# Reconciling Social Constructivism and Realism in GIS[1]

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**Abstract** An epistemological and discursive divide separates critics of GIS and its researchers. An assumption exists among many users and developers of GIS that the technology models reality and can thus be used to predict and explain spatial processes. This realist position is not sanctioned by social science critics of GIS who have focused efforts on illustrating the social effects of technology as well as social influences on its development. In this paper, I attempt to mediate these positions by arguing that GIS is shaped by social parameters, but that this does not necessarily negate its value in modelling spatial processes. Emphasis exclusively on either realist results or social influences in GIS deny evidence of their reciprocal effect. GIS and other technologies are shaped by social factors, but these are not the sole influences and don't necessarily compromise the predictive value of GIS. A more constructive exercise is to "map" points of social influence in order to demonstrate points where future negotiation can take place. Three examples of social influence are analyzed: (i) model building; (ii) algorithmic solutions for line intersection; and (iii) generalization research. These examples provide a preliminary blueprint for detecting social effects on the technology, a map that can be used by both developers and critics for reconstructing GIS. Moreover, the blueprint provides an epistemological basis for collaboration between geographers concerned with social influences in GIS as well as those engaged in its technical development.

## Introduction

Geographers concerned with geographic information science or systems (GIS) have traditionally been divided between those who regard its practices as positivist — and therefore ill-conceived — and those who believe it to model reality — if only to a modest extent (Raper 1999; Taylor 1990; Taylor and Johnston 1995). The past decade has witnessed a movement to the center of this spectrum by both groups. Critics of GIS are now routinely engaged in its development (Goodchild et al. 1999; Sheppard et al. 1999). Likewise, a number of GIS scholars have integrated philosophical concerns and developed complex philosophical positions consistent with spatial modeling and analysis (Couclelis 1998; Kwan 2002a, 2002b; Raper 2000; Smith & Mark 1998). A significant number of GIS researchers and users, meanwhile, treat GIS analysis as a realist endeavour. GIS-generated analysis is equated with processes on the earth's surface much as physicians and lay persons alike equate medical imaging with the body. This conflation fails to account for multiple social (and technical) influences on processes of data, analysis, and display that confound realist interpretations of GIS results (Kwan 2000a; Schuurman 2000).

This paper begins by juxtaposing the realist philosophical stance common among GIS users and some developers to the social constructivist assumptions often held by Science and Technology Studies (STS) researchers. The second section of the paper provides a bridge between critics' contention that GIS is "socially constructed," and widely held realist assumptions of many GIS users and researchers. Explicit examples of GIS practices and theoretical principles are analyzed in order to demonstrate that GIS is affected by both social and digital/technical parameters. Three examples of social influences with respect to GIS are analyzed: (i) model building; (ii) algorithmic development as social metaphor; and (iii) generalization research. Each points to evidence of definite, incontrovertible social constraints to GIS development.

The third and final section of the paper explores the prejudice that evidence of social influences in technology negates its value. I argue that all technologies are affected by the cultures in which they are developed and implemented and that this is self-evident, but does not affect their utility. Moreover, despite profound social influence on technical elements of GIS, it frequently represents spatial phenomena adequately and permits prediction of future events. Of greater import is that social parameters of the technology are constructively identified in the hope that future research acknowledges the joint constraints of the technical and social realms.

## The Social Constructivist Impulse versus Realism in GIS

Discussing social influences on GIS is complicated by a profound disjuncture between the metaphysical frames of reference used by STS scholars and researchers in the field (Kwan 2000b; Schuurman 2000). At a fundamental level, most GIS researchers assume that GIS represents the "real" world adequately, if imperfectly. Spatial representation, as practiced by GIS researchers, has become a way of linking scientific theories to the real world (Raper 1999). GIS researchers, like many scientists, have been able to eschew explicit attention to metaphysical issues by allowing technical constraints to dictate research directions. Nevertheless, there is an implicit belief that spatial representations generated through GIS clearly reflect a linkage with physical space and geographical processes. This connection can be broadly described as "realist."

Realism means different things in different contexts. In art and literature, for example, realism refers to forms of representation (such as paintings) that are meant to correspond directly to the world. In philosophy, realism implies a belief in causal structure and mechanisms that can be discerned through careful empirical research. This implies, however, that things including geographical phenomena exist independently of their perception, that there is an *a priori* reality. In this epistemological scenario, the social world consists of structures — like the relationships that govern capital and labour. Events, like crises of overproduction, are generated from structures. Particular objects can be discerned in reality, but those objects are generated from deeper structures. Realist research seeks to "tease out causal chains which situate particular events within these 'deeper' mechanisms and structures" (Gregory 1994, 500). When realism is applied to science, abstraction is used to identify and describe causal powers and structures that give rise to phenomena under certain, specific conditions (Gregory 2000). In science, generally, realism has "become shorthand for a very long conjunction of theories" that the scientist is quite certain that the evidence points to (Sismondo 1996).

Realism must be differentiated from positivism partly because of its emphasis on specificity. It distinguishes between causes (what made it happen?) and empirical statements that can be applied to other data (Gregory 2000). Whereas positivism doesn't account for the space-time location of entities, realism connects events to specific situations. In this sense, realism is a more contingent epistemology. This is an important differentiation with respect to GIS for two reasons. First, GIS has been accused of positivism by critics from human geography (e.g. Taylor 1990; Lake 1993; Pickles 1993). This has led to considerable hostility between some GIS researchers and critics. Second, there is increasing attention to the space-time contingency of geographical entities in GIS (Raper, 2001). Recent papers have advocated the introduction of a fourth dimension to the spatial entities in order to achieve a more nuanced, contingent description (e.g. Kwan 2000b; Hornsby 2001; Couclelis 1999; Raper & Livingstone 1995).

GIS is frequently concerned with prediction rather than explanation that requires identification of structural and causal mechanisms, hallmarks of realism. Nevertheless, GIS scholars are far from agreeing epistemologically. Indeed, they approach the modelling of space from every conceivable angle which may speak to the nature of space as much as their investigative skills. It is safe to say, however, that the tradition of philosophical inquiry is weaker in the GIS community than in social geography. Despite recent concerted efforts to investigate ontological implications of data models (e.g. Smith & Mark 1998; Kemp & Vckovski 1998; Peuquet, Smith & Brogaard 1999; Schatzki 1991; National Center for Geographic Information Analysis (NCGIA) 1998), there has been less attention to epistemological influences on the structuring of spatial information (Schuurman 1999). This is quite understandable as few people have the energy or inclination to sort out epistemologies of everyday life (Gregory 1994), especially when solving more pressing technical problems.

It would be facile nevertheless to categorize all GIS researchers as realists, or to suggest that they are simply tactical, run-of-the-mill realists. A few fit Bhaskar's brand of realism which admits the possibility of explanations of the real world in social science, but eschews claims to prediction due to complicating entanglements with methods and measurements (Bhaskar 1979). In this view, science in dealing with natural, closed systems may be better able to yield predictions. Anti-representationalists, of which there are precious few, also escape the realist label (Couclelis 1999). Increasingly, however, there is a cohort of GIS researchers that seeks to explicate its epistemological lineage and define a brand of realism that accounts for human cognition as well as structures and mechanisms that govern spatial reality. This group self-identifies as "experiential realists."

Based on an epistemological model introduced by Lakoff (1987), experiential realism rejects assumptions of objectivism that have often been associated with science, arguing instead that cognition structures perception, and therefore representation, of reality. Lakoff's influence suggested an inherent spatiality to human thinking and language. In this view, thinking is tied to the body and is neither reductionist nor logical in the mathematical sense. As a result, thinking is neither literal nor representational but has an "ecological structure" (Lakoff 1987). Cognitive science is already well ensconced in GIS research, and this view became very popular. Many articles on cognition and ontology published in the 1990s contained at least passing tribute to Lakoff's views (e.g. Burrough & Frank 1995; Couclelis 1992; Couclelis & Gottsegen 1997; Frank & Mark 1991; Frank 1996; Gray 1997; Mark 1993, 1997, 1999). Moreover, experiential realism has had discernable effects on GIS research during the 1990s as image schemas were literally written into the *corpus*.

Lakoff (1987) proposed that our bodies structure experience through cognitive devices called *image schemas.* Image schemas were interpreted by GIS researchers as structures that pattern our everyday life and experiences and act as metaphorical vehicles or "cognitive surfaces" (Volta & Egenhofer 1993; Freska 1991) for perceptions of reality. They include concepts such as containers, path, links, forces, up-down, front-back, whole-part, center-periphery, blockage, merging, and iteration (Frank 1996; Kuhn & Frank 1991; Frank & Raubal 1998) (see figure 1).

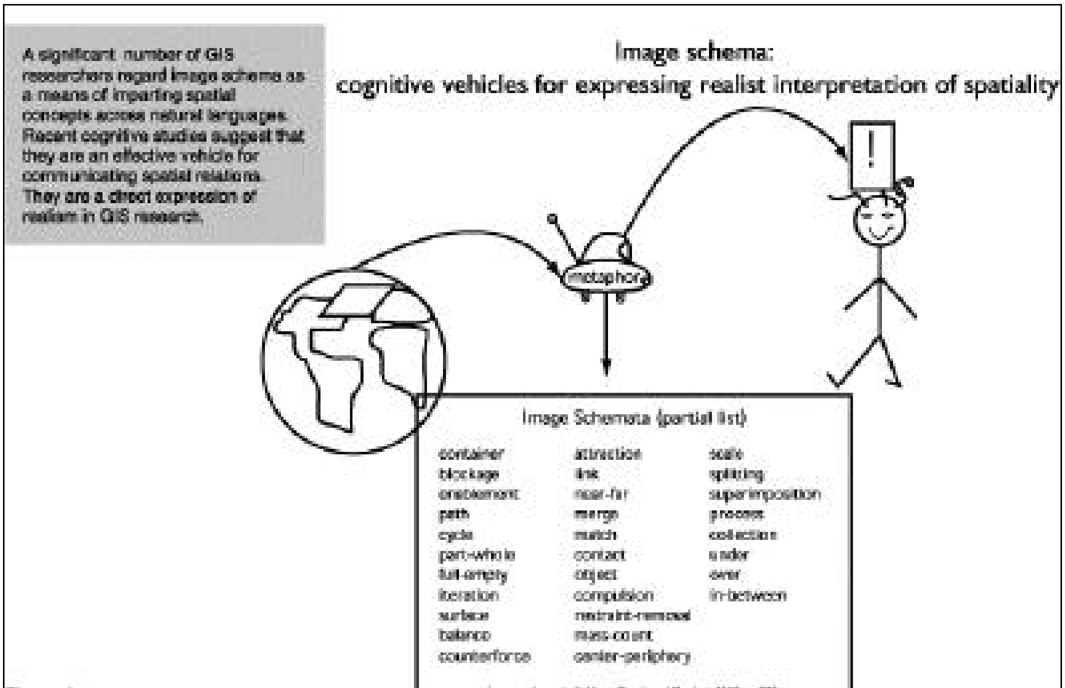

Figure 1

Image schema fall somewhere between mental pictures and more abstract logical relations that allow people to make connections between experiences with the same structures. They are believed to be "recurring imaginary patterns" found in every culture and language (Frank & Raubal 1998). Understood to be inherently spatial, image schema were proposed as a way to model concepts and mental activities in relation to space (Kuhn & Frank 1991; Frank & Mark 1991). They also provide evidence of the influence of realist epistemologies in GIS. This increased epistemological focus in GIS research gave rise, moreover, to a more nuanced realism. Smith and Mark (1998), for instance, are sophisticated in their realist claims, with their attention to both space and practice. Likewise, Raper (2000) subscribes to a "weak realism" that takes into account the difficulty of perceiving entities, as well as the role of cognition.

Critiques of GIS, from human geographers, meanwhile, have evinced impatience with realist notions and with what they believe to be the epistemological naiveté of GIS researchers (Sheppard 1993; Pickles 1993, 1997). A range of critics has been keen to illustrate that GIS is the servant of social processes, and certainly not a beacon of scientific truth (e.g. Lake 1993; Pickles 1997, 1999; Taylor 1990, 1991). These criticisms were initiated within a climate of scepticism toward science that developed during the 1970s and 1980s. They are tied to a complicated and contentious dispute between social and physical science, known as the "science wars." Even a rudimentary outline of the dissension would mention that social scientists are increasingly critical of science 'proper' (Gross 1996; Haraway 1991; Harding 1991; Latour 1993; Pickering 1995; Rouse 1996). Writers in STS have made the case that science *is* culture; that it is impossible to separate scientific truth from the social parameters of its inception (Lynch & Woolgar 1990; Ross 1996). The science wars were part of a broader negotiation over the value and meaning of science and technology, and their relationship to the culture in which they are embedded.

STS researchers have been traditionally categorized as following either the "weak program" or the "strong program." Proponents of the weak program concede that the pace and direction of technology and science are clearly influenced by cultural factors. They maintain that science, nevertheless, produces results over time which have predictive value. A great majority of sociologists of science adhere, however, to the strong or relativistic program which maintains that scientific knowledge is not based on discernable reality but social goals that are negotiated between the scientific community and institutional structures (Sullivan 1998). The strong program renders what scientists consider to be knowledge or reality as social construction. GIS is clearly a social technology in the sense that it both reflects and can direct institutional policy. Evidence of this influence is found in urban planning, forest management, and modern warfare (Smith 1992). By the same token, few would argue that GIS fits the requirements of the weak program of STS. But neither of these categories provides sufficient nuance to describe GIS.

A broader framework for STS, heterogeneous constructivism, was recently described by David Demeritt (2001). Heterogeneous constructivism refers to the ways in which facts of nature are influenced by a broad range of social practices. It follows from insights by Heidegger that science and nature are configured in ways that are recognizable to us (Demeritt 2001). According to Demeritt, this acknowledgement remains realist at an ontological level while recognizing that epistemological constraints are invariably anti-realist. I would argue that epistemology does not automatically imply anti-realism; rather, we have no way to ascertain the degree to which knowledge-gleaning tactics are faithful to phenomena *as they truly are*. Deutsch (1997) explains this constraint by arguing that it is a mistake to confuse impressions of the world created by our five senses with an understanding of reality. This is congruent with Lakoff (1987) who suggests that mathematics appears to closely resemble reality because it is generated by the same cognitive senses that are used to apprehend the world. Our perception and description of laws of nature are related to the self-similarity of physical reality and cognition. That is, cognitive structures used to apprehend reality also inform models of the world. In this view, epistemological influence on ontologies is acknowledged while the possibility of degrees of realism represented by GIS is admitted.

In rhetorical fashion, a postmodernist might offer the counter argument that science only *appears* to be an incrementally more accurate picture of reality due to a process of social negotiation in which science and society agree upon what is and isn't true so that, ultimately, science *emerges* as a rational way of describing reality, thus canonizing a Newtonian view of the world. The scientist (or GIS user) might argue back that "the practice of everyday life shows that everyone intuitively feels there is an external reality because … we don't walk off cliffs" (Keylock 1999, personal communication). The argument itself is dead-end. Kitcher (1998, 39) summarizes:

> If the constructivist reminds us that we haven't shown on the basis of a set of principles that precede the deliverance of empirical science that our scientific opinions are reliable, the right response is to respond that we haven't. There is no such set of principles that will do that job, but by the same token, no set of principles will establish a constructivist picture.

Kitcher articulates the basis for misunderstandings between scientists and their critics across a range of disciplines, many of which have been played out in the discipline of geography.

GIS critics were and remain justified in drawing attention to the social implications of GIS while GIS researchers are correct in defending the power of spatial models to describe and predict geographical phenomena. Many models have been developed as the result of rigorous empirical investigation, and the predictive value of GIS models have been shown to improve progressively (Tobler 1999). GIS is, in this view, both a social and realist technology. It obeys a modified version of heterogeneous constructivism in which ontological realism can be variably reflected through epistemological semi-realism. GIS models and digital architecture remain socially contingent but are linked through evolving principles of science to a form of reality.

A history of very different methodologies between human geographers and the GIS community has limited the possibility for investigating social influences on GIS. Critics, while often well-versed in philosophical issues, were seldom equipped to analyze specific instances of GIS' construction. Furthermore, there is an — albeit receding — history of mutual antagonism between objectives of the two groups (Schuurman 2000). The result has been that empirical research into social parameters of GIS has been overlooked. That gap is filled by this examination of ways in which GIS practices are established at the model, conceptual, and algorithmic levels. This paper differs from conventional epistemological assessments of GIS by closely scrutinizing the technology itself in order to demonstrate that the science incorporates — and often achieves — realist goals while remaining social in its construction for it articulates the relationship between social and digital parameters of GIS' construction and argues that both are implicated in the development of the technology.

I next move to the most abstract level of my argument by evaluating the assumptions that under-lie spatial modelling. Models are increasingly the basis for decision-making as GIS moves from a descriptive to prescriptive science. Investigating modelling is the basis for understanding the repercussions of implementing GIS results.

## Model-building as a Social Process.

Modelling in GIS is frequently differentiated from other forms of description such as language or graphics (Casetti 1999). Modelling can be broadly described as the practice of linking geographical ideas to the mathematical form. This practice is frequently preceded by diagrams. These are equivalent to flowcharts which are used in computer science as a pre-formalization exercise. A flowchart creates entities (geographical objects) like hexagons in the process of developing deductive descriptions of geographical relationships. Casetti (1999) provides the example of Central Place Theory which was first described through a series of diagrams and later mathematicized. The process of mathematicization — from graphs to formalization — is motivated "by a quest for precise rigorous thinking" *and* authoritative results (Casetti 1999, 335). The notion of producing graphs (or graphicacy), however, is a way of literally "drawing together" elements of an argument. Like the equations that follow, the charts are a means of conceptualizing and producing the entities (Barnes 1998).

Models, however, are not realist reflections of entities, but ways of simplifying reality so that we can better understand environments. The problem with models is that they are often confused with reality. In fact, they are indexical systems that are reliant on "theory-laden signs" (Baker 2000, 6–8). Schrader-Frechette (2000) illustrates the potential for models to be differently interpreted depending on the motivations of policy makers. Hydrogeological models are used as the basis for locating burial sites for nuclear waste. These models are in turn being used by the United States Department of Energy (DOE) to assess the suitability of Yucca Flats, Nevada, for the burial of high-level radioactive waste. One panel of experts in 1992 used existing models to determine that the site is not well-suited for long-term waste burial given projections of tectonic activity and other uncertainties. A subsequent report in 1995 found that the geological record supports the burial of the same waste at the same site (Shrader-Frechette 2000). Clearly, the stakes are high in the interpretation of scientific models of earth systems for their relationship to the world can be differently interpreted.

Translating geographical questions into mathematical variables in order to analyze variables in relation to each other is a mainstay of much geographical research, especially in disciplinary niches concerned with modeling physical processes. Models rely on a morphism — or mapping — between the entity and the representation. Models do not pretend to be the real-world, but are used to determine critical properties of a given system (Herring 1991; Worboys 1995). Nevertheless, models become the basis for much geographical science. They are theories that become programs. Once a model is ensconced in GIS, it manufactures entities.

Each modeling system generates abstract entities from geological cavities to ecological systems. The entity relationships manufactured by models substitute for a broader understanding of a reality that we cannot apprehend — or model. They are iterations of virtual reality, renderings that gain materiality partly through social processes. Events and objects generated by models gain a materiality as they enter the parlance of science and society. They may initially be treated as hypothetical, but over time they are normalized and institutionalized, finally becoming part of our vocabulary. It does not follow that GIS or other modelling systems are "social constructions" in the sense that the results are not founded on physical reality. It does, however, raise the question: if GIS is so vulnerable to the policy instrumentation and differential interpretation, then how can it have any basis in the realist-rationalist world of science?

The great irony that confounds STS researchers that maintains the position of science in western society is that models are capable of generating predictive information that helps us understand the world. At the same time, society creates the context for the development and use of scientific knowledge, thus influencing the facts that are discovered (Sarewitz 2000). If we think of GIS as a system of representation, not unlike a language, then clearly its vocabulary is socially constructed "[b]ut it doesn't follow that those vocabularies are therefore incapable of meeting the standards of adequacy relevant to the expression and discovery" of relevant information about the world — however mediated (Boghossian 1998, 29). It does imply that the models used to describe those relationships are expressions of social discourses.

If modelling provides a conceptual framework for GIS operations, then algorithmic implementation of representational and modelling exercises are more concrete. They are the basis for describing ideas and entities in digital terms. Algorithms and their computational counterparts — programs — are more like plumbing than architecture. Programs are patchworks of code, cobbled together, and endlessly de-bugged until they run more or less consistently. The implicit relationships between the points, lines, and areas that users see on the screen are encoded in a pragmatic fashion that is shaped by both social and technical constraints.

## Algorithms as Social Metaphors

Agendas can literally be encoded in models of reality and in science more generally. When successfully encoded, agendas *seem* to represent the environment being modelled. Someone might object that this level of recursion or sequentiality between the social and the software exists only at the level of tool selection and analysis, but there is ample evidence to suggest that algorithms are developed and deployed in response to social metaphors. It was Aristotle who first wrote: "Metaphor consists in giving the thing a name that belongs to something else" (Aristotle cited in Barnes 1991, 112). Metaphor doesn't negate the possibility of deep structure, but describes it using a familiar sign. This is a form of substitution, not a negation of realism. Rorty (1989) claims that metaphors underlie most of our philosophical convictions. My contention is that the role of metaphor does not end with philosophy but permeates science. Algorithms in GIS are steeped in metaphors.

Metaphors of nature and biology are common in GIS and information technology. Neural nets and genetic algorithms, for instance, are two artificial intelligence (AI) methods that have been incorporated into GIS. Neural nets are based on metaphors from neural science that are, in turn, based on current understandings of parallel processing in the brain. Genetic algorithms (GA), like neural nets, imitate biological constructions of human behaviour. Based on principles of natural selection, GA use recursive techniques to develop new solutions to problems and evaluate then until the goal has been met or a maximum number of iterations has been reached (i.e. failure). Both are based on metaphors from biology.

Metaphors are, of course, gross approximations of physiological processes, but they remain prevalent and powerful inspirations for subsequent science and technology. Martin (1994) described how the body's immune system has been successively described by different metaphors. In the early twentieth century, and well into the 1940s and 50s, scientific discourse constructed the body as a machine. Regular habits of hygiene, sleep, diet, and exercise were analogous to vehicle maintenance. Cleanliness was paramount in this regime as being germ-free was equated with being disease-free. During this period, resistance to disease was dependent on habit; it could not be built up and the only strategy was to avoid infection. With the introduction of gamma-globulin in 1954, attention to antibodies and the interior of human bodies was initiated. By the 1960s and 70s, the body's immune system was imagined as an army, as "fighting back" when invaded. AIDS and other infectious diseases gave rise to the metaphor of a besieged nation with antibodies and attackers in hierarchies parallel to gender, race, and class. Martin's salient point is that the language of science and technology is the language of contemporary culture. Haraway (2000, 86) has succinctly noted that "I cannot *not* think through metaphor." Nor it seems can scientists.

The role of metaphor in designing algorithms for GIS is illustrated by an example from previous research in which I illustrated that the points, lines, and areas that we see on the screen are not faithful even to Euclid's geometry as most people would assume (Schuurman 1999). Because of space constraints in a computational environment, it is impossible to store the infinite number of points that comprise a map area in GIS. Instead, domain grid points similar to the intersections of the blue lines on graph paper are used. When a line is drawn from point *a* to point *b*, for instance, there are points on the line that are outside the set of domain grid points (Worboys 1995) (see figure 2).

The intersection point *x* is not in the set of possible grid points. The intersection point can be moved to point $x_{new}$, but that is a temporary solution. If a new line *cd* is drawn, then its intersection point with *ab* would now be below point $x_{new}$, violating the topological relationship between *ab* and *cd*. A number of solutions to this problem were devised for early GIS (Worboys 1995) until a paper by Greene and Yao (1986) introduced an algorithm based on the metaphor of a "peg-board" to resolve such conflicts. They imagined that the grid points were pegs on a peg board (Greene and Yao 1986) and that the lines *ab* and *cd* are drawn by elastic bands stretching between their end points. When intersection points are rounded off to domain points on the grid (such as $x_{new}$), it is done in such a way that the elastic bands cannot pass over the grid nodes (or pegs) but are allowed to rest against them. Subsequent lines are subject to the same constraints. They can press against but cannot pass over the pegs. This solution is illustrative of the mix of metaphor and pragmatism that informs much scientific and technical research.

The most common metaphor in GIS is that of "overlay" (Chrisman 2001). It refers to the manual cartographic process of overlaying map layers on a light table to discern pattern or to determine best-path routes. There are equivalent algorithmic procedures to examine multiple attributes in a gestalt manner — referred to as "overlay." The metaphor of overlay remains despite a dramatic shift in the technology. Chrisman points out that a strong attachment to "overlay" remains because they are compatible with administrative hierarchies "with their implicit division of labor and responsibility" (Chrisman 2001). Metaphors extend to the most minute corners of implementation in GIS. A visualization technique known as "depth-sorting" uses the "painter's" algorithm. In this case, the algorithm is used to conceal surfaces hidden from particular visual perspectives. It is executed by mimicking the way that a painter works by drawing foreground objects on top of background objects (de Berg 2000). These examples of the links between metaphor and algorithms illustrate the persistence of social-technical relationships in GIS.

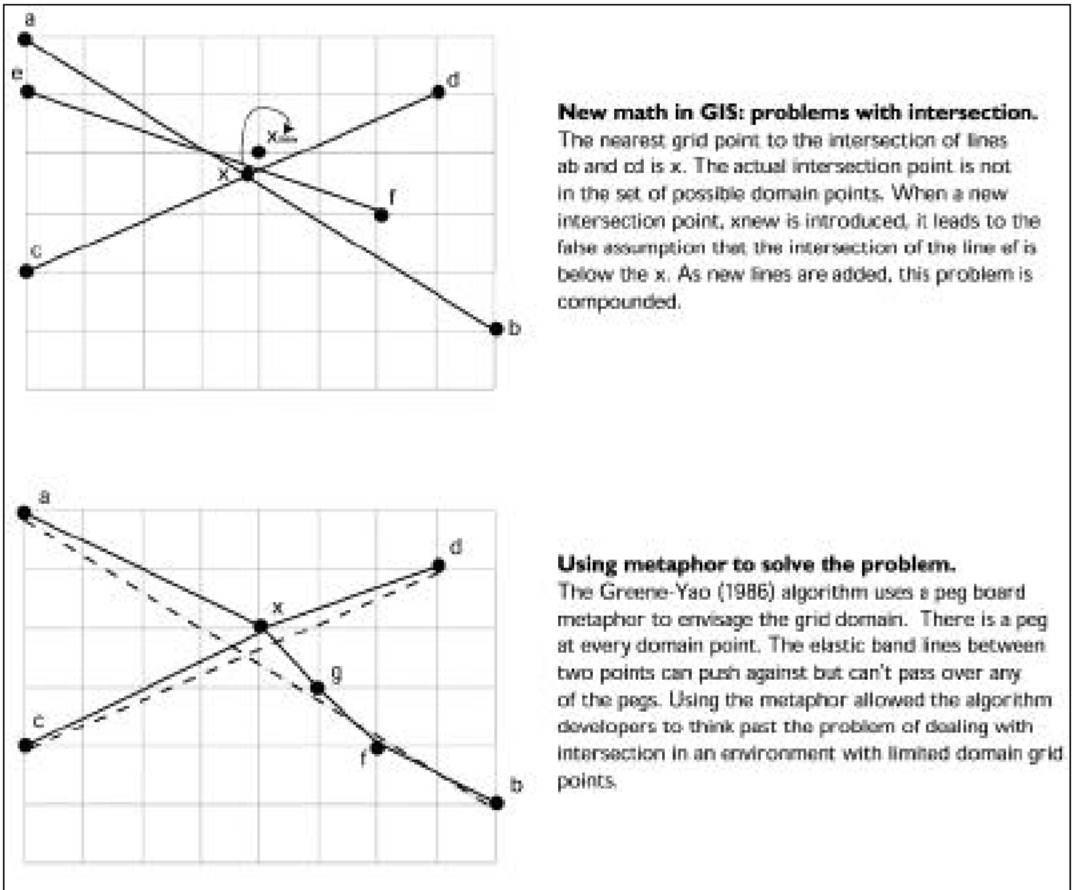


Figure 1: Thinking with metapor

## Social Parameters of Research Directions: Cartographic and Model Generalization

Models and algorithms have traditionally been considered sacrosanct — or at least reliable — in science, while the direction that scientific research takes has been generally acknowledged to be affected by the ambient culture. Even among hard-core realists, there is a general acknowledgement that scientific research direction is affected by culture (Sullivan 1998). Evidence of this is suggested by claims that women's health problems have been understudied, or that computer science research attracts better funding than astronomy. The influence of cultural precedents on research directions in GIS is clearly discernable in the history of generalization research. Generalization refers to the simplification of detail and elements as scale decreases.

Computerized generalization is complicated by its distinction between model and cartographic simplification. "Model" refers to the database and "cartographic," to its display. In order to appreciate the difference between model and cartographic aspects of generalization, it is necessary to think of the map one sees displayed on the screen as the tip of an iceberg. The body of the iceberg, lying hidden below the surface, is the database and geometrical properties of the spatial entities (Schuurman 1999). It is not always necessary to simplify the database in order to simplify the map. Model-based generalization focuses on reducing the detail in the database while cartographic generalization simplifies the display.

In traditional cartography, there was little differentiation between data and map simplification. The map was the singular repository for the data. Granted, cartographers worked from sources, but when the map was produced, the sources were stored away in files forever separate from the map. After the map was drafted, the map and the data became synonymous. The map was the repository of data and it was the map that was subject to revision — without reference to the *original* data. In GIS, the map is an ephemeral and transient by-product of the database. The map might last only 40 seconds; the data are the basis for its display. Likewise, the data in GIS, *not the map*, are updated when necessary.

Generalization in GIS involves simplification of the database followed by appropriate *re-visualization* of the information. These two steps are distinct yet inseparable; the data are never disassociated from the map, but the principles of generalization are different for both. Though this differentiation may seem self-evident, it took two decades of generalization research for it to be articulated. Brassel and Weibel (1988) published made the distinction between model and cartographic processes of generalization. They distinguished between model processes that relate to the database and the visual display of data. Fundamentally different aims are associated with each procedure. Model generalization affects the database while cartographic generalization is concerned only with the modification of graphic detail and figures only at the point of display (Brassel and Weibel 1988). The conceptual and algorithmic gaps between these two processes now seem apparent, but until they were articulated, generalization research had focused on the wrong level of representation.

A culture of cartography, especially dominant in North America, was responsible for the long lag in switching from a map to model-oriented approach to generalization. European GIS researchers are steeped in statistical and mathematical approaches to geographical data (Richardson 1998, personal interview). Buttenfield (1998, personal interview) notes that, in contrast, many GIS researchers in the US were trained as cartographers. Paradigms were essentially cartographic and generalization researchers were working with files of one-string coordinates. She recalls that:

> We knew that we were missing the point but we didn't know how to get there. The reason that Kurt and Rob's paper [Brassel and Weibel 1998] was so important was that we read that paper and [realized] they know how to do it. Maybe they don't know how to actually implement it but they at least intellectually can get around the cartographic impasse (Buttenfield 1998, personal interview).

Europeans had developed a *landscape model* that is based on derived data. They took that landscape model — the database — and then developed multiple separate cartographic models from it. They separated the theoretical approaches for the two processes. This was a critical distinction that enabled the generalization community to bridge an important hurdle (Schuurman 1999). The result has been more concentrated focus on model level generalization, as well as a recognition that procedures consistent with digital architecture must be established at the database level. Model level emphasis shifts the focus in GIS from displaying points, lines, and areas to a spatial representation based on data. This was a social and perceptual shift that entailed an abandonment of the traditional cartographic research model that had previously driven generalization.

## Constructing GIS

These examples of social infusion in models, algorithms, and generalization research could have been made about any number of procedures or paradigms in GIS. Whether one is discussing digital terrain models or line simplification algorithms, it is inevitable that a combination of social and digital factors have contributed to the GIS as we know it. The particular cultural metaphors and stumbling blocks that contributed to implementation will vary, but there is no technology that is *outside* the social. Yet to pronounce GIS an entirely social construction denies its application in realist contexts.

Ironically, these illustrations of the social influence at the technical level might serve to reinforce suspicions held by some that GIS is an *exclusively* social technology. Hacking (1999) has written about the mad rush to show that *X* or *Y* is socially constructed. He makes the point that the exercise is often motivated by a desire to show that *X* is not inevitable and furthermore not desirable. In extreme cases, efforts to illustrate that *X* is socially constructed are motivated by a desire to rid the world of *X*. I have argued in this paper, however, that GIS is socially produced and supports a weak form of realism.

The realism associated with GIS is two-pronged. Realism is located in the algorithms and hardware as well as the empirical interpretation of results. It is important to recognize that GIS structures enquiries about geographical phenomena and it is this structure that influences empirical outcomes and interpretation just as the epistemology of its users does. Evidence of social constructivism must be separated from the results that point to underlying structure/causal mechanisms. Two avenues for future research emerge from this multivalent realism associated with GIS. The first is to explore how algorithms and data models structure events and the second is to address how hardware, software, research parameters, and study definitions are socially produced.

In Geography, critics of GIS have called attention to cultural implications of using GIS for marketing or war (Goss 1995; Smith 1992). Critiques like this dispel the "march of progress" myth that frequently frames GIS and remind us that there remain legitimate queries about the application and bases of GIS (Chrisman 2001). Such criticism can be extended to include a constructive engagement with the technology. A critical first step is understanding how GIS' (or any technology's) construction is indeed social. The second step is recognizing the potential for realist claims about GIS. Illustrating that a feature of GIS emerged out of a particular set of circumstances provides both digital and social bases for possible refinement and, perhaps, better models of reality.

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## References

Baker, Victor R. 2000. Conversing with the Earth: the Geological Approach to Understanding. In, Robert Frodeman (ed.), *Earth Matters: The Earth Sciences, Philosophy, and the Claims of Community*. Upper Saddle River, NJ: Prentice Hall, pp. 2-10.

Barnes, Trevor J. 1998. A history of regression: actors, networks, machines and numbers. *Environment & Planning A* 30, 203-224.

Bhaskar, Roy 1979. *The Possibility of Naturalism: A Philosophical Critique of The Contemporary Human Sciences*. Brighton, UK: Harvestor Press.

Boghossian, P.A. 1998. What the Sokal Hoax Ought to Teach Us. In, Noretta Koertge (ed.), *A House Built On Sand: Exposing Postmodernist Myths About Science*. New York: Oxford University Press, pp. 22-31

Brassel, Kurt E. and Robert Weibel. 1988. A review and conceptual framework of automated map generalization. *International Journal of Geographical Information Systems* 2 (3), 229-244.

Buttenfield 1998. Personal interview conducted by Nadine Schuurman August 26, 1998: telephone interview between Boulder, CO and Phoenix, AZ.

Burrough, Peter A. and Andrew U. Frank. 1995. Concepts and paradigms in spatial information: are current geographical information systems truly generic? *International Journal of Geographical Information Systems* 9 (2), 101-116.

Casetti, Emilo. 1999. The Evolution of Scientific Disciplines, Mathematical Modeling, and Human Geography. *Geographical Analysis* 31 (4), 332-339.

Chrisman, Nicholas. 2001. Configuring the User: Social Divisions of Labour in GIS Software. Paper read at Geographic Information Systems in a Changing Society, May 18-20, 2001, at Columbus, Ohio. (MS available from author: chrisman@u.washington.edu)

Coulelis, Helen. 1999. Space, time, geography. In, Paul A. Longley, Michael F. Goodchild, David J. Maguire and David. W. Rhind (eds.), *Geographical Information Systems: Principles, Techniques, Management and Applications*. New York: John Wiley & Sons, pp. 29-38.

__________. 1998. Geocomputation in Context. In, Paul A. Longley, Sue M. Brooks, Rachel McDonnell and Bill Macmillan (eds.), *Geocomputation: A Primer.*. New York: John Wiley & Sons, pp. 17-29.

__________. 1992. People manipulate objects but cultivate fields: Beyond the raster-vector debate in GIS. In, Andrew U. Frank, Irene Campari and U. Formentini, (eds.), *Theories and Methods of Spatial-Temporal Reasoning in Geographic Space.* Berlin: Springer-Verlag, pp. 105-138.

Couclelis, Helen and J. Gottsegen. 1997. What Maps Mean to People: Denotation, Connotation, and Geographic Visualization in Land-use Debates. In, Stephen C. Hirtle and Andrew U. Frank (eds.), *Spatial Information Theory: A Theoretical Basis for GIS, COSIT '97*. Berlin: Springer, pp. 65-77.

de Berg, Mark. 2000. Visualization of TINS. In, Marc van Kreveld (ed.), *Algorithmic Foundations of Geographic Information Systems*. New York: Springer, pp. 79-97.

Demeritt, David. 2001. The Construction of Global Warming and the Politics of Science. *Annals of the Association of American Geographers* 91 (2), 307-337.

Deutsch, David. 1997. *The Fabric of Reality: The Science of Parallel Universes — and Its Implications*. New York: Penguin.

Frank, Andrew U. 1996. Towards an Operational Typology of Geographic Entities with Ill-defined Boundaries. In, Peter A. Burrough and Andrew U. Frank (eds.), *Geographic Objects with Indeterminate Boundaries*. London: Taylor & Francis, pp. 3-28.

Frank, Andrew U. and David M. Mark. 1991. Language Issues for GIS. In, David J. Maguire, Michael F. Goodchild, and David Rhind (eds.), *Geographical Information Systems: Principles and application*. New York: John Wiley & Sons, pp. 147-163.

Frank Andrew U and Martin Raubal. 1998. Specifications For Interoperability: Formalizing Image Schemata for Geographic Space. In, Tom Poiker & Nicholas Chrisman (eds.), *Proceedings from the 8th International Symposium on Spatial Data Handling*, Vancouver, IGU Press, pp. 331-348.

Freska, Christian. 1991. Qualitative Spatial Reasoning. In, David Mark and Andrew Frank (eds.) *Cognitive and Linguistic Aspects of Geographic Space*. London: Kluwer Academic Publishers, pp. 361-372.

Goodchild, Michael F., Max J. Egenhofer, Karen K. Kemp, David M. Mark and Eric Sheppard. 1999. Introduction to the Varenius Project. *International Journal of Geographical Information Science* 13 (8), 731-745.

Goss, Jon. 1995. Marketing the New Marketing: The Strategic Discourse of Geodemographic Information Systems. In, John Pickles (ed.), *Ground Truth*. New York: Guilford Press, pp. 130-170.

Gray, M.Violet. 1997. Classification as an Impediment to the Reliable and Valid Use of Spatial Information: A Disaggregate Approach. In, Stephen C. Hirtle and Andrew U. Frank (eds.), *Spatial Information Theory: A Theoretical Basis for GIS, COSIT '97*. Berlin: Springer, pp. 137-149.

Greene, Daniel and Frances Yao. 1986. Finite-resolution computational geometry. In *The 27th Annual Symposium on Foundations of Computer Science*. Toronto, Ontario, Canada: IEEE, pp. 27-29.

Gregory, Derek. 1994. Realism. In, Ron J. Johnston, Derek Gregory and David M. Smith, (eds.), *The Dictionary of Human Geography*, 3rd Edition, Oxford: Blackwell, p. 500.

Gregory, Derek. 2000. Realism. In, Ron J. Johnston, Derek Gregory, Geraldine Pratt and Michael Watts, (eds.), *The Dictionary of Human Geography*, 4th Edition, Oxford: Blackwell, pp. 673-676.

Gross, Alan G. 1996. *The Rhetoric of Science*. Boston, MA: Harvard University Press.

Hacking, Ian. 1999. *The Social Construction of What*. Cambridge, MA: Harvard University Press.

Haraway, Donna J. 1991. *Simian, Cyborgs and Women: The Reinvention of Nature*. New York: Routledge.

Haraway, Donna J. 2000. *How like a leaf: an interview with Thyrza Nichols Goodeve/Donna J. Haraway*. New York: Routledge.

Harding, Sandra. 1991. *Whose Science, Whose Knowledge? Thinking from Women's Lives*. Ithaca, NY: Cornell University Press.

Herring, John R. 1991. The mathematical modeling of spatial and non-spatial information in geographic information systems. In, David M. Mark and Andrew U. Frank (eds.), *Cognitive and Linguistic Aspects of Geographic Space*, London: Kluwer Academic Publishers, pp. 313-350.

Hornsby, K. 2001. Temporal Zooming. *Transactions in GIS* 5 (3), 255-272.

Kemp, Karen and Andrej Vckovski. 1998. Towards an ontology of fields. Paper read at The Third International Conference on GeoComputation, September 17-19, Bristol, UK.

Keylock, Chris. 1999. Personal electronic communication, March 2, 1999.

Kitcher, Philip 1998. A Plea for Science Studies. In *A House Built On Sand: Exposing Postmodernist Myths About Science*, edited by N. Koertge. New York: Oxford University Press.

Kwan, Mei-Po. 2000a. Interactive geovisualization of activity-travel patterns using three-dimensional geographical information systems: a methodological exploration with a large data set. *Transportation Research Part C* 8, 185-203.

Kwan, Mei-Po. 2000b. Gender differences in space-time constraints. *Area* 32 (2), 145-156.

Kwan, Mei-Po. 2002a. Is GIS for Women? Reflections on the Critical Discourse in the 1990s. *Gender, Place and Culture* forthcoming.

Kwan, Mei-Po. 2002b. Other GISs in Other Worlds: Feminist Visualization and Re-envisioning GIS. *Annals of the Association of American Geographers* forthcoming.

Kuhn, Werner and Andrew U. Frank. 1991. A Formalization of Metaphors and Image-Schemas in User Interfaces. In, David M. Mark and Andrew U. Frank (eds.), *Cognitive and Linguistic Aspects of Geographic Space*. London: Kluwer Academic Publishers, pp. 419-434.

Lake, Robert W. 1993. Planning and Applied Geography: Positivism, Ethics, and Geographic Information Systems. *Progress in Human Geography* 17, 404-413.

Lakoff, George. 1987. *Women, Fire, and Dangerous Things: What Categories Reveal about the Mind*. Chicago: University of Chicago Press.

Latour, Bruno. 1993. *We Have Never Been Modern* (trans. Catherine Porter). Cambridge MA: Harvard University Press.

Lynch, Michael and Steve Woolgar, (eds.). 1990. *Representation in Scientific Practice.* Cambridge, MA: MIT Press.

Mark, David M. 1993. Towards a Theoretical Framework for Geographic Entity Types. In, Andrew U. Frank and Irene Campari (eds.), *Spatial Information Theory: A Theoretical Basis for GIS*. Berlin: Springer-Verlag, pp. 270-283.

Mark, David M. 1997. Cognitive Perspectives on Spatial and Spatio-temporal Reasoning. In, Helen Couclelis and Massimo Craglia (eds.), *Geographic Information Research: Bridging the Atlantic.* Bristol, PA: Taylor & Francis, pp. 308-319.

Mark, David M. 1999. Spatial representation: a cognitive view. In, Paul A. Longley, Michael F. Goodchild, David J. Maguire and David W. Rhind, (eds.), *Geographical Information Systems: Principles, Techniques, Management and Application.* New York: Wiley, pp. 81-89.

Martin, Emily. 1994. *Flexible Bodies: Tracking immunity in American culture from the days of Polio to the age of AIDS*. Boston: Beacon Press.

National Center for Geographic Information Analysis (NCGIA). 1998. The Ontology of Fields: Report of a Specialist Meeting held under the auspices of the Varenius Project. Bar Harbor, Maine.

Peuquet, Donna, Barry Smith and Berit Brogaard. 1999. The Ontology of Fields: Report of a Specialist Meeting held under the Auspices of the Varnius Project. Bar Harbor, Maine.

Pickering, Andrew. 1995. *The Mangle of Practice: Time, Agency, and Science*. Chicago and London: University of Chicago Press.

Pickles, John. 1993. Discourse on method and the history of discipline: Reflections on Jerome Dobson's 1993 “Automated geography”. *Professional Geographer* 45 (4), 451-455.

Pickles, John. 1997. Tool or Science? GIS, Technoscience and the Theoretical Turn. *Annals of the Association of American Geographers* 87, 363-372.

Pickles, John. 1999. Arguments, debates and dialogues: The GIS social theory debate and the concern for alternatives. In, Paul A. Longley, Michael F. Goodchild, David J. Maguire and David W. Rhind, (eds.), *Geographical Information Systems: Principles, Techniques, Management and Application.* New York: Wiley, pp. 49-60.

Raper, Jonathan. 1999. Spatial Representation: the scientist's perspective. In, Paul A. Longley, Michael F. Goodchild, David J. Maguire and David W. Rhind (eds.), *Geographical Information Systems: Principles, Techniques, Management and Application.* New York: Wiley, pp. 71-80

Raper, Jonathan. 2000. *Multidimensional geographic information science.* New York: Taylor & Francis.

Raper, Jonathan and David Livingstone. 1995. Development of a geomorphological spatial model using object-oriented design. *international Journal of Geographical Information Systems* 9 (4), 359-383.

Richardson, Dianne 1998. Personal interview conducted by Nadine Schuurman October 8, 1998. Telephone interview between Ottawa, ON and Phoenix, AZ.

Rorty, Richard. 1989. *Contingency, irony and solidarity*. New York: Cambridge University Press.

Ross, Andrew 1996. Introduction. *In Social Text* 46/47, 1-13.

Rouse, Joseph 1996. *Engaging Science. How to Understand Its Practices Philosophically*. Ithaca/London: Cornell University Press.

Sarewitz, Daniel 2000. Science and Environmental Policy: An Excess of Objectivity. In, Robert Frodeman (ed.), *Earth Matters: The Earth Sciences, Philosophy, and the Claims of Community.* Upper Saddle River, NJ: Prentice Hall, pp. 79-98.

Schatzki, Theodore 1991. Spatial ontology and explanation. *Annals of the Association of American Geographers* 81, 650-670.

Schuurman, Nadine. 1999. Critical GIS: theorizing an emerging discipline. *Cartographica* 36 (4), 1-107.

Schuurman, Nadine. 2000. Trouble in the Heartland: GIS and its critics in the 1990s. *Progress in Human Geography* 24 (4), 569-590.

Sheppard, Eric. 1993. Automated Geography: What kind of geography for what kind of society? *Professional Geographer* 45, 457-460.

Sheppard, Eric, Helen Couclelis, Stephen Graham, J.W. Harrington, and Harlan Onsrud. 1999. Geographies of the information society. *International Journal of Geographical Information Science* 13 (8), 797-823.

Shrader-Frechette, Kristin. 2000. Reading the Riddle of Nuclear Waste: Idealized Geological Models and Positivist Epistemology. In, Robert Frodeman (ed.), *Earth Matters: The Earth Sciences, Philosophy, and the Claims of Community.* Upper Saddle River, NJ: Prentice Hall, pp. 11-24.

Sismondo, Sergio. 1996. *Science without Myth: On Constructions, Reality and Social Knowledge*. Albany: State University of New York Press.

Smith, Barry and David Mark. 1998. Ontology and Geographic Kinds. In, Tom Poiker and Nicholas Chrisman (eds.), *Proceedings from the 8th International Symposium on Spatial Data Handling*, Vancouver: IGU Press, pp. 308-320.

Smith, Neil. 1992. History and Philosophy of Geography: Real Wars, Theory Wars. *Progress in Human Geography* 16, pp. 257-271.

Sullivan, Paul 1998. An Engineer Dissects Two Case Studies: Hayles on Fluid Mechanics and MacKenzie on Statistics. In, Noretta Koertge (ed.), *A House Built*

*On Sand: Exposing Postmodernist Myths About Science.* New York: Oxford University Press, pp. 71-98.

Taylor, Peter J. 1990. GKS. *Political Geography Quarterly* 9, 211-212.

Taylor, Peter J. 1991. Further thoughts on geography and GIS. *Environment & Planning A* 23, 1087-1090.

Taylor, Peter J. and R.J. Johnston. 1995. GIS and Geography. In, John Pickles (ed.), *Ground Truth*. New York: Guilford Press, pp. 66-87.

Tobler, Waldo 1999. Linear pycnophylactic reallocation — comment on a paper by David Martin. *International Journal of Geographical Information Science* 13 (1), 85-90.

Volta, Gary S. and Max J. Engenhofer, 1993. Interaction with GIS Attribute Data based on Categorical Coverages. In, Andrew U. Frank and Irene Campari (eds.), *Spatial Information Theory: A Theoretical Basis for GIS, COSIT '93.* Berlin: Springer-Verlag, pp. 15-31.

Worboys, Michael F. 1995. *GIS: a Computing Perspective*. Bristol, PA: Taylor & Francis.