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The Prevalence of Objects with Sharp Boundaries in GIS

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1. INTRODUCTION

The debate on vector versus raster based models is nearly as old as the concept of a GIS (Dutton 1979). It was restated as a debate between GIS with an object concept (not to be confused with object-oriented as used in software engineering; (Worboys 1994) uses the term object based GIS, where objects have sharp boundaries delimited by vectors and the GIS which model the continuous variation of attributes over space using a regular tessellation - e.g. a raster (Frank 1990). Efforts to merge the two representations were attempted (Peuquet 1983). It has been a very fruitful debate as it has forced us to consider and reconsider the epistemological bases of our work and has led to an extensive discussion of fundamental questions (Chrisman 1987), (Mark and Frank 1991), (Mark 1993). The debate has promoted the development of ever more powerful software, achieving a nearly complete integration of vector and raster data (Herring 1990).

It has been pointed out repeatedly that only few objects in geographic space have natural boundaries which are sharp and well determined (Couclelis 1992). Most geographic objects seem to be an abstraction of things which have unclear, fuzzy boundaries, if they have boundaries at all. The list includes most natural phenomena, from biotope to mountain range; extensive research efforts center around soil type data (Burrough 1993);(Burrough 1986) and often use the techniques of fuzzy logic (Zadeh 1974). Nevertheless, many practically used GIS model reality in terms of crisply delimited objects. Cadastral systems, GIS used for facilities' management and automated mapping (AM/FM) and communal information systems all are appropriately oriented towards distinct objects with well defined boundaries. The same systems, with the same models are also used to manage soil maps and land use data, where the fiction of sharp boundaries contrasts with our view of reality.

Depending on the application area or profession, one or the other spatial concept is more appropriate and allows one to capture the aspects of interest more succinctly. Users are accustomed to see a process described in a particular spatial framework, a legal discussion is most often cast in the framework of spatial objects with crisp and determined boundaries whereas a discussion of the application of fertilizer might consider soil types as having indeterminate boundaries. (Burrough and Frank 1995) and (Couclelis 1995) classify applications or phenomena according to an evolving taxonomy of object types and of boundary types. This leaves two questions open, namely

- where do these models of well-defined objects come from and
- why are object models with sharp boundaries very often used in applications of GIS despite all obvious problems with delimiting geographic objects?

This paper attempts to address these two questions, starting from the point of view of experiential realism (Lakoff 1987). Experiential realism argues that the natural categories of human cognition are based on the experience we have of the world and that the way we perceive the world is influenced by our cognitive apparatus (Couclelis 1992) for a practical application to geography (Mark 1993). There are two different environments for our experience, namely small scale and large scale (geographic) space. Our daily experience with handling small objects in small scale space, e.g., apples, stones, leads to a concept of objects with well defined boundaries. This contrasts with the direct experience of large scale space, which leads to a different conceptual structure of space, mostly without dividing large scale space into delimited objects. These are both fundamental experiences for human beings which are deeply embodied in our thinking and give rise to the 'object' and 'field' concept.

Experiential realism also assumes that metaphorical mapping (Lakoff and Johnson 1980) can be used to conceive situations in terms of previous experiences in different circumstances. For example, the experience with small prototypical objects with well determined boundaries is metaphorically translated to conceive the large scale

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space situation, typically by creating conceptual objects with more or less clear boundaries in the landscape. The mechanism to map geographic objects from the large scale space to the small scale space or, more specifically, to 'pictorial space' (Montello 1993) is, in a wider sense, an application of this method of metaphorical mapping.

The tendency to structure the world in objects can be observed in many application areas. Scientific methods often need to construct distinct objects, which can be the object of discourse, of measurement and formal description. Technical tools, e.g. Computer Aided Design (CAD), lead to the same pressure to 'objectize' the world. Most important is the use of small scale objects in all situations where things are manipulated and managed, as indicated by verbs like 'fetch', 'buy' (Couclelis 1992). This is extremely visible in the legal and administrative process dealing with large scale space, again forcing the creation of (legal) objects in geographic space. These metaphorical transformations of experiences with small objects applied to large scale space are in contrast to the direct experience with large scale space and the concepts which follow from them.

The paper is structured as follows: Section 2 briefly reviews recent literature and indicates where in-depth reviews can be found. Section 3 discusses the prototypical object concept as experienced in small scale space and links it to Euclidean geometry. Section 4 contrasts the small scale object view with the experience of large scale space, discussed in section 5. The metaphorical use of objects in science to organize large scale space is pointed out in section 6. The legal and administrative 'object' concept is developed in section 7. The concluding section 8 summarizes why the object view is so prevalent despite all problems and argues for systematic research in the experience of large scale space.

2. THE RECENT OBJECT VS. FIELD DEBATE

Initially, the choice between raster and vector representation of geometry was considered a technical issue of implementation. The early discussion often mixed conceptual and implementation considerations (for an early and extreme example see (Corbett 1979), where fundamental mathematical considerations from topology are expressed in the assembler code of a particular computer). An attempt to summarize and bridge the gap is (Peuquet 1983).

With the attempts to clarify the underlying abstract models and provide for their formalization (Frank 1987); (Frank 1990); (Goodchild 1990) a separation from the implementation issues and concentration on the conceptual level took place. One of the implicit goals was to find a universal representation into which all other representations could be translated (Mark, Frank et al. 1989); (Mark and Egenhofer 1994); (Frank and Mark 1991); (Mark and Frank 1991). In this process the terminology moved from '*raster vs. vector*', stressing an implementation point of view, to '*field vs. objects*', which points to the conceptual issue. (Worboys 1994) proposes to call them 'object based' GIS and separate them from GIS using object-oriented technology for the implementation.

Most authors contrast objects with distinct boundaries with continuous fields. Objects have prototypical sharp boundaries, but often the limits are not so well defined or are not precisely determined or measured. Objects have properties and are homogenous within their boundaries (at least with respect to some properties). The field concept assumes a function in such a way that for each point a property value results (Goodchild 1990).

$$f(x,y) = a.$$

A rich discussion about the errors occurring when abstracting from a field concept to a concept with sharp boundaries starts from this point (Goodchild and Gopal 1989).

The distinction between objects and fields is not a complete taxonomy. Further distinctions are necessary; for example Burrough and Frank consider in respect to object conceptualization (Burrough 1993).

- if objects are complex (i.e. further subdivided into objects which are composed to form complex objects (Haerder, Meyer-Wegner et al. 1987) or simple, i.e. existing only on a single level of resolution. This issue has previously been treated under the more general heading of 'multiple representation' (Beard and Buttenfield 1991) or
- if the model includes processes and allows changes in time. Many of the difficulties of determining boundaries relate to the changing nature of reality and how a GIS models temporal aspects (Goodchild and Gopal 1989).

Couclelis points out that there are many different types of objects with undetermined or unclear boundaries and any analysis must precisely note which particular case is discussed (Couclelis 1995) She has also extensively surveyed the psychological tradition in this area [Couclelis - unpublished manuscript], extending the position in (Couclelis and Gale 1986).

The *'object vs. field'* debate is intimately linked with the two prototypical cases of space perception. Summarizing the discussion of spatial cognition related to GIS (Couclelis 1992) (Montello 1993) and earlier (Mark, Frank et al. 1989) one can see agreement to differentiate between at least two major different kinds of spaces from a human perception point of view, namely small scale space and large scale (or geographic) space (Kuipers

1978). *Small scale space* describes a situation where objects are smaller than the human body and can be moved; the configuration can be perceived as a whole at once. *Large scale space* contains objects much larger than the human body and the human being can move among them; the configuration can not readily be perceived at once, but knowledge must be integrated over time. The intent of this contribution is to show that these two different types of experiences are relevant for the distinction of objects and fields.

3. EXPERIENTIAL REALISM AND SPATIAL IMAGE SCHEMATA

Experiential realism (Lakoff 1988) posits that human cognition is based on practical experience. The physiological similarities of all human bodies lead to the similarity of most basic aspects of human life and thus to similar experiences - independent of culture or language. All children have essentially the same experiences in the first years (eating, grasping things, letting things drop etc.) and cultural and individual differentiation follows later. If the conceptualizations are appropriate for a purpose they will be retained for future usage.

Many of these early experiences common to all human beings are spatial, leading to the fundamental concepts of 'in' /'out', 'up'/'down' etc. Following the framework of experiential realism meaning is associated with abstract concepts through repeated experience. The concepts of space (and other similar concepts) are thus dependent on the physiological construction of the human body in a similar way that the value of the primary colors are dependent of the sensibility of our retina (Rosch 1973). The kind of experience differs according to the sensors involved, for example Couclelis differentiates sensory-motor, visual etc(Couclelis and Gale 1986).

The spatial experiences are aggregated to schemas, which abstract the essence of a prototypical situation. Of particular interest here are image schema, which describe a number of fundamental situations, many of them spatial.

> "... Much of the structure, value, and purposeness we take for granted as built into our world consists chiefly of interwoven and superimposed schemata... *My chief point has been to show that these image schemata are pervasive, well-defined, and full of sufficient internal structure to constrain our understanding and reasoning.* [Johnson's italics] To give some idea of the extent of the image-schematic structuring of our understanding (as our mode of being-in-the-world or our way of having-a world), consider the following partial list of schemata, which includes those previously discussed:

Container	Balance	Compulsion
Blockage	Counter force	Restraint Removal
Enablement	Attraction	Mass-Count
Path	Link	Center-Periphery
Cycle	Near-Far	Scale
Part-whole	Merging	Splitting
Full-empty	Matching	Superimposition
Iteration	Contact	Process
Surface	Object	Collection" (Johnson 1987) p. 126.

These image schemata are then metaphorically transformed to structure other situations where they partially match the situation (Martin 1990); (Kuhn and Frank 1991). This mechanism is so powerful that it can be used to explain completely abstract situations, as in a sentence like, 'the candidate is midway to the Ph.D.'. Here is no spatial position intended, but the spatial metaphor is used to convey the abstract non-spatial meaning. Often the spatial experience includes also value assessment, as in 'up' is 'more' or 'better', leading to metaphors as the 'upper class'.

4. OBJECTS IN SMALL SCALE SPACE

Human experience can be divided roughly into experiences in small scale space and experiences in large scale situations. Small scale space is characterized by a layout which can be perceived with a single glance; objects are smaller than human beings and can easily be moved. The list of spatial image schemata can be divided into the ones where the (likely) prototypical situation is one of small scale space and into others, where the prototypical situation is taking place in large scale space. Large scale space experience often involves the movement of the observer in space. Among the spatial image schemata for small scale, we note

container(in/out), object, link, up/down, left/right, before/behind,
surface, support, part/whole, contact.

Experience in small scale space primarily takes place with movable objects which have sharp boundaries; other types of objects, without well defined boundaries, exist, e.g., fluids, grains, balls of cotton. The generic properties of prototypical objects can be analyzed, e.g. the handling of a fruit lying on the floor. What operations can be performed? What are the generally available properties, independent of the particulars of the fruit in the case. This can be described in terms of an universal algebra (Birkhoff and Lipson 1970) as it is now customary for the specification of semantics in software-engineering (Liskov and Guttag 1986). The properties of an object are described as operations which can be performed with it:

The object has an *identity*, each object is an individual and is differentiated from any other. The identity of an object is immutable during the lifetime of an object (Al-Taha and Barrera 1994). One may form classes of objects which are replaceable among them, but this is already a second level of abstraction.

The object has properties, which are not dependent on its current location (*invariance of properties* under movement).

The object has sharp boundaries and a *geometrical form and size*, which are not variable (again invariant under movement).

The object *can be moved* around and remains where it is until it is moved (this is known as the 'frame problem' in artificial intelligence (Hayes 1985).

Objects can be joined: Two similar objects are twice as long (or high) as a single one.

An object cannot be placed at the same location where there is already one.

The object falls down until it rests on something: it obeys the effects of gravity (there are other non-prototypical objects, e.g. birds and smoke, which are not subject to gravity).

Other objects can be put on top of another.

An object can be put into or taken out of a container.

Objects can be split in parts and put together again.

Experience in small scale space leads quite directly to the abstraction in Euclidean geometry. Euclidean geometry is structured after the experience with rigid, movable objects, i.e., objects which allow solid body motion. The classical geometric instruments, ruler and compass, are rigid objects, which are moved in space to produce marks where they are placed. Theoretical investigations demonstrate that the requirement of 'rigid body motion', meaning that material objects can be moved around without change of shape, leads to a class of geometry of which the Euclidean is the simplest case (curvature 0) and respects our daily experience with relatively small objects at rest (Adler, Bazin et al. 1965).

Small scale space is in principle static - nothing moves until a force is applied and our perception is primarily one of a static situation. The image schemata describe situations, not motions. Changes are brought about swiftly, nearly instantaneous, things are moved from one place to the other without consideration for the path nor the time the move requires. The image schemata describing force and movement, e.g., compulsion, blockage, restraint, belong to the experience in small scale space.

Of particular interest in our context is the aspect of a sharp boundary: if an object can be moved, its boundary is determined by lifting it up. What is moved is the object, what remains is not part of it. The boundary which might not have been clearly visible at first is sharp and becomes determined when the object is moved and can be measured with any precision desired.

There are also experiences with other things without all these properties. Some classes of unbounded objects are so fundamental that they have found expressions in language, for example liquids and in general 'mass nouns', where not identified objects are meant but an indefinite or measured amount from a particular material. Words like 'water', 'sand' etc. usually do not have a plural form and languages often have particular constructs to indicate an amount (the Latin partitiv case).

From an experiential point of view, objects are a basic experience of small scale space. Object identity and sharp boundary, invariance of shape and properties under movement etc. are the most salient characteristics of objects. They are significantly different from the properties found in large scale space.

5. Experience in Large Scale Space

> Q: What goes uphill and downhill and always stays in the same place?
> A: A road.
> Children's riddle

The typical experience in large scale space is one of moving around in a landscape which is only partially visible. The most important operation is navigation, to find the way back and to enter the 'cave' after a day of hunting or collecting nuts and berries. Extensive psychological literature exists about how people navigate, mainly relating to an artificial environment. The paper of Kuipers details the most fundamental elements (Kuipers and Levit 1990).

There are *places* which can be recognized, but they are neither objects with definite boundaries, nor abstract points from Euclidean geometry. Places are connected by *paths*, which can be followed to get from one to another. Paths and links are examples of two very similar image schemata, one from the small scale, the other from the large scale space. The abstract formulation for the relations between places and paths is found in graph theory, which deals with a bipartite set of objects (nodes and edges) and the relations between them (adjacency) (Deo 1974)

Graph theory does not capture all experiences of large scale space, as it does not cover the area between nodes and edges: A path goes through a wood or across a field. This is most often expressed in language as 'fictive motion' described as if a person actually would walk along the path: the path winds along the valley (Talmy 1983). Fields, woods and other areas which extend to the right and left of a path are visible, but they do not have boundaries and can gradually change from one to the other (from wood to grazing area). Woods and fields do not typically have set boundaries and are not perceived in their totality as objects. The experience of the local neighborhood, as it is experienced in large scale space, is leading to the theory of topology (Spanier 1966).

Along a path there are intermediate locations which are not sharply determined and not even named. The path also goes up and down gradually, with highest and lowest points which might qualify as places, but all intermediate points are just relatively higher or lower than others. The flow of water - extremely important for human activities - follows the same pattern. One might assume that this is the prototype for the mathematical field $f(x) = h$, which leads to calculus, discussing gradual changes of a surface embedded in space.

This fuzzy organization is sufficient because things do not move and remain stable in time. Natural change in landscapes is usually very slow. Changes in vegetation or even snow cover or light changes, are slow in comparison to movement in small scale space. Thus society can create places through conventions, typically selecting landmarks of importance which do not change rapidly (Lynch 1960) Topographic maps then depict stable objects in the landscape which can be useful for navigation.

Movement of animals in the landscape is still slow enough that gradual movement along a path is perceived. Of great importance, however, is the deduction of temporal sequence from spatial clues; we know of the famous Indians reading from marks on the ground and deducing which animals or humans have passed and when (for the application of the same concept to geology see (Flewelling, Egenhofer et al. 1992).

Experiences of small scale and large scale space are substantially different, but with a strong tendency to carry over the experiences gained from one to structure experiences in the other one. Most obvious is the application of the 'container' metaphor in large scale space applied to landscape elements like mountains, lakes, swamps, good hunting areas, fields for planting and finally territory. Even if they lack the 'clear boundary' property (recall that for metaphorical transformation not all the properties of the source domain must be present in the target domain (Martin 1990) they can be treated as objects. For example one says 'the deer is in the wood', not implying that the wood has well defined boundaries.

6. Scientific use of Objects to Structure large Scale Space

The most successful model for modern science is physics, in particular mechanics. It is - like Euclidean geometry - an abstraction of the movement of ideal objects in small scale space. Classical mechanics being the example of a 'rational' science is firmly based on mathematics, algebra and Euclidean geometry. It deals ideally with mass points (the abstraction of regular balls, i.e. prototypical objects) which move on a frictionless, ideally plane and horizontal surface. The image schemata used are 'force', 'counter force', 'blockage', 'link', 'restraint' etc. It uses infinitesimal calculus to model fields of forces which are not directly visible, covering the image schema of 'attraction'.

Concepts from mechanics are used extensively in science. Mechanics embodies the image schemata of causal thinking, fundamental to science. As a consequence, the things discussed in a scientific discourse must be converted to objects ('reified'); speaking of the 'deer population' or of 'a rainfall' one applies the same operations one would apply to simple objects like an apple. Geography (and other sciences) also use fields to model influences, often in the form of a 'gravity law' where attraction spreads out from a center towards a periphery.

Much human reasoning is not quantitative but qualitative as are most arguments in science (Kuipers 1994) The quantitative revolution, which attempted to move geography and other sciences towards full quantitative modeling as used in physics, has not been successful in completely converting the discipline. Much scientific reasoning remains qualitative, but even in applications of physics, qualitative reasoning is introduced to solve problems which are too complex to be modelled quantitatively.

7. Legal Objectization

Management in the widest sense requires the manipulation of objects and action applied to objects. The human social interaction calls for rules pointing out what is permitted and what not. Most cultures have developed a concept of ownership of a single individual (or of a small group) on small scale space objects: fruits collected, tools prepared are 'privately' 'owned'. The owner is free to determine what to do with the objects, even to destroy them or to give them away. Every culture has developed its own rules what can be owned, how ownership is established and what rights it grants. Ownership is linked to the 'container' image schema: I own what I have in my hand and I can exclude all others from using it.

From this simple ownership relation between a person and an object many other legal relations can be deduced. Ownership of a (mobile) thing is the fundamental concept of Roman Law, which is uniformly used by analogy for ownership of animals, slaves and real estate. Similarly, civil law in continental Europe is based on the concepts around ownership of things (and similar rights). From this prototype the extensions for ownership in real estate are made (called 'Immobilar-Sachenrecht' in German, 'vastgoed' in Dutch, always betraying its origin from ownership of things). Other extensions of the concept of ownership of things lead to rights of immaterial 'things' e.g., intellectual property (patent, copyright) etc. In all cases a 'metaphorical' transformation of the basic concepts of ownership of small scale objects to a new situation is used to structure the legal situation of, say, ownership of a piece of text.

In order for this metaphorical transformation to work, the fields and woods must become objects, so they can be dealt with like tools or cattle - sold as individualized pieces: I sell you this parcel of land, this head of cattle. Alternatively, land can be seen as a mass and is sold by quantity: I sell you 10 acres of land.

It should be noted that the original German law, as found in the "Sachsenspiegel", was having particular provisions for the ownership of land and how land is sold, different to the rules for buying and selling movable goods. But even then the thing had to be individualized and bounded. There have been extensive and detailed descriptions how boundaries are to be created - an obviously difficult thing and the details (religious ceremonies, wars etc.) indicate how 'artificial' (i.e. man made) these boundaries are. Similarly, the Roman mythology reports in detail, how the original boundaries of the town have been created with a plough and admonish respect of the boundary, even if it could have been physically easily crossed.

As ownership rights are the 'fundamental' schema of law, all administrative law relates to objects and relations between objects. For any legal decision, a person or an individualized object must be determined - if the administrative action applies to land, the land must be an 'object' with an identity and a clean boundary. Thus any GIS relating to administrative action affects bounded land-objects; application areas like planning, where phenomena without clear boundaries must be dealt with, incur problems in the administrative process.

8. CONCLUSIONS

The basic experiences of mankind and individual human beings leading to an understanding of the fundamental schema of spatial cognition have been considered. Two major situations for spatial experience have been discussed, namely *the experiences in small scale space and with movable objects smaller than human beings*. From this the fundamental concept of an object emerges, which has the following properties:

an identity, which is independent of minor changes in attributes and properties,
can be moved,
have geometric forms and other properties, which are not affected by movement of the object,
an object cannot be placed where another object is,
an object can be placed on top of another object, etc.

The second environment for *spatial experience is the human moving in large scale (or geographic) space:* visiting recognized *places* and wandering along a *path* through woods and *fields* over an undulating *landscape*.

From these two experiences emerge the fundamental spatial image schemata which are used by all humans to structure their experience with space. They can be separated in small scale and large scale image schemata:

small scale: container (in/out), object, link, surface, support, part/whole, contact
large scale: place, path, near/far, centre/periphery

The two basic conceptual models for GIS are directly linked to these two experiences: the object (vector) model, where individual parcels of land with sharp boundaries are treated, is using the 'small scale' object experience. The field (raster) model, where variable properties are modelled without individualizing objects or determining boundaries, builds on the 'landscape' experience.

Humans have the ability to use metaphorical transformation through the image schemata from one experience to structure experience in another situation. Two trends to transport the object metaphor to the landscape and to bound ('objectize') the unbounded phenomena are found:

- Science often requires individualized objects which can be measured, counted and described (but science also uses the 'field' metaphor extensively).

- Law and administration use the object concept, in particular the concept of a person owning an object, to structure other legal situations. It is thus required that all things become 'objects' with identity and boundary.

This explains why GIS for administrative use as well as many scientific uses of GIS enforce an 'object' view and resolves some of the puzzle, why from the immense variability of objects - with definite boundaries to all sorts of fuzzy limits - the sharp boundary variant covers so many applications.

This should, however, not be construed as a conclusion that all the models we need have been fully developed. Indeed, it indicates the need for more complex models, which allow the true integration of large scale image schemata and related processes in the GIS. This becomes extremely pressing when process models are required, as is currently typical for environmental applications. The experience of small scale space does not provide the necessary conceptual tools.

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