# People Manipulate Objects (but Cultivate Fields): Beyond the Raster-Vector Debate in GIS

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**Abstract.** The ongoing debate in GIS regarding the relative merits of vector versus raster representations of spatial information is usually couched in technical terms. Yet the *technical* question of the most appropriate data structure begs the *philosophical* question of the most appropriate conceptualization of geographic space. The paper confronts this latter question in the context of the opposition between the "object" and "field" views of space. I suggest that GIS can turn a rather dry debate into a source of insights regarding the nature of its subject matter by learning from how people actually experience and deal with the geographic world. Human cognition indeed appears to make use of both the object and field views, but at different geographic scales, and for different purposes. These observations suggest a list of *desiderata* for the next round of thinking about spatial representation in GIS.

## 1 Introduction

Is the geographic world a jig-saw puzzle of polygons, or a club-sandwich of data layers? Probably neither, notwithstanding what the ongoing vector-raster debate in GIS might suggest (Gahegan and Roberts, 1988; Goodchild, 1989; Peuquet, 1984). It is fair to say that most participants in that debate would sooner stay clear of the shoals of ontology: GIS is, after all, a technical field. Still, the technical question of the most appropriate data structure for the representation of geographic phenomena begs the philosophical question of the most appropriate conceptualization of the geographic world. It is this latter issue that the present paper sets out to confront, initially in the context of the vector-vs.-raster controversy, more appropriately rephrased, for our purposes, as the opposition between the "object" and "field" views of geographic space. This, it turns out, is closely analogous to the opposition between the atomic and plenum ontologies in the philosophy of physics, which remains equally open.

I suggest that, unlike physics, GIS has the means to turn a rather sterile debate into a positive source of insights regarding the nature of its subject matter. The key is to be sought in human cognition, in learning from how people actually experience and deal with the geographic world. Seen from that perspective, both the object and field views, as they currently stand, appear very limited, but some directions for further development and synthesis can be discerned. The paper ends with a list of *desiderata*, not quite yet for the next generation GIS, but for the next round of thinking about spatial representation.

## 2 Objects and Vectors

The intellectual pedigrees of vector and raster GIS reveal a lot about both their contrasting underlying ontologies of geographic space, and their status in the field relative to each other. Vector GIS is firmly rooted in the view of geography as spatial science, formulated in the 1950's and 60's, which resulted in the geometrization of the geographic world and its reduction to a body of theories about relations between points, lines, polygons, and areas. In more recent years, the computational geometry developed for CAD/CAM systems designed to model actual geometric objects, provided a critical part of the technical toolkit necessary for the computational representation of geographic space in the spatial science tradition. Points, lines, polygons and areas representing geographic entities thus became geometric "objects", inheriting the sensible qualities of the prototypical objects that surround us: their discrete and independent existence, their relative permanence of identity, attribute, and shape, and their manipulability. Objects in a vector GIS may be counted, moved about, stacked, rotated, colored, labeled, cut, split, sliced, stuck together, viewed from different angles, shaded, inflated, shrunk, stored, and retrieved, and in general, handled like a variety of everyday solid objects that bear no particular relationship to geography.

There are problems with this view of the geographic world, of course. For one, Euclidean points, lines, and polygons do not exist in the natural, full-scale geographic world, any more than trend lines exist in a scatter plot of data. It is only at some phenomenon-specific but generally ill- defined scale that points, lines and polygons become reasonable approximations, if at all. (The only notable exceptions are visually induced structures and configurations such as the horizon, ridge lines, or constellations). This is true not only of straight lines and regular polygons (a la Christaller), but even of features such as stream networks, shore lines, fault lines and capes ("points"), notwithstanding their geometric- sounding names: witness the relatively recent excitement over the fractal representation of coastlines, or the continuing perplexity generated by the resistance to mapping of phenomena such as soil quality or natural vegetation. The lesson to be learned from the success of fractal geometry in modeling the appearance of many natural features, is not just that surfaces are coarse and lines wiggly. Rather, it is the interpenetration and blending of matter, form and phenomenon at practically every geographic scale -- the problem of deciding where the valley ends and the hill begins, the doubt about the actual course of the water channel, the challenge of trying to geo-code the soil of type A versus that of type B, the futility of even thinking to vectorize the hurricane, the avalanche, or the rain cloud -- briefly, the difficulty of carving up the continuous landscape into discrete objects, the resistance of natural geographic phenomena to being treated like plane geometric figures or table-top things.

The points, lines and polygons that do exist in the geographic world are practically all human artifacts, falling into two broad categories: (a) *engineering* works such as roads, bridges, dykes, runways, railway lines, and surveying landmarks, and (b) administrative and property *boundaries*. (It is instructive to remember, in this context, the origin of geometry in the need to safeguard property boundaries in the ever-flooded Nile valley. As for the association of lines in the landscape with man-made projects, remember how earlier in this century, some recently observed linear features on Mars were interpreted as canals and seen as proof of the existence of Martians!).

Throughout the history of Western culture, these two categories of Euclidean features have been essential to the regulation, domination and control of the geographic world: the natural world, in the case of engineering works; the social world, in the case of boundaries. The profound cultural significance of boundaries in particular has been extensively analyzed by scholars in the traditions of political and critical geography. In an early essay on this subject, Soja (1971) discusses the Western bias of rigidly compartmentalized space, and the concomitant hierarchy of nested bounded areas, from the modern nation-state all the way dowm to the individual parcel. Western culture is apparently unique in its treatment of land as *property*, as commodity capable of being bought, subdivided, exchanged, and sold at the market place. It is at this lowest level of *real* estate (from the Latin *res*, meaning thing), that we find the cultural grounding of the notion of space as object. Further up the hierarchy, at the level of counties, states, or nations, precise boundaries are needed again to determine what belongs to whom, who controls whom and what, and for what purpose. As Soja (1971) put it,

> It is almost as if the world were considered a cadastral map, with clear boundaries separating the "property" of the French and Germans, the Americans and Mexicans, just as the conventional cadastral map outlines the property of the Joneses and the Smiths, the factory and the business corporation. (p. 9)

One way or the other, boundaries carve out distinct objects in space, characterized by the prototypical object qualities of discrete identity, relative permanence of structure and attribute, and potential to be manipulated.

The view of the geographic world as composed of Euclidean objects also puts the focus on the kinds of spatial *relations* that may hold among such objects: namely, metric, projective, and topological relations. But, as Sack (1986) notes, this misses out a good part of relevant relations in human geography, namely the relations characterizing territorial behavior. In his words,

> Territoriality, as the basic geographic expression of influence and power, provides an essential link betwen society, space, and time. Territoriality is the backcloth of geographical context - it is the device through which people construct and maintain spatial organizations... Its geographical alternative is non-territorial spatial behavior. Focussing on the latter has led geography and social science to emphasize the effects on human behavior of such metrical properies of space as distance. Unfortunately, this focus has been too constraining to permit development of a complex spatial logic. (p 216)

Indeed, the problem with natural human territories, the reason why they elude spatial analysis, is that they lack some of the basic properties of objects. First, they require constant effort to establish and maintain. Second, they are defined by a nexus of social relations rather than by intrinsic object properties. Third, their internal structure changes not through the movement of anything physical, but through changes in social rules and ideas. Fourth, they do not partition space, although they may share it. Fifth, their intensity at any time varies from place to place. Sixth, they are context- and place-specific: one cannot move a territory like one moves a factory to another more suitable location. The same is not true of boundaries, as the sad case of Poland in our century attests. Possibly the majority of tensions and armed conflicts between neighboring nations in history have been at least in part the result of the discrepancy between established ethnic territories (which need not partition space, and are thus non-exclusive) on the one hand, and arbitrarily drawn political boundaries (which do partition space, and are thus exclusive), on the other. Territorial views, behaviors, and relations also underlie more localized spatio-social phenomena such as the NIMBY (Not In My Back Yard) syndrome, which has been called the problem of the decade in American planning. It is no wonder that neither GIS-based approaches, nor any of the conventional "rational" planning methodologies have been able to make a dent at that problem.

## 3 Fields and Rasters

If vector-based GIS over-determines the geographic world by forcing it into a uniform mold of geometric objects, the raster-based alternative is guilty of feigning maximal ignorance as to the nature of things in that world. All of us have experienced frustration at some time or other looking at a remote-sensed image in which the phenomenon of interest is blithely bisected by the image frame, and resented the mindless mechanical eye for which everything in the world is just another array of pixels. But just as vector-based GIS derives its credibility from the spatial analysis tradition, raster-based GIS is strongly supported by the increasing importance of satellite imagery not only in geography, but in wide areas of applied natural science. Raster GIS shares with these developments in the earth sciences not only a convenient direct compatibility in data structures, but also an implicit view of the geographic world as a vector field of measurable values, discretized into a pixel array. Groupings of pixels in particular configurations, or sharing particular attributes, can be identified with specific "features" on the Earth's surface, but it is understood that a different range of measurements (say, made within a different band of the electromagnetic spectrum, or represented by a different data layer in the GIS), may not reveal these same features, or any features at all. Features may be purely accidental clusters or patterns of values, they may be unstable at the relevant time-scales, they may or may not be bounded in Euclidean space, they may be part of an object, or themselves contain several objects. This fleeting nature of "features" is in stark contrast with the strong individuality of "objects" in vector-based GIS, which are identified and defined as discrete, localized individuals prior to any attributes they may possess.

The object-vs.-field debate in GIS closely parallels a much more fundamental controversy in the philosophy of science, that between the atomic and the plenum ontologies. Both these views exist in parallel in modern physics, and allow two conflicting hypotheses about the world to be formulated:

a. there exist things in time and space which have (known and unknown) attributes;

b. the spatio-temporal clusters of known attributes are the things.

The first, more conventional view, which grants things an existence somehow independent from their properties, entails that object identity must persist throughout any abstraction or simplification or generalization process by which non- essential attributes are eliminated. This is because, according to this view,

> all laws (in particular the laws of change) are reducible to fundamental laws concerning spatio-temporal relations among fundamental individuals [the "things"], and their fundamental properties. (Hooker, 1973, p. 211)

In contrast to this, the "plenum" view implies that each different cluster of properties is simply a different (abstract) object, and it cannot be expected to behave like another, sufficiently different cluster of properties (another object), even if both are abstractions from the same real thing. Thus

> the laws of nature will concern fundamentally the relations among properties and property-complexes, and again, prior to any roles which they might play in actual scientific theories, all such relations are on an equal footing. (Hooker, 1973, p. 211)

This view is especially popular in cosmology and quantum physics, both of which deal with objects outside any direct human experience, objects that many suspect to be no more than theoretical artifacts. Accordingly, it is the relations among different kinds of measurements that give rise to the laws of physics, rather than any relations among fundamental individuals which happen to be carriers of the properties measured. Put in a spatial context, the atomic-plenum debate is also one between the Newtonian view of space as inert container populated with objects, and the more contemporary, dynamic view whereby space is a "plenum" characterized by a ubiquitous field. As Einstein (1960) wrote in *Relativity*, .

> There is no such thing as empty space, i.e. space without field. Space-time does not claim existence on its own, but only as a structural quality of the field. (p. 155)

Outside physics, the atomic-plenum debate has a bearing on all theoretical model-building, because of the opposing answers these two views give to the question of theoretical abstraction. Will the same object, described by two sufficiently different subsets of its attributes, continue behaving roughly "like itself" in any valid model that involves that object (the atomic view), or will it become two different theoretical objects (the plenum view)? Formal model theory has dealt with this issue, and Zeigler (1976) clearly sides with the plenum ontology when he defines the Real World as "the universe of potentially acquirable data".

I explored the theoretical and practical implications of the plenum ontology for geographical modeling in my PhD dissertation (see Couclelis, 1982), where I demonstrated that different definitions of geographic space and human populations, involving different subsets of attributes for each, must necessarily lead to very different and often mutually incompatible model structures.

## 4 Cognitive Geography

Applied geography has a major advantage (or disadvantage) over theoretical physics, in that it describes not a system of abstract equations, but a visible, tangible, empirical world. Human cognition had sorted out the basic properties of that world long before digital spatial databases came about, and (unlike what is the case with the next law in quantum electrodynamics), it probably has little to learn from the next spatial data model that is built. Thus, in applied geography - the geography that GIS is supposed to serve - the question of whether an object or field view is more correct, is neither a philosophical nor a theoretical issue, but largely an empirical one: how is the geographic world understood, categorized, and acted in by humans?

It appears that cognitive geography will not side with either the object nor the field side of the controversy, but supports a little of each, and much beyond. It is interesting to note in this connection that traditional pen- and-paper cartography, which GIS and its cousin, computer cartography, are about to render obsolete, used to accommodate both the object and the field views of geographic space. Lakes may be polygons, and coastlines may be lines, but the contour lines of topography only work in concert, as in a field: they are not independent objects, slices to be sorted, stacked and manipulated, and checked for illegal overlaps. Similarly, the seasonal stream may be shown by a blue line, but that line gets thinner and gradually disintegrates as we follow it up the canyon. And where is the bounding polygon around that marsh, indicated by dainty blue plant symbols strewn across the lowlands? Map symbolism evolved over the centuries through extensive trial and error, guided by the need to minimize the distance between the cognitive and the graphical representations of the geographic world. There may be a baby in the bathwater we are about to throw out.

Spatial cognition is flexible, dynamic, eclectic, and opportunistic: it does not abide by the Boolean *either-or*'s of theory, methodology, or technique. How the geographical world is understood is a function of at least two kinds of separate considerations: one has to do with geographic scale, the other with human intentionality, or *purpose*.

A growing body of work in cognitive psychology, anthropology and linguistics, some of it explored in Initiative 2 of the NCGIA (see, for example, Frank and Mark, 1991), supports the "experiential" hypothesis that human understanding of space develops against a background of largely preconceptual bodily and cultural experience (Lakoff and Johnson, 1980; Lakoff, 1987). Herskovits (1986) has explored in more detail the subconscious spatial idealizations that seem to underlie the use of prepositions and other locative expressions in natural language. Along similar lines, Couclelis (forthcoming) has proposed a theoretical framework for cognitive geography, according to which spatial cognition is established at several levels simultaneously (physical, biological, kinesthetic, perceptual, syntactic, cultural), of which only one, the syntactic level, supports the kinds of symbolic manipulations of abstract spatial objects represented in formal geometries. Consistent with the experiential hypothesis is also Zubin's (1989) cognitive typology of spatially distributed percepts as a function of geographic scale. This agrees well with the framework outlined in Couclelis (forthcoming): indeed, the cognitive means by which the physical world is known vary greatly with scale, and this is likely to result in a range of qualitatively different spatial experiences. Zubin's typology distinguishes a sequence of four categories of space of increasing geographic scale, designated as A, B, C, and D, and briefly outlined in the following:

*A-spaces* are those of everyday objects smaller than the human body, which are contained in a static visual field, and can be manipulated. Thus, knowledge of space A is strongly grounded at the physical and kinesthetic levels of spatial cognition, and it is consistent with the Newtonian notion of container space and with Euclidean properties. This is the scale of prototypical "objects": chairs, books, cups, keys. Since this is also the first space to be explored by the developing infant, it appears to have a psychological primacy that may explain the intuitive appeal of the Kantian notion of Euclidean space as a synthetic *a priori.*

*B-space*, the space of larger every-day objects, is very similar to space A, despite the fact that the visual appearance of these objects must be pieced together from many non-simulataneous views, and their knowledge is not aided by manipulation. But while an elephant cannot be picked up like a cat, and a real house cannot be put back in its box like a doll house, such objects are sufficiently similar to scaled-up versions of space-A objects to inherit the basic cognitive properties of the latter.

*C-spaces* contain the vast landscapes seen from some vantage point - apprehended through a sweeping glance, but otherwise not directly accessible to sensorimotor experience. Here, perspective, depth, atmospheric distortions, and the curvature of the Earth, cancel many properties of Newtonian spaces and objects, including the fundamental ones of a rectangular Cartesian reference frame, and of Euclidean transformations.

*D-spaces*, finally, are those of regions and realms beyond the range of direct experience, spaces pieced together by means of a very diverse range of spatial and other knowledge, information, and belief. Decades of work on mental maps and environmental cognition by geographers and psychologists has provided insights into both the contents and the partial structure of such spaces (for a review, see Garling and Golledge, 1988). It is evident that higher cognitive functions of inference and calculation, as well as world knowledge and cultural conditioning, are involved in their construction. Still, the Columbus of D-space is likely not yet born.

The point of this classification is that the experience of geographic space is not homogeneous, but varies with scale. More significantly for our discussion, it appears that the perception of a Newtonian space of Euclidean objects is confined to spaces A and B, which are below the range of geographical scales proper. The experience of landscapes and territories, by contrast, is most active at the levels of cognition (perceptual, syntactic, cultural) which are not directly grounded in the world of classic Newtonian bodies, and their physical and kinesthetic properties. Spatial experience of a natural landscape seen from above (C-space), for example, is more field-like than object-like. There are things in it - valleys, hills, marshes, forests and fog banks - but these are not "objects" to pick up and move about: they are salient *features*, breaks in a plenum that is otherwise *continuous*, not by the mathematical criterion of infinite subdivisibility, but because of the indefinite number of different ways one could draw boundaries around these features. It is even harder to say what D-type spaces might be "like" as formal approximations, especially given the pervasive influence of geographic imagery (maps, charts, GIS layers, subway plans, satellite pictures, space shuttle photographs...) on modern human consciousness: is the whole Earth now cognized as a vast landscape, much vaster, but not dissimilar to the one seen from the local hilltop - or are there still Terrae In-cogn-itae beyond the visible, imparting to the cognitive map a wholly different topological order?

But human cognition is also *intentional*, not content with a single passive set of representations. Next to geographic scale, *purpose* also determines how the geographic world is conceptualized. I commented earlier, in my discussion of engineering works and boundaries, on how the purpose of surveillance, control and manipulation of both the natural and the social worlds requires things to be objectified that are not, strictly speaking, objects.

I would further suggest that a scientific description of the geographic world is best compatible with the field perspective. As the supporters of the plenum ontology in physics have pointed out, quantitative descriptions can only deal with relations between properties, not between things, and it is properties, not things, that mathematical fields are about. Also, a field-based framework is much better suited to modeling change, and therefore time, because it is much easier both for our minds and for our formal tools to deal with volatile variables than with volatile objects. The Cheshire Cat would have not made literary history if it had just sat there and gradually lost its grin.

If the purpose however is neither scientific description nor control, but simply to carry out the spatial tasks of everyday practical existence, things can be considerably more complex. When we *manipulate* spatial concepts mentally, these too need to be made into *objects.* In their study of language and metaphor, Lakoff and Johnson (1980) have pointed out that we categorize and bound in discourse even what is continuous and unbounded: we pedal our bicycle *around* the hill and meet *at* street corners. But that objectification is intentional, contextual, reflexive, and fleeting. It is as if *ad hoc* objects were pulled out of a continuum of largely uninterpreted features, temporarily invested with whatever required properties, highlighted and used, then let to sink back in a background of tacit world knowledge. That background may itself be as interesting to study as the objects themselves, and the notion of *territory*, briefly discussed above, may be part of what is to be found there. Territories too become objects when they need to be defended or fenced, but it is in their field- like, background form that they appear to have their most pervasive effects on human behavior.

The flexibility of cognitive objectification extends to the treatment of spatial relations themselves. Indeed, unlike what is the case in any known geometry, the meaning of spatial relations appears to change with the nature of the entities being related, and their role in discourse. Examples of these phenomena abound in the work of cognitive linguists such as Lakoff and Johnson (1980), Lakoff (1987), Herskovits (1986), and Talmy (1983), and have by now become common intellectual property among those of us involved in NCGIA Initiative 2. Remember the case of "the boat on the lake" (object A supported by surface B), versus "the house on the lake" (object A just outside the boundary of polygon B), versus "the fish in the lake" (object A inside volume B): what should then be the "objective" representation of the "lake" object, and what does *on* really mean?.

The intentional, contextual, and reflexive quality of cognitive objectification is manifest in areas well outside the study of language. In environmental psychology, for example, a *landmark* is something that stands out relative to its surroundings, that is used for the purpose of place recognition, orientation, or behavioral adjustment in navigation, that is subjectively chosen, that is a function of geographic scale, and that is not a landmark unless someone sees it as such. Similarly, the quintessential question of spatial cognition, the "where am I" question, cannot be usefully answered either in latitude-longitude coordinates, nor in bee-line distances from Paris, San Diego, and the Hard Rock Cafe. (As the anthropologist Paul Bohannan notes, "We are the only people in the world who use seafaring instruments to determine our position on the ground": reported in Soja, 1971; and giving someone's home address in UTM coordinates is a practical joke among some geographers). Indeed, the meaningful answer to the personal locational question is rather something like "in the classroom", "thirty miles offshore", "five minutes from home", or "a few inches from the precipice", depending on the purpose and context of the question. It is as if landmarks, places, and other geographic entities were defined in neither an absolute nor a relative, but in a *relational* space, where object identity itself is at least in part a function of the nexus of contextual relations with other objects.

To go back to our original theme, not too much should be made of the object versus field debate, as both miss much that is fundamental to spatial representation. After all, as every GIS expert knows, vector and raster operations are inter-convertible. Topologically, object and field spaces are duals of each other [manuscript in preparation], and both, in their current formulations, support the classical view of categories that cognitive science has shown to be too restricted. For many of the purposes that GIS serves, one or the other of the two views will usually be fully sufficient. In other respects, however, it looks like we may still have a long way to go.

A basic underlying assumption throughout this last part of the paper has been that the human mind still remains the most accomplished system for the representation, explanation, and prediction of geographic phenomena. This much was ensured by natural selection, since the world of applied geography (as opposed to, say, the rarified worlds of physics, chemistry, or geometry), is the actual world in which humans evolved. The scientific representations of the Earth and social sciences can extend what the cognitive representational system can do into scales of space and time and levels of detail that are beyond the direct reach of the latter. In doing so, they inevitably modify the contents of cognition itself (though not its basic properties). Still, it is useful to think of "cognitive geography" as both the starting point and the guiding thread for the construction of meaningful, applicable formal geographies. Scientific representations of geographic space, and GIS in particular, cannot and should not try to mimic spatial cognition. On the other hand, in its search for better spatial languages and representations, the brash newcomer still has a great deal to learn from the old master. This paper argued that the field-object debate is just one such area where insights from spatial cognition can bring valuable illumination. I believe there will be many, many more.

These thoughts, tentative and speculative though they may be, lead to the formulation of some provisional

## 5 Desiderata for the Next but One Generation of GIS (Users)

1 Choose your system to fit your main purpose. All applications with the word "management" in their title require an object perspective, more consistently implemented in vector-based GIS. The same is true of social-science work based on statistical analysis of census-type data, which presuppose the rigidly partitioned spaces of official surveillance and control. But stick to the field perspective (and raster GIS) if you do research in a mathematical earth science. Don't be misled to think that features and objects are the same.

2 If in doubt, choose raster, as it is better compatible with phenomena at geographic scales (i.e., the scales of Zubin's spaces C and D, where objects fade into features, and Euclidean absolute space gives way to the relative space of fields and properties).

3 Better still, demand a system that supports both raster and vector equally, and that allows the purposive creation of temporary objects out of features.

4 Consider the possibility of spatial data structures that are neither raster- nor vector-oriented. Fields may not always have to be represented as data layers; objects (e.g., objects as defined in object-oriented programming) need not always be Euclidean points, lines, areas, and polygons.

5 Be open to the notion of spatial representations that may not be mappable, and to GIS that do not work primarily through map-like displays.

6 Ask whether we can represent *relational* as well as absolute and relative space, i.e., a space in which spatial units carry information about their relations to other relevant spatial units in the vicinity. One way to

their relations to other relevant spatial units in the vicinity. One way to approach this notion would be as a generalization of the potential field concept. Getis (unpublished) is working on operationalizing this notion of relational (or "proximal") space, which is discussed in connection with modeling in Couclelis (1991).

7 Be humble. The most significant geographic spaces may never make it into a computer. Even so, the quest for their representation may prove the most exciting kind of geography we've ever done.

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