographic projections. Third, there is the group of concepts used by the various sciences that are concerned with geographic phenomena, concepts such as nearest neighbor, gravity model, trend surface.

Geographic concepts apply to entities of different kinds. Some concepts apply to entities that are very different from common-sense objects, entities—for example population density—that are themselves in fact more like concepts, in that they may have no material substance. Although population density within a given area is not directly perceivable, one might still argue that it is in fact an entity with a real-world existence just as the individuals contributing to it have real-world existence. But one may also have reasons for claiming that population density is a mere mathematical abstraction, and that only the individuals themselves are real.

The problem with concepts like that of population density is that the entity to which it applies is a field-like entity rather than an object-like entity. Thus, the population density at a point is not univocally determined: it varies in systematic ways according to our demarcation of the area in relation to which it is measured. Many geographic concepts apply to such field-like entities. Now *field* is a well-established concept within the realm of physics, where we find entities like gravitational fields, electro-magnetic fields and so forth. But it is less clear what a field in geographic space might be. What exactly is required in order for something to be a field? Are there different kinds of fields? How do we think about concepts that apply to field-like entities and how can we represent and explain these concepts through the application of appropriate methods of analyses? These questions can be collected under the same heading as questions concerning the ontology of fields; i.e., the nature of fields.

In order to advance research on the ontology of fields the NCGIA organized a three-day Specialist Meeting, a workshop intended to illuminate the nature of fields and to identify researchable questions on the topic.

The background paper for this meeting was the paper *Ontology and Geographic Kinds* presented by Barry Smith and David M. Mark at the International Symposium on Spatial Data Handling (SDH ’98) in Vancouver, Canada 12-15 July, 1998, an abstract of which is included in Appendix II below. Here, an attempt is taken to develop an ontology of geographic kinds, that is, of the categories or entity types in the domain of geographic objects in order to arrive at a better understanding of the structure of the geographic world. While we know intuitively that there is some objective reality that contains what we might call *bona fide* objects, such as islands, rivers, lakes and roads, Smith and Mark argue that human geographic reality includes also objects that exist only in virtue of our individual and social conceptualizations of the relevant areas of space; they are objects; objects delineated though human reasoning and language. These are called fiat-objects. While some fiat objects such as countries and census tracts approximate to the status of concrete things that occupy pieces of land on the surface of the Earth and have discrete boundaries, there are also more abstract fiat objects such as areas defined by specific soil or vegetation type. Fiat objects may in fact in many cases be much more field than object-like. But the question still remains as to what the nature of such field-like entities is, and how we are to think about and conceptualize them.

To develop a better understanding of categories or types of geographic objects, it must always be remembered that all entities can be viewed as field or object-like for specific purposes. To this degree making a listing of entities according to whether they are field- or object-like is a futile exercise. This division of reality into objects and fields is an ongoing process of construction for every science and for every individual as we continuously learn about the complex interworkings of our environment. We also change our perspective or world view to suit the particular context or level of knowledge. Thus, we may view vegetation cover as a continuous field over space, or as consisting of discrete objects such as meadows and stands of forest.

The remainder of this report reviews the talks and a selection of the group discussions on this topic. It is hoped that readers of this report will get an insight into the ontology of fields. It is furthermore hoped that the report will function as a guide for future research within the area. More information can be found on the Web at http://bbq.ncgia.ucsb.edu:80/~vanzuyle/varenius/ontology.html

3.2 Note on the Origin of the Field Concept

Before turning to the discussion of what a geographic field is and how the concept of field is used in geography it might be worthwhile to take a brief look at the origin of the field concept.

The idea goes back to the ancient Greek thinkers, who became interested in the divisibility of matter and space. Anaxagoras introduced the concept of infinite divisibility into natural philosophy. This thesis served as the basis of early Greek thinking on the mathematics of the continuum and is the foundation of the scientific doctrine of continuous space. A differing vein of thought that developed from this was atomism, which reduced everything to infinitely separable (and separate) particles–bodies adrift in space, with space itself (the void) as the container of these objects. Atomism has earlier roots in Pythagoreanism. The Pythagoreans thought of the cosmos as a harmonious unity of such basic opposites as the limit and the unlimited. This represents the origins of the notion that space has two aspects: on the one hand as the Void and infinite, as a box-like receptacle of objects; on the other hand, as the order of spatial relations of these objects.

Aristotle rejected the notion of atoms and the Void. Instead, he developed his famous conception of space as *topos*, that is, space as an order of places. According to Aristotle, place exists together with objects, and all objects are located in some place. Place thereby becomes a necessary condition for the existence of any object. Space is, on this view, continuous and never empty.

The introduction of the concept of field into contemporary science in the middle of the nineteenth century by the British scientist Michael Faraday was something like a revolution in scientific thinking. Until that time it was generally accepted that the most fundamental level of reality was composed of material things or particles each having a particular location at any given time. Such particles were believed to be capable of moving under their own intrinsic energy or under the influence of other particles. What we today often think of as a *gravity field* was before Faraday thought to be a force exerted by an element on another element; that is, action at a distance.

When Faraday introduced the field concept he also asserted that the thesis according to which the most fundamental level of reality is composed only of material things is wrong. Some of the most fundamental constituents of reality, he claimed, have none of the properties possessed by particles: they do not have an exact location at a given time, they do not move and they are not forced to move by the interaction with other entities. These fundamental constituents were called *fields*.

The introduction of the concept of fields, in fact, began with an experimental discovery made by the Danish physicist H. C. Ørsted who observed that a straight wire conducting electrical current in one direction could turn a compass needle that was placed in directions perpendicular to the direction of current flow. Faraday interpreted Ørsted's result in terms of a single electromagnetic field in which the magnetic component is an electric field in motion.

An electromagnetic field is an entity that fills all of space in a continuous fashion without moving from one point to another. Such a field can also be described as an electromagnetic wave, but the latter metaphor is rather misleading to the extent that waves in the literal sense (for example ocean waves) presuppose more fundamental entities, namely water-molecules, they are vibrations of water that propagate from one place to another. When the electromagnetic field was discovered, it was believed that electromagnetism could be understood as vibrations in a plenum, but vibrations that propagate instantaneously, that is, with an infinite velocity.

Faraday also argued that all forces should be described in terms of fields. Newton′s universal gravitational force was thus to be understood not as a force exerted by a body on another body, but rather as a field created by and stretching between two bodies. This view is, of course, incompatible with the older scientific view that all physical phenomena depend, fundamentally, on the configuration of forces which reflect the impact of particles of matter on each other. According to Faraday, at least, electricity and magnetism were to be understood, not as bits of matter, but as continuous fields. Electric charges can influence other electric charges because they are manifested in terms of fields of influence which extent continuously through all of space and time.

For further information on the field concept, see Sachs 1973.

4. Barry Smith: An Introduction to Ontology

4.1 Formal Ontology, Material Ontology

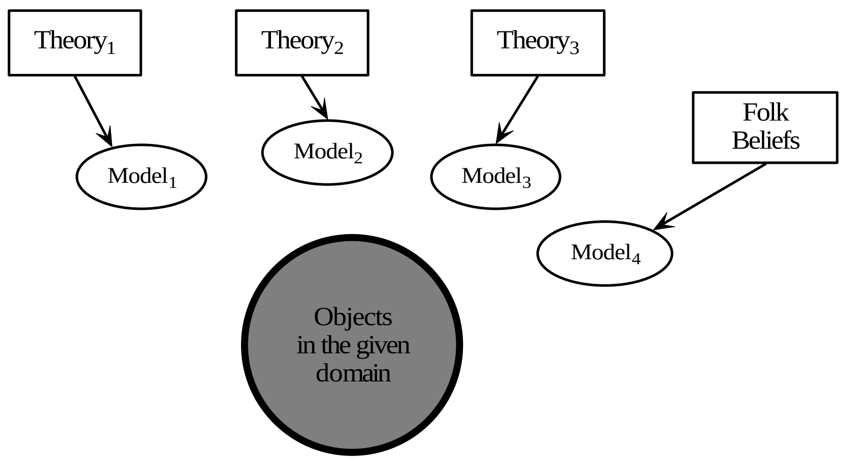
Ever since the Greek philosopher Aristotle, ontology has served as a basis for our theories and construction of models. But what is ontology? Why do we need to think about an ontology within the context of geographic information science? An ontology is either an abstraction of the formal features that characterize all scientific areas, or it is a statement of the necessary and sufficient conditions for something to be a particular kind of entity within a given domain. The ontology of law, for example, is a description of the necessary and sufficient criteria for something to be law or to be a legal object. The first kind of ontology is called *formal ontology*, while the second kind is called *material ontology*. Formal ontology, in contrast to material ontology, does not study the phenomena of a specific institutional, social or natural domain. Rather, formal ontology is like mathematics. All sciences, such as biology, chemistry, physics and so forth, presuppose mathematics. Scientists cannot carry out their experimental research without presupposing mathematics. Formal ontology is like mathematics, that is, the study of the structures that are shared between the different scientific domains. It is the study of identity and difference, of unity and plurality, of properties and relations, of part and whole, of measure and quantity. Much of ontology is very simple (for example that identity is transitive). Hence it has not been studied in systematic ways to the degree that mathematics has been studied.

Ontology as traditionally conceived is not a description of how we conceptualize the world, but rather a description of the world itself. This, of course, assumes that there is only one true reality to be described. If ontology were based on conceptualizations, then we would have as many proper ontologies as there are conceptualizations. But to say that ontology is a description of true reality is not the same as to say that we cannot recognize a distinction between good and bad work in ontology. There is, however, no easy way of judging whether a given ontological proposal is a good or bad one. But there are some criteria for this judgment. For instance, an ontological proposal or hypothesis that is incompatible with physics is ipso facto a bad one. This is, of course, a weak criterion. Ontology does not have to be in complete correspondence with physics, but it should not be incompatible with it.

I have already talked about the analogy between ontology and mathematics. Let me extend this analogy a little further. If we based mathematics on what people in different cultures think, we would end up having a number of different mathematical theories. But they cannot all be true. Some of them are closer to the truth than others. Hopefully, the mathematical and ontological theories developed by different groups of people in different cultures will eventually converge to single true theories. It may take a very long time before we can be satisfied that such convergence has been achieved.

With this extended analogy between mathematics and ontology we have moved over to the question of epistemology. Ontology in itself does not presuppose epistemology; in fact, it is completely independent of our knowledge of the world in the following sense: what we can or cannot know about X at any given stage has no implications for the ontology of X (for the properties of X, the relations in which it stands). That the relation of part to whole is transitive holds true independently of whether any cognitive agent knows this or any other truth, and it is independent also of how knowledge is gained or evaluated. Yet the evaluation of ontological proposals touches upon epistemology. We cannot know what the world is like via any simple method. We can only gradually move closer to the truth. But the comparison of ontological proposals requires a specific form of knowledge, namely knowledge of the world of the sort that is provided by science, and also by common-sense experience.

Consider the following figure:



Within the shaded circle we have the domain of objects with which we are concerned. Above this circle we have various theories and beliefs, together with the corresponding models of the domain of objects in which we are interested. With the development of our knowledge, we can hope that these models will converge on each other, and that they will come more and more to resemble the world itself. That this is not an unreasonable hope is shown by the high degree of successful interaction between and cooperation among existing theories and beliefs.

Theories that are correct descriptions of a given domain of objects allow us to infer the material ontology for that domain. By investigating what is shared by all material ontologies we can infer the principles of formal ontology.

In the specific case of geography, the real world consists on the one hand of physical geographic features (bona fide objects). On the other hand, there are the various fiat objects, for example legal and administrative objects, including parcels of real estate, areas of given soil types, census tracts, and so on, each of which coincides at any given time with a certain portion of the entire physical surface of the planet. Components of a material ontology for this domain will now include, in addition to the types of objects mentioned, also people, their beliefs and their actions (for example, the actions of those who work in land registries or in census bureaux). Once we have understood the basic entities of ontology we can begin to look at how, for example, people relate to both fiat and bona fide objects in the areas that concern them. These relations, too, will then form part of the ontology. The ontologist is interested in the world, including those portions of the world that are created or constructed by the people in it. He is interested also in the beliefs (both true and false) people have about the objects in the world.

4.2 Applied Ontology, Referent-Based Ontology and Elicited Ontologies

Nowadays ontology is being put to use also for a variety of practical purposes, so that one might speak of something like ‘applied ontology’. What purposes can ontology serve within the context of information science in general and within geographic information science in particular? Some answers to these questions are provided by the recent volume edited by Nicola Guarino (1998) of LADSEB-CNR in Padua. This volume contains papers by philosophers on the one hand and by information scientists on the other hand demonstrating the ways in which ontological ideas are increasingly being put to use for example in the construction of software tools for merging large databases, in facilitating database integration within a single enterprise (enterprise integration), in conceptual modelling and information systems design, in the design of software for multi-lingual information retrieval and extraction, in the construction of systems for electronic commerce, and in a variety of other areas, including geographic information science (Frank 1997). In each of these fields it has proved fruitful to develop common ontologies in terms of which divergent bodies of data derived from different sources can be unified together into a single system. Ontological engineering of this sort was pioneered in the ARPA Knowledge Sharing Initiative and in the work of Tom Gruber (1993) and his colleagues on the Knowledge Interchange Project in Stanford.

Unfortunately, however, philosophers and information scientists have different conceptions of what ontology is, and these conceptions may indeed appear incompatible. Above all, ontology on the philosopher’s understanding is the science of being, or the science of what is, of the types of entities making up reality. On this understanding to talk of a plurality of ontologies in the manner which has become common among information scientists is a solecism (analogous to the solecism which would be involved in referring to different biologies, rather than to different branches of biology).

Some clarification can be gained on this front if we make a terminological distinction between referent- or reality-based (hereafter R-) ontologies on the one hand, and elicited or epistemological (hereafter E-) ontologies on the other. An R-ontology is a theory about how a given referent-domain (which might be the whole universe) is structured, what sorts of entities it contains, what sorts of relations obtain between these entities, and so on. An E-ontology, in contrast, is a theory about how a given individual or group or language or science conceptualizes a given domain, a theory of the ontological content of certain representations. The practitioner of R-ontology is concerned with principles that are true of reality. The practitioner of E-ontology elicits principles from subjects (or theories, or systems) by a process which might be called ontology-mining. The elicited principles may or may not be true; their significance lies elsewhere—for instance in yielding a correct account of the taxonomical system used by experts in a given domain, for example by the designers of a geographic information system. There are as many proper E-ontologies as there are conceptualizations.

An R-ontology is not a description of how we conceptualize the world, but rather a description of the world itself. This, of course, assumes that there is only one reality to be described. To develop ontology as a description of reality is not a trivial exercise. Ontology so conceived must be compatible with physics and with other developed sciences. All branches of R-ontology (all R-ontologies of specific sub-domains) should be compatible with each other, and R-ontology in toto should contain the resources to account for the relations between the objects treated of in each of these branches. To the extent that incompatibilities remain between different branches of R-ontology, corrections to one or other of the disciplines involved are still required.

The analogy introduced above between ontology and mathematics can be extended somewhat further in order to throw light on the claim, popular in some circles, to the effect that the very idea of an R-ontology is misconceived because it presupposes some sort of God's eye perspective which would be independent of all specific human points of view (and thus of all specific E-ontologies) and thus simply true. To see what is wrong with this argument imagine how it would look if applied to the case of mathematics. It would amount to the proposal that mathematics be reduced to ethnomathematics. Mathematics would be based on what people in different cultures think of numbers, geometrical figures, and so on. We would end up with a spectrum of different mathematical theories, no one of which could be held to be more or less true than any other (since to accept such an evaluation would be to commit oneself once more to the existence of some God's eye perspective).

With these remarks we have moved once again into the realm of epistemology. We can now say more precisely that the evaluation of competing proposals as to the proper concent of R-ontology touches upon epistemological issues. We cannot know what the world is like by some simple and easy method. At best we can only move gradually closer to the truth via an incremental process of theory-construction, criticism and testing, and amendment.

5. Geoffrey Jacquez: Spatial Statistics. Talking about Talking about Spatial Data

5.1 Motivation

Recently I have had discussions with Susan Maruca (who is running a project at BioMedware to develop software for the analysis of geographic boundaries) on the topic: Are boundaries present in continuous spatial fields? Related questions include: Within a given field, are there boundaries that are more significant than others? and: How can we determine which boundaries are the most significant? A statistical null model that is often used for the assessing the significance of spatial statistics is Complete Spatial Randomness (CSR). However, this model may not be appropriate for boundaries, where spatial pattern (such as spatial autocorrelation) may be expected even in the absence of boundary-generating phenomena. Boundaries in the natural world, for example ecotones, reflect underlying space-time processes such as natural selection, inter- and intra-specific competition and so on. It seems reasonable to suppose that boundary characteristics may be caused by, or at least related to, the space-time processes that gave rise to them. Similarly, the *signature* (e.g., correlogram) of any spatial statistic may provide clues to the space-time processes that generated the spatial field. We can think of *any* spatial statistic as being sensitive to specific features or objects (patterns) on spatial fields. This suggests that a proper ontology would answer the question of what features on a spatial field are meaningful (have the most information content) for increasing our understanding of the underlying space-time processes. Here, I shall focus on the problem of what significant means in the context of features/objects on spatial fields.

5.2 Representing Data

In spatial statistics we use the term *spatial response surface*. This represents the notion of spatial variation through geographic space. An everyday analog of the spatial response surface is topography. What is the vocabulary we use to describe topography? We use words like *peak*, *plateau*, *valley*, *saddle*, etc. Such words describe objects that are part of our ontology, and they are used to describe features in our everyday world that are meaningful. In addition, these features have large information content in terms of the geological processes that gave rise to them. The U-shaped valley was gouged by a glacier, the plateau is an igneous intrusion, and so on. When working with spatial response surfaces, the concept meaningful features essentially degenerates to the kinds of patterns (signatures) our arsenal of spatial statistical tools can detect. So the current ontology implicit in spatial statistics is something of an artifact, emergent from the signatures that can be distinguished via spatial statistics. A proper ontology would, rather, define features on spatial fields that are meaningful to our understanding of underlying space-time processes. We then could design spatial statistics whose signatures are sensitive to those features.

5.3 Vocabulary

Consider the kind of stuff we call snow. In English we have but one single substantive for snow, but we can, of course, qualify it in various ways in order to describe several snow phenomena *granular snow*, *melted refrozen snow*, etc. Similarly, when we represent geographic data we can pick out a phenomenon and describe it by a single term or we can describe it in more detail.

5.4 Methods

In the 1990s we have various words describing features on spatial response surfaces, depending on the spatial statistical technique: Spatial autocorrelation tests lead us to speak of *positive spatial autocorrelation*, *complete spatial randomness*, and *negative spatial autocorrelation*. Words used in boundary analysis include *fuzzy boundaries*, *crisp boundaries*, *open boundaries* and *closed boundaries*. The field of cluster analysis speaks of *general clustering* and *focused clusters*. These words describe the kinds of patterns that can be detected by specific statistical tests. But are they useful for describing those features with high information content?

5.5 Fundamental Problem

The fundamental problem of data representation is that of inferring past processes from observed spatial data. We typically work with spatial data representative of one or a few *snap shots* in time. Typically, the time frame of space-time processes is much longer than our observational time scale. Rarely, if ever, are we able to watch a spatial response surface evolve as its determining forces are at work.

5.6 Analytic Approaches

In general analytical approaches may be divided into (1) models of process, (2) models of data, and (3) exploratory spatial data analysis (ESDA). Models of process are expressed in terms of the biological and physical parameters of the system under study. For example, a compartmental model of a structured population whose coefficients describe migration between subpopulations. In addition to the data, a model of process requires sufficient knowledge to model the system in a meaningful fashion. Models of data are expressed in terms of relationships among the observed data. For example, the slope and intercept in a regression model are useful for prediction but do not necessarily convey any information regarding the system′s basic physical and biological mechanisms. In addition to the available data, constructing a model of data requires selection of a statistical model (e.g., regression and ANOVA)—detailed knowledge of the mechanics of the system is not needed. ESDA seeks to identify patterns in the data that may suggest and eventually lead to a model of data or even to a model of process. It requires the available data and tools (e.g., spatial statistics) for pattern identification.

5.7 Methods for Identifying Patterns

The objective, then, is to identify spatial patterns. There are a number of components of statistical inference for identifying patterns within spatial data:

- Test statistic
- Null spatial model
- Null distribution of the test statistic
- Null hypothesis
- Alternative hypothesis

- Alternative spatial model

The *test statistic* is a number that summarizes an aspect of the data that is of scientific interest. The *null model* describes the space-time distribution of the variable(s) expected when the null hypothesis is true, it defines the null distribution (defined below) of the proposed test statistic. The *null distribution* of the test statistic is obtained either theoretically or empirically through Monte Carlo simulation. Both the theoretical derivation and the randomization procedure must be consistent with the null model. Probability values under the null hypothesis are obtained by comparing the value of the test statistic to the null distribution. The *null hypothesis* is usually stated in terms of parameters of the null model. The observed value of the test statistic is compared to the null distribution arising under the null model. The *alternative hypothesis* is stated in terms of parameters of the null model or in terms of additional parameters used in constructing the alternative model. The *alternative model* may be an omnibus *not the null model* or a more specific model describing spatial pattern.

5.8 Summary

The objective of spatial field analysis is the inference of space-time processes. Spatial statistics is concerned with (a) quantifying spatial patterns and (b) determining whether or not a pattern is unusual. To be useful to scientific inference an ontology must: (a) be descriptive of spatial structures, that is, of the patterns expected under relevant space-time processes, and (b) include quantifiable objects useful for purposes of spatial statistical inference.

6. Brandon Plewe: Data Modeling, GIS Integration, Vagueness

6.1 Fields in Data Modeling

In thinking about how fields relate to spatial databases, I adopted a standard database modeling approach. This, under various different terms, consists of going from reality to some kind of conceptual model (i.e., thinking about whatever it is we are trying to model), from there down to a logical data model (a general strategy for the data organization), and from there down to the actual data structures, where we have specified exactly how we are going to structure and organize the information once we get it.

How does this relate to the ontology of fields? I will start with reality. I am not exactly going to specify what reality is. Reality is something; I am not sure what. As to conceptual models of this reality, we can distinguish four conceptual models of space:

- The *plenum* is something that fills space, such as water or air. It may be a real phenomenon or an ideal space. You can measure various properties at any point. Water will have several variables, while population density only has one.
- The plenum can be divided into regions to form what we call a *categorical coverage*. The boundaries of these regions are determined from the data. You should think of it as a matter of regions that have been defined by some kind of data.
- The third model is the *hard partition*, that is, a partition where the boundaries are officially set. They may or may not originally have been the result of real properties of space. An example of this is the boundaries of countries. Another example is the set of census tracts, where the city has been carved up into areas long before the data was collected. These two categories look very similar. If you look at a map with no descriptions it would be difficult to tell the difference. The difference is in the source and *meaning* of the regions, not in their appearance.
- The fourth model is the object or entity view. Objects are here thought of as existing in their own right. Think of Africa cut up into countries. You are here thinking of each country as a lone unit without thinking of how the boundaries were created and without any supposition to the effect that it is only part of the overall continent.

This is not necessarily the way reality is, but these models are ways we commonly think about reality. We may look at the same thing (say, vegetation cover) and see any of the four models. The entities in the fourth model are more object-like; those in the first category are more field-like.

The more object-like formal representations or data models are based on models of the fourth kind, while the more field-like representations are based on models of the first kind. The vector data model is based on the strategy of extracting the geometric properties of individual entities (and is thus more object-like). The raster idea is one according to which you break up space into rectangular or square bits and pieces that are equally distributed and you sample information pertaining to each piece, or you make an average. In this way continuous fields are made discrete. The two intermediate conceptual models will usually have to be remodeled either as objects or fields.

Vector, object-based GIS is more popular than raster, field-based GIS in the GIS industry. This is because there are some important limitations of raster. Thinking of GIS in terms of fields is not as common as thinking of it in terms of discrete entities. This is not because of differences in their respective powers of analysis. The capabilities of raster in this regard are at least as strong as vector. Although there are many things that we cannot yet do. Still, there is a lot we can do with raster GIS. Data entry has been more difficult in the past, but we now have data entry sources that make it easier, such as satellite imagery and softcopy photogrametry. Does the problem lie with the subject-matter? Many of the types of GIS subject-matter which have driven the industry, for example urban modeling, have a more object-like character. But a business market area is an example of a subject-matter that is more field-like. Perhaps, then, the reason for preferring vector to raster is a matter of comprehension–that we have a more difficult time understanding and communicating about fields.

6.2 GIS Integration

One of the crucial issues in GIS and in the study of spatial databases today is that of *integration*. We can think specifically about the integration of raster and vector. Currently, if you want to integrate objects and fields, then you have to convert the one into the other in order to compare them. But this may not be a good way of doing things; we lose something in the translation.

An important emerging trend is the integration of GIS with database management systems designed to allow you to combine your spatial information with the rest of the information in your enterprise. Traditionally this has been much easier to do with vector than with raster, since most common vector data structures are themselves essentially relational databases. We also want to tie GIS information into other kinds of scientific models.

But can we solve these problems? Can we just take existing data structures and somehow do better processing? Or do we need better data models or better data structures? I do not know. Here are some of the properties the solutions should have.

- One is that it should have a data structure that is capable of integrating both field- and object-type information. We have talked about this for years. Donna Peuquet wrote a paper about it over ten years ago (Peuquet, 1988).

- We would also like to have operations that can integrate data of various types. It would be nice to be able to take field data, say pertaining to the atmosphere, and combine it with object-like data, such as data pertaining to the boundaries of cities. In that case we would not have to convert one into the other.
- The last thing has to do with comprehension. It would be nice if we could have some data model that could preserve the detail that is available in fields, e.g., the temperature in the atmosphere, but yet still enjoy the comprehensibility possessed by data-models based on objects. Perhaps the answer for these last two properties is some kind of multiple representation, where we represent something in two forms at the same time. However, the difficulties of doing this utilizing a traditional raster-vector view of geographic data representation were also documented by Peuquet (1988).

6.3 Vagueness, Indeterminacy, Gradients (Fuzziness)

Rather than speaking of fuzziness or vagueness, I prefer to talk in terms of *gradation*. The idea is that you have something that has gradual rather than crisp boundaries. If I have a region, then there is a *core* area that definitely is in that region. Then I have a *boundary* that is actually an area or zone of gradual change rather than a line. Finally, there is the *exterior,* which is definitely not part of the region.

Such graded regions exist not only in real geographic space but also in the thematic dimension. Think of the concept *hot*. There are certain temperatures that are definitely "hot," others that are not. In between there is a range of temperatures in the area of gradation. There is also a temporal dimension of gradation, where there is a gradual change within a region extended over time.

The theory of fuzzy sets can be used to model this phenomenon and hence it is often referred to as *fuzziness*. The problem is that in common usage (i.e., outside of fuzzy set theory) *fuzzy* is a much broader term and has unfortunate connotations. *Vague* is an ambiguous term, too. *Gradation* is a better term to describe the phenomenon we have in mind.

Let us talk about gradation and *uncertainty*. Gradation is not a question of uncertainty, even though they often look similar when represented or conceptualized. Uncertainty lies in measurement and observation, while gradation is inherent in an entity itself. Uncertainty just means that I do not *know* where a given boundary is, only that it is somewhere (somewhere determinate) within a certain area; gradation means that the boundary itself really is an area.

Uncertainty arises as we measure reality and force it to conform to our data base. But what causes gradation? For my dissertation, I looked at some twenty-five examples of gradation, but I was not able to find it in the real world. Where I did find gradation was within things that we might call *conceptual entities*. I thus argue that gradation arises when we think about reality and conceptualize it. A problem arises as we try to simplify reality in order to comprehend it.

For example, suppose I have a field of population density, which I created from a large number of objects (i.e., people). I want to use that field to determine the boundaries of a metropolitan area (an object). One criterion for a metropolitan area is that of high population density. *High* is a gradual term. I apply it to the area where the density is higher than a given value and call that area *urban*. I can do that, but it is problematic, because over-simplification is involved.

The problems inherent in such transfer between conceptual models are important because this is not an isolated phenomenon: we spend a lot of time moving between different models. Take the example of population density. I start by thinking of people in terms of population density and then I want to go back to a city or an urban area. All kinds of problems then arise. It appears that the conceptual objects we artificially create out of fields often involve gradation, for example, a *hill*, which is created from elevation. Think also of soil; it does not change at a line, but when we talk about it and represent it, we are forced to create crisp, line-like boundaries.

A lot of research could be done on this kind of switching between conceptual models. Are there situations where we can avoid it? In the past we have avoided it by creating crisp boundaries, but then we are just creating a problem. Perhaps the idea of integrated object-field data models will be a solution to the problem of vagueness and gradation. This would make it more possible for us to switch between models without simplifying too much, i.e., in such a way that we can preserve the details.

Another research question is: Can we really handle gradation as such? The problem with fuzzy set theory and related formal models is that it presupposes that we are able to quantify exactly to what degree each given point does or does not belong to the object. For example, you would have to say that a point on a hillside is *35% part of the hill* and that is far-fetched. There are situations where you can do that, but it rarely works so nicely.

7. Helen Couclelis: Perception and Visualization

Helen Couclelis addressed the theme of *Cognition and Re-Presentation*. She began with two issues drawn from the position papers of Anthony Chemero and Violet Gray: the challenge of anti-representationalism, and the question of the ontological status of discrete versus continuous models of space. Taking a mildly anti-representationalist stance herself, she put forward three propositions: (a) there is a duality between fields and objects, (b) this duality holds for both space and time, and (c) there exist principles for helping us to determine the appropriate representation (field- or object-based) in different contexts. The first point has its roots in the traditional debate in the history of science between atomistic ontology, which favors the primacy of objects (*there are things in the world; things have properties*), and the plenum ontology, which favors the primacy of fields (*there are fields and properties in the world; the relatively stable spatiotemporal clusters of properties are the things*). The latter gives rise to the minimum assumption one can make about the *real world* that is compatible with science, namely, that the *real world* is the universe of potentially observable characteristics (Zeigler, 1976). Thus the plenum ontology may be preferred on epistemological grounds as more parsimonious.

Couclelis then argued that the fields/objects distinction holds for time as well as space. *Clock orientation* treats time as a plenum of instants at which observations can be made, whereas *event orientation* views time as made up of individual events identifiable through observation. Thus we may set up a time-space correspondence between, respectively, instants and points, durations and fields, events and objects, and view spatiotemporal phenomena consistently from either the atomic or the plenum perspective. Accepting that neither kind of representation is ontologically superior to the other requires us to spell out criteria for determining the appropriate one in each case. Couclelis suggested that the three main criteria should be the empirical nature of the relevant variables, the mode of observation, and user purpose.

8. Roberto Casati: Fields, Maps and Semantics

The linguist Leonard Talmy makes a distinction between two classes of linguistic features. Open class features change rather easily, whereas closed class features are relatively stable over time. The open class features include the lexicon, above all nouns. The closed class features include syntactic elements such as prepositions. Each open class is characterized by the fact that it can change relatively fast over time, while each closed class acquires or loses items at a relatively slower pace. Thus it is very easy to add new nouns into a language; rather difficult to add new prepositions. (Compare, for instance, the difference between the terms *computer* and *betwixt*.) Talmy′s hypothesis is that this distinction reflects two different cognitive functions encoded in language. Words in the open class reflect lexical, specific, marginal classifications; words in the closed class express syntactic, general, core functions. Expressed another way: Closed class features represent formal or structural features of the world as we cognize it, open class features represent content or matter. This distinction between these two types of functions explains the stability of closed class words.

If we generalize this thesis, we might say that grammar encodes the ontological commitments of cognition. For instance the subject/predicate distinction expresses a commitment to the object/property distinction:

- This apple is red
- *This red is apple

Another example is given by the closed class of suffixes, such as walk-*s*, walk-*ed*, etc., which can express time, tense, agent. One can compare the difference between two types of words within a single sentence:

- John moved across (the room/the ocean)
- *John moved across (the doughnut, the sphere)

Room and *doughnut* encode fine-grained and marginal information about shapes and sizes, *across* encodes core information. Thus if language is to serve as a guide to cognition′s ontological commitments, then we ought to look primarily at the syntax rather than at the lexicon in order to understand the core, structuring commitments in our ontology. Thus we will not make much headway in our present text with a study of the different meanings of a noun like *field*. On the other hand, we can find in language structural, *core* representations of field-like phenomena and of the field-object contrast. These are provided by the well-known distinction between *mass* and *count* nouns. Examples of mass nouns are: Water, smoke, gold. Examples of count nouns are: Dog, man, wastebasket. Count nouns, but not mass nouns, take quantifiers:

- Much water
- ?Much dog
- Some water is in the glass
- *Some dog is in the room
- *There is a water in the glass
- A dog is in the room
- *There are some waters in the glass
- Some dogs are in the room

Count nouns, but not mass nouns, take numeral as prefixes and plurals:

- *Three waters
- Three dogs
- ?Waters
- Dogs

These syntactic distinctions reflect some underlying semantic facts. Mass terms, such as *water*, *smoke*, *gold*, denote sum-individuals that are cumulative and dissective. Count nouns, such as *dog*, *man*, *wastebasket* denote individual objects; they are used for identification and re-identification. This is why you cannot ask “How many waters? but you can ask “How many dogs?”

The underlying difference can be expressed in terms of part/whole relationships. Mass entities are *dissective*: every part of a quantity of water (down to a certain size) is a quantity of water; but not every part of a dog is a dog. If we choose, as a framework, the axiomatic part/whole theory and predicate calculus, we can express the difference by saying that for any property R, R is dissective whenever the following holds:

$$Rx \rightarrow (y)(Pyx \rightarrow Ry)$$

If *x* has the property *R*, then every *y* which is part of *x* also has the property *y*. Fields are dissective entities in this sense. Thus every part of a field is a field.

The analogy between mass-like entities and fields breaks down, on the other hand, at certain points:

- Dissectivity holds nontrivially for uniform fields.
- Dissectivity holds (more trivially) for some *mereologized* or *spatialized* properties of some nonuniform fields (fields having nonzero curvature at all points).
- Dissectivity holds trivially for certain very general properties of fields (e.g., being a part of a field; but this is not a problem for fields only).

9. Berit Brogaard: Fields, Objects and Dependence Relations

In discussions of the ontology of fields the question naturally arises as to what the ontological status of fields and objects is. How are fields and objects ontologically related to each other? If we were to follow in rigorous fashion the exact sciences, especially physics, we would probably claim that fields belong to the absolutely most fundamental level of reality. Common-sense objects such as chairs, tables, human beings, lakes, mountains, landscapes and so forth, would then not exist unless there existed a reality with a micro-structure in the form of a net of fields. In fact, it could be claimed that strictly speaking bits of matter such as atoms and molecules are, at some more fundamental level, much more field-like than object-like. But what about geographic fields? Does the nature of geographic fields resemble the nature of physical fields? And does the nature of geographic objects resemble the nature of objects at smaller scales, including dogs and cats, atoms and molecules? And does the existence of geographic fields actually presuppose the existence of geographic objects, or is it the other way around?

What we are here concerned with is something that could be called *ontological dependence*. The question of ontological dependence may be formulated as follows: given two entities *a* and *b*, (i) can *a* exist if *b* does not exist, and (ii) can *b* exist if *a* does not exist? We say that we have (one-sided) ontological dependence whenever an entity *a* cannot exist unless *b* exists. Such ontological dependence we find everywhere in reality. A particular smile cannot exist unless a particular face exists and so forth. We are here talking, in fact, about what we might call *rigid* ontological dependence, because we are not addressing the dependence relationship between *any* smile and *any* face, but rather a certain quite specific relation which pertains between these two individual entities *a* and *b* here and now. The question of whether smiles in general are ontologically dependent on faces in general is a different one (though one that is also to be answered in the positive). Here, we are concerned with whether any entity of a given kind *F* is ontologically dependent on some entity of another kind *G*. The latter kind of dependence we might call *generic* dependence.

Perhaps we can better illustrate the difference between the two kinds of dependence with the following example. The event of my birth is rigidly dependent on the existence of a human being; but since not all human beings have human parents (if we take evolution into consideration) we cannot say that a similar *generic* dependence relationship holds for all human beings. We can formulate the two forms of ontological dependence in the following way (see Simons 1987, p. 297):

Rigid Dependence:

> *a* is rigidly dependent on *b*: it is necessarily the case that if *a* exists then *b* exists and *b′*s existence is not necessary.

Generic Dependence:

> every individual of the kind *F* is generically dependent on an individual of kind *G*: given any *x* that is *F*, *x* exists only if there is an individual, different from *x*, which is a *G*.

We can now return to the question of whether either fields are ontologically dependent on objects or objects are ontologically dependent on fields. Since we are talking about geographic fields, let us consider a few examples of such. First, let us consider a field such as *population density*. It is clear that a field of this kind is an extrapolation of the densities 1 or 0 which characterize certain small regions of space at each given instant. If a correspondingly small spatial area is occupied by an individual, then the value is 1 and if it is not, then the value is 0. From this it follows that a particular population density is rigidly dependent on a particular group of people within a given region. But the population density is also dependent on the region of space in question. While the individuals contributing to the population density are material objects, the region of space within which they are located is more like a field. It is within this spatial region that values are attributed to spatial points at given times.

Another simple example is that of the salt-concentration of a lake. Here both the lake in the form of a region of space and the distribution of salt have the character of a field. Although the salt-concentration can only be measured at certain spatial points (or perhaps also at certain space-time-points, if time is taken into consideration), the measurement does not consist in an act of counting, as in the case of a population density, but rather in a direct measurement of the values of a field that already exists. Of course, since salt-concentration is an attribute of the lake which itself is rigidly dependent on its particular composition of water, plants, animals and so forth, salt-concentration is not ontologically primary. It is itself dependent on other, lower-level phenomena.

Thus, we have here at least two different kinds of geographic fields, namely (1) fields that are rigidly dependent on objects within a field (e.g., population density), and (2) fields that are themselves rigidly dependent on fields (e.g., the salt concentration of a lake). The latter kind of geographic field also includes fields such as the elevation in a given spatial region, where the elevation can be seen to exist independently of our measurements as an attribute of the surface of the Earth, or more precisely, of a certain portion of the Earth (on a *fiat object*, in Barry Smith′s terms: see Smith 1995). Let us call the former kind of fields *object fields* and the latter *continuity fields*. The relationship of ontological dependence is different in the two cases:

Object fields: A particular object field (e.g., population density) is rigidly dependent on the distribution of discrete objects (the population) within a given spatial region, which again is rigidly dependent on the particular distributed individuals.

Continuity Fields: A particular continuity field (e.g., the measured salt-concentration) is rigidly dependent on the existence of a (broadly) continuous field (the salt spread through the lake).

10. Selected Breakout Group Discussions

10.1 Parts of Fields

Initial Questions:

- What are the types of fields?
- What are the parts of fields?
- What are the boundaries of and in fields.
- If we think of fields as functions, what are the restrictions on variables which fields must satisfy?

Types of fields (fields which are dependent on regions or spatial domains):

- The maximum field (for instance, the entire atmosphere).
- A two-dimensional land-area.
- A three-dimensional portion of the entire atmosphere.

- Physical fields such as a gravitational field or a magnetic field. These are causally integrated fields which do not admit of subdivision or holes.
- Scattered fields

  - involving scattered domains (e.g., the temperature over Europe)

  - involving the phenomenon of settings or niches–fields with holes, e.g., the fields occupied by fish in a lake where the temperature varies in such a way that some portions of the lake are hospitable and some are not.

Casati's suggestion:

(a) If x is a field domain and y is a spatial region, then x+y is a field domain.

(b) If x is a field domain and y is a spatial region which is part of x, then x-y is a field domain.

Drop (a) and you will only have closed fields. Drop (b) and you will only have non-gappy fields.

10. 2 What is a Field?

We can have fields of different dimensions, but they are all spatially anchored. Not every collection of things constitutes a field. We shall divide fields into two kinds:

- those which exist because of variations in some intrinsic measure of value, for example a gravitational field;
- parasitic fields, for example the density of population (population itself is not a field).

An interesting question is whether or not there can be gaps in a field. In order to answer that question, we have to consider the following problems:

- zero-value–this means that the point in the field has a value, namely zero.
- null-value–this means that there is no value at this point (not the same as zero-value)
- non-observed value–this is an epistemic problem
- non-observable value–this also is an epistemic problem
- the value at a given point is not relevant–this means that the point is outside of the spatial domain over which the quantification is made.

There are different interpretations of the so-called null-value: (1) The null-value could correspond to a gap in the field. And (2) the null-value could be a possible place for a value. For example, if a location at the sea has a null-value for a field such as the density of a given population, then its value could be possible rather than actual.

10.3 Do Fields Exist?

In the plenary session, fields were defined not in commonsensical terms but rather in the technical sense of a domain or region on which a function is defined: a field is a *field of values* of this function. Our question here is whether or not we agree with this view.

The concept of *field* comes from perception, as in *visual field*. It also derives from topography (from real fields e.g., cornfields). Other examples of fields include quantum fields, fields as a mathematical construct, etc. What drove the mathematical construct of field is the fact that in all of these cases there is something at every point, some value of a common characteristic.

From Aristotle, is derived the focus on the properties of objects or substances, above all organisms. Aristotle's influence meant that this object-orientation dominated for almost two millennia. Substances are moveable concrete entities that are bounded in space and time. Now, the problem is to identify the properties of fields.

When it comes to fields in the naive or non-technical sense, like fields of corn, people prefer to refer to the aggregate rather than to the individual objects. Fields have properties that objects (e.g., apples, boulders) do not.

The group pointed out that it is hard to conceptualize a gradient over a point set. People are better at saying here is a thing and it has these properties, and this may be related to how we think about objects versus fields. Regular-sized objects are more salient to us, for various reasons: they are manipulable, they might be edible. They might be predators. Fields are not as important to us as from an evolutionary perspective as objects are. This problem, of course, is related to the problem of figure-ground. We see the objects, but not the background or plenum out of which the objects are extracted.

We conclude by offering elements of a definition of the term *field*.

- A field is an aggregate of certain items of interest but of a certain minimal scale: the aggregate should contain many items; it should be substantially larger than the items which it comprehends (so that it is the forest which is more salient, rather than the trees it contains).
- A field cannot be an active agent. Some discussion centered on wind as an example of an active agent which is at the same time a field. Wind is conceptualized as a vector field. Other forces, too, are commonly conceptualized as fields.

What can you do with fields?

- differentiate and integrate them,
- extract discrete objects from them,
- extract a function from them, or
- use them to deal with and manipulate more dimensions than would otherwise be possible.

Fields appear to have some useful mapping to the real world. We cannot prove that fields exist. Indeed, space-time was a field for Einstein; there is no empty space-time in relativity theory.

Using topographic elevation as an example of a field, how do you represent or describe it?

- Cartographic practice uses isolines.
- Naive practice talks about the shape of say, Mt. Desert.
- Using objects to describe the field leads to the result that Mt. Desert is in fact seven mountains.

With certain fields, such as zone or area of influence for instance, the internal parts may not be distinguished. There need be no crisp boundary. You cannot reduce such fields to the individual parts.

10.4 Types of Fields

What can we do with fields? How can we think about them? There is a number of terms that we have not defined: *reality*, *field*, *object*, *feature*, and so forth. If we want to get a coherent idea about how we are using such terms, we need to define them. We need a clarification of the foundation, of where we stand. What we sought to do in this group was to establish an ontology of fields. The concept of boundary goes hand in hand with that of fields. Different kinds of fields have different kinds of boundaries. One sort of field will have just gradual changes or no changes at all. Fields have different textures. One texture is a continuous kind of texture, another is a network kind of texture. The difference between these two kinds of fields is that the first has a source-point from which everything flows, while the network kind of structure is more like a tree without a specific source-point. A third kind of structure has contour-lines. Finally, you have fields that are divided into zones, for instance, if a planetary system is thought of as a field, then it is divided into zones corresponding to the separate planets. There are, of course, instances of these four kinds of fields. We can characterize the four kinds of field as more or less field- or object-like. The first is most field-like, whereas the fourth is most object-like.

We suggest that the four kinds of fields are conceptual models. A country in Africa is like an object, but we can also represent it as a field. The problem, however, is whether or not we call these conceptual models *fields*. A person, for example, is an object, but if the person is part of the population which gives rise to a population density field, then he is represented by a value, rather than by some object-representation.

What is the purpose of conceptualizing reality? Cognitively, we continually move back and forth between different conceptual models. All models fail to completely describe reality. But if that is the case, how do we find the essence of fields? In one sense *field representation* is just a different name for *function*. The domain of the function is a topological space, which means that it is continuous. We have different data models to represent such functions.

The difficult question, however, is how we discretize fields in order to represent them. How do we go from a continuous function to discrete entities? How do we indexicalize or instantiate field representations. How do we anchor field representations to the underlying reality and to the objects which it contains?

A boundary within a field is something that bounds a set. If there is something that lies within a set (of space-time points, for example) and also outside the set, then it crosses the boundary.

The ontology of fields is close to the ontology of the plenum. Representations of fields do in fact not stand for fields as such, but for fields that are already made discrete cognitively. The fundamental reality, in contrast, is a plenum (no delineatory act has occurred); all other fields are based on a cognitive act of delineation. This means that there are at least two kinds of fields. The fields which present the plenum transformed as basis for our cognitive actions, and the underlying real physical entities which can give rise to cognitive, delineated fields. For example, we need a region in order to determine population density, but we also need discrete entities, which are not, however, treated as discrete entities in the field-representation.

One thing that makes it difficult to identify the nature of fields is that they are not part of our common-sense knowledge as such. While we can see a chair or a cat and hear a melody and identify them as such, we also perceive fields, but in a visual sense, for example, a visual field is merely an image, an array of light and color. We can measure fields and there are various technical devices by means of which we can detect them. Yet fields are not constructions of the human mind in that they do not have *meaning*, per se. The boundaries we draw within a field, on the other hand, are products of our cognitive activity. It seems that such interposed boundaries are fundamental for understanding that part of reality that is not already divided into discrete entities.

11. Researchable Questions

11.1 Ontological Perspectives on Fields

- **Examine whether there is a general-purpose ontology for geographic phenomena and determine how fields are incorporated into this ontology.**

  What are the geographically-relevant ontologies? Can we build a general purpose ontology for geographers (and for those working on, for example, geographic cognition)? How should fields, including moving fields, flows, be incorporated into this ontology? Are entirely new types of ontologies for GIS necessary to facilitate this incorporation? What mathematics would be the necessary to support such an ontology? Consideration of alternative kinds of mathematics including: classical, intuitionistic, constructive; alternative statistics; alternatives to Cartesian spaces, non-metric geometries, tolerance geometries.
- **When can fields be reduced ontologically to objects?**

  And when, correlatively, can field-based theories or reasoning systems be reduced to object-based theories or systems?
- **Define the criteria for adopting a fields-based approach *vs.* an object-based approach.**

  Is a dense aggregate of points by definition a field? This could lead to research identifying common properties for those applications or scientific theories which prefer a field ontology over an object ontology. It could also lead to efforts to understand the linkages between sciences (and applications) which use a field ontology and those which use an object ontology.

11.2 Formalization of Fields

- **Develop a data model for fields.**

  Develop a data model and appropriate data structures for fields and field-based meta-data.
- **Define a typology of fields.**

  What would be a complete set of field types? What would be a complete set of field representations? What would be a complete typology of field-object relations? Formalization of the field concepts used in specific domains (e.g., legal, natural resources, planning, or navigation, population density, Bathymetric problem).

- **Formalize field parts *vs.* field boundaries.**

  What are the types of constituents of fields? Differentiate between field extent and field boundary. Fields need some extent, but they need not have a (determinate) boundary. A field without an extent, for example, would be a single point. Are there formal/mathematical differences between fields in the physical domain and fields, for example in the legal or political sphere, which are subject to human demarcations? What are the ontological implications of the Smith-Varzi work on formal interrelations between fiat-based and classical topology? To what degree does set theory impose an object-based partition and mereo(topo)logy a field-based view? What sorts of topologies are possible where both objects and fields are included within a single domain?

- **Develop a theory of interpolation with respect to fields.**

  Can the approach employing *virtual data sets* (Vckovski and Bucher), which implies an interpolation method, be expanded and further systematized? What are the best criteria for selecting one interpolation method rather than another?

- **Assess the effect of incomplete, incoherent and inconsistent information on fields.**

  This includes the problem of fusion of different types of information (compare: route description and polygon description of street map); the problem of fusion of knowledge gathered from different perspectives; and the problem of how to recognize incompleteness.

- **Develop dynamic field-object algebras. Consider how to extend Tomlin's map algebra for dynamic fields.**

  How to apply techniques of pattern recognition and inference of spatio-temporal processes to fields.

- **Define fields for a sphere. Do fields on the sphere have a different ontology?**

  What are the appropriate formulae for the description of fields on spheres, and what is the appropriate interpolation method. The relevant mathematics exists, but needs careful screening to identify what is usable.

11.3 Operations on Fields

- **What operations are possible on fields?**

  Operations at a high level of abstraction include *create*, *update*, *extract*, *compare*, etc. Determine what are the constraints on operations (e.g., interpolation). What are the criteria for the equivalence of operations? How do these operations differ for materialized fields *vs.* fields that are created on the fly?

- **Define meta-operations for fields.**

  A study on meta-operations could include, for instance, research into how we can store and use information on lineage and data quality relating to fields. This could also include operations that support field-to-object transformations including uncertainty propagation.

- **Construct a field operations library.**

  What is an organizational metaphor for cataloging field operations? If we are to develop a library of interoperable algorithms incrementally there has to be a framework to guide and organize the algorithm development.

- **Develop methods for converting between field representations.**

  What operations are necessary to support transitions from, for example, raster to functional representations? What methods can be used to assess quantitatively (and qualitatively) the loss of information from such a conversion? Examine conversions from quantitative fields to qualitative fields.

- **Interoperating models that incorporate fields.**

  How do we describe operations on fields in such a way that we can combine different operations on different fields referencing the same underlying space (cf. the mathematical techniques described in category theory)? What are the conditions for interoperability?

- **Develop operations that support identification of objects in fields.**

  Develop an approach for identifying an object in a field (e.g., through use of thresholding and statistical methods). Other operations could include multi-summed fields.

- **Measurement, measurement models and opportunistic sampling.**

  Can we construct re-usable models for integrating measurements/samples that are collected on an “as available” basis (not randomly, not based on criteria such as point of perceptible change) to produce an overall model that gains or retains reliability as the available/relevant universe of measurements changes. In some cases the resulting model gains reliability and/or precision; in other cases, for example where measurements are time-bound, the model retains value despite *expiration* of some measurements. Note that measurements may come and go, for example, seasonal fluxes or things that rise and fall with heat. There are many situations where we want to use the data we can get, but we do not get all the data we would like to have Environmental issues provide a host of examples (currents or convection in oceans or air, dispersion problems of all sorts), precise models of geographic features, such as the geoid or the ocean floor; epidemiology, crime, all sorts of human behavior.

- **Consider issues of scale for fields.**

  How do changes in scale affect fields. Relevant for field-to-object transitions.

- **What role do fields play with respect to overlay operations in GIS?**

  Could we construct layers with non-metric information (route, fuzzy objects) and combine topological with metric information? What sort of output should this generate (e.g., prescriptive plans for action)?

12.4 Cognitive Aspects of Fields

- **Perspective switching between field-based and object-based representations.**

  Examine the role of geographic reference frames with respect to fields. How are people able to merge perspectives in their heads? There are aspects of spatial and geographic thinking that humans perform better than computer programs. How to identify, formalize, and integrate these methods (this could be a central research question for naïve geography)? What are the heuristics involved? Examine qualitative reasoning involving fields. Study of children's understanding of environment/geographic space and of maps.

- **Cognitive aspects of field perception and object perception.**

  What are the situations (tasks) where one or the other is preferred? Visualization of fields. Cognitive problems pertaining to the predominance of objects over fields e.g., in perception and in the lexicon. Consider linguistic and software (usability) implications.

- **How does the concept of *place* relate to fields?**

  Fields and the naive-geographical notion of place; how do we use place to reason spatially?

How to formalize this notion? How do we understand the fact that one place/field is contained within another?

- **Fields from a cross-cultural perspective.**

  Study the range of ways in which people solve a problem against the background of different sorts of constraints (cognitive, environment and cultural; individual-based vs. group-based strategies).

12. Conclusions

The most central question among the various issues discussed during the Ontology of Fields Meeting in Bar Harbor was the question of what a geographic field is. Many of the discussions boiled down to this one central question. A first answer to that question is that a geographic field, like an electromagnetic field in physics, is an entity which fills a given area in a continuous fashion. However, although physical and geographic fields resemble one another under this general description, they differ considerably with respect to their ontological status. While a physical field cannot be reduced to more fundamental entities, such as particles, most geographic fields seem reducible to objects and functions on such objects. An example of a geographic field is that of population density. Yet the population density in a given area is reducible to the distribution of a number of discrete objects. Thus, it seems that discrete objects are at least in some cases ontologically more fundamental than fields in geography. In fact, geographic fields are often a special kind of *fiat* entities insofar as they are results of acts of human *fiat* (see, again, Smith 1994). For example, a geographic field such as that of population density requires that one delineates a certain spatial area as the pertinent region for the field. Other geographic fields, such as the salt concentration in a lake, are more like physical fields insofar as the extrapolation made from the measurements on the lake gives rise to a field representation that represents a physical entity.

In addition to the questions of what a field is, the question was discussed in many of the sessions as to what a field representation is and what kind of field representation is the best representation of a given field. This question involves several components. For example, what is the plenum within which measurements take place, how is the plenum must efficiently divided into sub-regions, what does a field representation actually represent and how do we cognitively understand such field representations?

13. References

Frank, A. 1997 Spatial Ontology, in Oliviero Stock (ed.), *Spatial and Temporal Reasoning*, Dordrecht/Boston/London: Kluwer, 135–153.

Gruber, T. 1993 A Translation Approach to Portable Ontology Specifications, *Knowledge Acquisition*, 5(2),199-220.

Guarino, N. (ed.) 1998 *Formal Ontology in Information Systems,* Amsterdam, Oxford, Tokyo, Washington, DC: IOS Press (Frontiers in Artificial Intelligence and Applications). http://www.ladseb.pd.cnr.it/infor/ontology/ontology.html

Mark, D. 1997 Cognitive perspectives on spatial and spatio-temporal reasoning. In Craglia, M., and Couclelis, H., *Geographic Information Research Bridging the Atlantic*, London: Taylor and Francis, pp. 308-319.

Peuquet, D. 1988 Representations of Geographic Space: Toward a Conceptual Synthesis, *Annals of the Association of American Geographers* 98 (3): 375.

Plewe, B. 1997 The Representation of Gradation in Geographic Information Systems, Dissertation, State University of New York at Buffalo, June 1997.

Sachs, M. 1973 *The Field Concept in Contemporary Science*, Charles C. Thomas Publisher, Springfield.

Simons, P. 1987 *Parts: A Study in Ontology*, Clarendon Press, Oxford.

Smith, B. 1994 Fiat Objects in N. Guarino, L. Vieu and S. Pribbenow (eds.), *Parts and Wholes: Conceptual Part-Whole Relations and Formal Mereology, 11th European Conference on Artificial Intelligence, Amsterdam*, 8 August 1994, European Coordination Committee for Artificial Intelligence: 15-23.

Smith, B. (1995): On Drawing Lines on a Map, *Spatial Information Theory*, Austria: 474-484.

Smith, B. and D. Mark. 1998. Ontology and geographic kinds. *Proceedings of International Symposium on Spatial Data Handling (SDH'98)*, 12-15 July 1998, at Vancouver BC, pp. 308-318.

Zeigler, B. 1976 *Theory of Modelling and Simulation*. Wiley, New York.

Appendix I

Towards an Ontology of Fields

Karen Kemp and and Andrej Vckovsky

Abstract

While philosophers define ontology as *a branch of metaphysics concerned with the nature and relations of being*, within the knowledge representation and reasoning community, a more tractable definition exists. There, an ontology is *a specification of a conceptualization* or a definition of the vocabulary used to represent knowledge. An ontology describes the concepts and relationships that exist within a specific domain and describes all that can be represented about that domain. An ontology of fields that explicitly characterizes spatially continuous phenomena in order that they can be consistently modeled and completely described within spatial databases is needed.

An ontology of fields must be based on a formal definition of fields. We argue that the classical definition of a field as a function on a domain which is a subset of space-time is accurate, explicit and expressive, and provides access to the full set of mathematical tools for the characterization of fields. Thus, we conclude that there is no need for more ontology.

Presented at GeoComputation'98, Bristol UK, Sept 17-19, 1998. Distributed on the Conference Proceedings CD.

Appendix II

Ontology and Geographic Kinds

Barry Smith and David Mark

Abstract

An ontology of geographic kinds is designed to yield a better understanding of the structure of the geographic world, and to support the development of geographic information systems that are conceptually sound. This paper first demonstrates that geographical objects and kinds are not just larger versions of the everyday objects and kinds previously studied in cognitive science. Geographic objects are not merely located in space, as are the manipulable objects of table-top space. Rather, they are tied intrinsically to space, and this means that their spatial boundaries are in many cases the most salient features for categorization. The ontology presented here will accordingly be based on topology (the theory of boundary, contact and separation) and on mereology (the theory of extended wholes and parts). Geographic reality comprehends mesoscopic entities, many of which are best viewed as shadows cast onto the spatial plane by human reasoning and language. Because of this, geographic categories are much more likely to show cultural differences in category definitions than are the manipulable objects of table-top space.

Keywords: ontology, mereology, geographic kinds, entity types, GIS

Presented at International Symposium on Spatial Data Handling (SDH'98), Vancouver, Canada, 12-15 July, 1998. See: `http://www.geog.buffalo.edu/ncgia/i21/SDH98.html`

Appendix III

Workshop Participants

Name	Address	email
Kate Beard	NCGIA and Department of Spatial Information Science and Engineering, University of Maine	beard@spatial.maine.edu
Lars Bernard	Institute for Geoinformatics, University of Münster	bernard@uni-muenster.de
Ling Bian	Department of Geography, State University of New York	lbian@geog.buffalo.edu
Thomas Bittner	Department of Geoinformation, Technical University Vienna, Austria	bittner@geoinfo.tuwien.ac.at
Berit Brogaard Pedersen	Department of Philosophy, State University of New York	bbp@acsu.buffalo.edu
Daniel Brown	Department of Geography, Michigan State University	brownda@pilot.msu.edu
Roberto Casati	Centre National de la Recherche Scientifique, France	casati@poly.polytechnique.fr
Anthony Chemero	Department of Philosophy, Indiana University	achemero@phil.indiana.edu
Helen Couclelis	Department of Geography, University of California	cook@geog.ucsb.edu
Beth Driver	National Imagery and Mapping Agency	driverb@nima.mil
Max Egenhofer	NCGIA and Department of Spatial Information Science and Engineering, University of Maine	max@spatial.maine.edu
Michael Esfeld	Center for Philosophy of Science, University of Konstanz, Germany	Michael.Esfeld@uni-konstanz.de
Douglas Flewelling	NCGIA, University of Maine	dougf@spatial.maine.edu
Michael Goodchild	NCGIA and Department of Geography, UC Santa Barbara	good@geog.ucsb.edu
Violet Gray	Dept of Geography, UC Santa Barbara	gray@geog.ucsb.edu

Kathleen Hornsby	NCGIA, University of Maine	khornsby@spatial.maine.edu
Geoffrey Jacquez	BioMedware, Inc.	Jacquez@BioMedware.com
Karen Kemp	NCGIA, UC Santa Barbara	kemp@geog.ucsb.edu
David Mark	NCGIA and Department of Geography, State University of New York	dmark@geog.buffalo.edu
Jeremy Mennis	Department of Geography, Pennsylvania State University	jmennis@gis.psu.edu
Donald Myers	Department of Mathematics, University of Arizona	myers@math.arizona.edu
Donna Peuquet	Department of Geography, Pennsylvania State University	peuquet@geog.psu.edu
Brandon Plewe	Department of Geography, Brigham Young University	bplewe@fhss.byu.edu
Barry Smith	Department of Philosophy, State University of New York	phismith@acsu.buffalo.edu
Daniel Sui	Department of Geography, Texas A&M University	D-SUI@tamu.edu
C. Dana Tomlin	Yale University	tomlins@tiac.net
Barbara Tversky	Department of Psychology, Stanford University	bt@psych.stanford.edu
Achille Varzi	Department of Philosophy, Columbia University	achille.varzi@columbia.edu
Nancy Yattaw	GIS Resource Group	yattaw@GISRG.com
Andrej Vckovski	Netcetera AG, Zurich, Switzerland	vckovski@netcetera.ch