Beyond Spatio-temporal Data Models: A Model of GIS as a Technology Embedded in Historical Context

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ABSTRACT

Most of the discussion of time in GIS fits into the general topic of developing a useful model of geographic data. Data models, at their most abstract level, describe objects, relationships, and a system of constraints or axioms. So far, most GIS research posits universal axioms with a strong geometric basis. Time is usually spatialized. Models of GIS should develop to include more than the data, since an operating GIS must be connected to its context in social, economic and administrative life. While time might be reasonably represented as an axis in data space, as a technology, GIS develops in a complex, multi-thread system of events. Understanding the historical nature of the participants in the GIS can help sort out the diversity of data models and the inability to develop common understandings. The logic of historical time, with its multiple threads, provides a rich source of axiomatic structure for a more comprehensive model of GIS. A few starting axioms are offered.

Data Models in GIS

Developing a model for the *data* in a geographic information system has remained a core issue in GIS research for over two decades. Recently, many research leaders in the field of GIS have written papers promoting models of spatial data (including, but not limited to Peuquet, 1988; Frank, 1987; Goodchild, 1987; 1992; Nyerges, 1991a). Due in large part to the reliance on mathematical frameworks and certain basic attitudes towards science, these authors have described abstract models based on universal principles. Most of the work on data models describes a structure of objects and their relationships, using the barest geometric axioms to complete the model (see Codd, 1981 for the connection between a data model and a mathematical theorem; also White, 1984; Corbett, 1979). GIS research must focus more attention on axioms; their origins and their utility. At the moment, the concept of a data model limits its application to the data, not the full understanding of a geographical information system as practiced inside human institutions.

Temporal Data Models

Recent research has devoted attention to incorporating time more fully into the data models of GIS (for example Armstrong, 1988; Barrera and Al-Taha, 1990; Hazelton, 1991). In most of the literature, including my own technical works, time is treated as an axis, a dimension of measurement similar to the spatial case. Langran and Chrisman (1988) reviewed the difficulties of adding time to geometry and attributes. The basic model of time offered – a consensus of research opinion – was a linear axis with a topology imposed by significant events (see Figure 1).

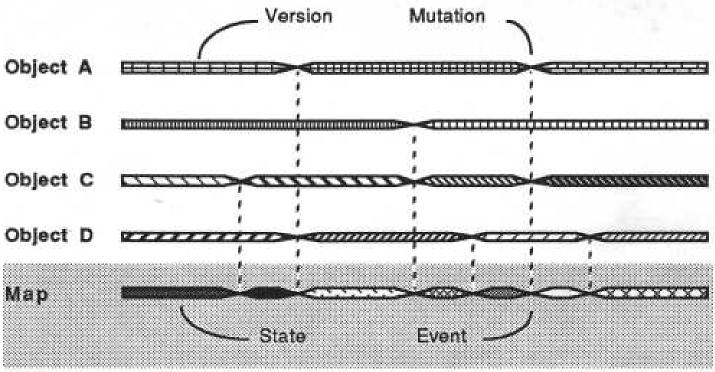

Figure 1: Topology of time (from Langran and Chrisman, 1988)

Langran (1991) provides the fullest discussion to date on the technical issues of incorporating time into GIS. Recent work on data models (such as Pigot and Hazelton, 1992) accept the treatment of time as an axis similar to a spatial one – a concept with deep roots in geography and cartography (Haggett, 1965; Szegö, 1987). As an initial approximation, analytical advances can be developed on this foundation. The use of abstract frames of reference, for both space and time, threatens to ignore the role of other forces in shaping the meaning of the raw measurements. Time in its historical form cannot become an abstract reference, it will be found to defy the unidimensional, monotonic character assigned to it.

Spatio-temporal reasoning should not be presented on a uniform plane against an abstract time axis. The important applications of spatio-temporal reasoning must be historically embedded, involving people in specific locations with complex historical roots to their societies, institutions and cultures. This goal can be achieved by reevaluating the axioms used as a basis for a data model.

Image Schemata: A Path Unlikely to Provide the Axioms

Other research on data models for GIS has recognized the need for some broader context than simply bald coordinate axes. Perhaps the most prominent component of recent literature on geographic data models is a move to add a cognitive component to data models. A number of researchers (including but not limited to: Mark and Frank, 1989; Nyerges, 1991b) have adopted various concepts from the work of Johnson (1987) and Lakoff (1987). While a cognitive emphasis connects the new GIS field more firmly to communication school cartography, this component deflects interest away from redefining the axioms. The concept of "image schemata" places central emphasis on the individual. Johnson's (1987) book is titled *The Body in the Mind,* which leads to mental constructs constrained by the experiential limits of bodies. GIS researchers then postulate that the *relationships* in a GIS must tie to the image schemata of human body experiences.

Human life and human information has become complex beyond the scope of single bodies. The major developments of the past 10,000 years have not included significant refinement in the human hardware. And yet, medical science has permitted dramatic increases in average longevity, but this achievement is not an example of body-based cognition. Medical research is an example of a social and economic enterprise carried out over the long-term by many cooperating individuals. Most of the interesting advances of the past 10,000 years arise from the creation of larger and larger social and economic structures that endure **despite** the vagaries of individual bodies. Culture is the general covering term for the mechanisms that organize concepts and meanings beyond the scale of the individual. Culture is at least as important to GIS than any image schemata based on individual cognition. The Johnson-Lakoff "image schemata" approach limits attention to the cognition of space inside one body, rather than recognizing the complexity created by cultural transmission of concepts and meaning. The image schemata offers an alternative understanding of relationships but little concerning the axiomatic structure as it is redefined by cultural history.

Discussing a social and cultural element in GIS is no novelty by now. The purpose of this paper is not to repeat the arguments of earlier papers, but to add to their direction. The work on data models has limited the focus precisely to "the data", and the image schemata does not move far into the realm of axioms. So far, there is no satisfactory approach to the historical nature of GIS as a technology and as an element inside human institutions.

VIEWS OF TIME IN GIS

The particular focus of this paper is the treatment of time in combination with geographic information, but not the time that is directly modelled in the database. Inside a data model, an abstract coordinate axis provides a reasonable simplification as a reference for the more complex logic required. However, there are other forms of time as well, particularly the historical sequence of ideas and technologies that lead to some particular GIS in some particular place. Understanding this context is critical to a correct interpretation of the reasons for installing and operating a GIS in some particular manner.

Some of the attitudes about time in GIS are unconscious, as opposed to the highly self-conscious formalisms of current data models. I will present a series of views of technology, each common or applicable in some portion of the field. These views about time and technology are critical to our view of the role of technology in society and thus to our views about GIS research and development.

Unconscious Views of Time

It is very hard to deal with GIS without all the gush of a "new age" or a "revolution" created by the new technology. This view is based on characterizing the GIS era as signally different from what preceded. At its most extreme, such a view places the past in the murkiness of the Dark Ages with the current era as one of enlightenment (as characterized in Figure 2).

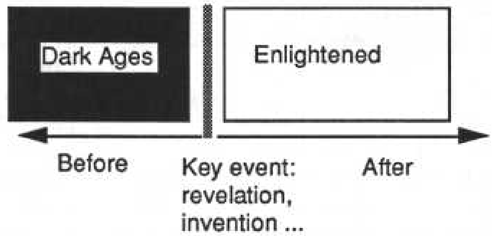

Figure 2: Rudimentary view of history (before and after)

While Figure 2 may seem a caricature, the field of GIS may fall back to this model a bit too easily. The tricky part of this model of development comes after the key event that begins the new age. There seems to be no further need for history, since everything has been resolved. Fukuyama (1992) has recently contended that recent geopolitical changes amount to an "end of history", but those changes simply may represent an end to the cold war mentality of simplifying abstractions; an era of new axioms for international relationships.

Despite the rhetorical recognition of revolutions, the image of time that permeates our culture to a much larger extent is the "March of Progress" (see Figure 3). Time is considered, not just to accompany, but essentially to cause the incremental improvement of material affairs. Since the Enlightenment, the rapid progress of industrial and other technology has contributed to popular acceptance. Time is associated with higher achievement and the phrase "onward and upward" forms an automatic association.

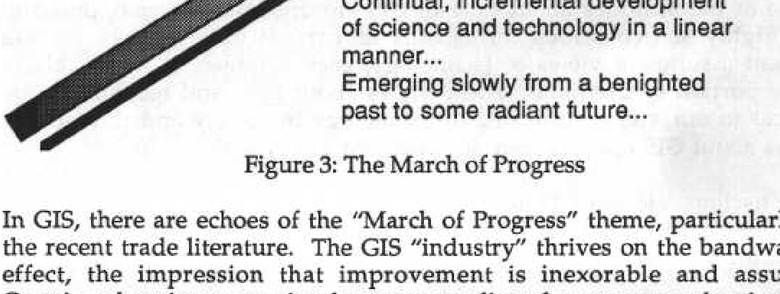

Figure 3: The March of Progress

In GIS, there are echoes of the "March of Progress" theme, particularly in the recent trade literature. The GIS "industry" thrives on the bandwagon effect, the impression that improvement is inexorable and assured. Certain advertisements simply present a list of customers adopting the particular product, thus fueling the impression that the central issue is simply participating, not the nature of the implementation. The general tone of feature articles in the trade literature trumpets the success (real or imaginary) of each new system. It is just such articles that bring the most furious attacks from the academic community (such as Smith, 1991).

It certainly may be true that some changes seem inevitable. For example, any computer purchased today will seem totally obsolete in a few years, even next month. As the components of the technology continue to get cheaper, do we arrive at the asymptote, the "zero cost hardware"? Even if we do, however, the ideas informing the software and the systems are not guaranteed to progress in any inexorable linear manner. Current adopters of GIS may not be assured of sharing in the success of those who have gone before, unless they listen very closely for the tales of the hard work associated with the successes (such as the memorable "advice" boxes in Huxold and others, 1982). During heady expansion, the distortion of stories, making success seem inevitable, does not serve any purpose. The image of a march of progress is so pervasive that it may be accepted without proof.

Beyond the March of Progress

As a refinement of the March of Progress, a purely linear view of history may be replaced with a recognition of competing forces and ideas. While expressed in various forms, Hegel's dialectic (see Figure 4) captures the basic framework. Marx's (and Engel's) view of history relies on this basic model. Like the march of progress, history follows an essentially linear set of phases or stages. Each stage develops out of the resolution of the previous problems and somehow inevitably causes contradictions that bring about the next conflict. Despite the overall linearity, at any one time the Hegelian dialectic does admit that there will be alternative explanations, thus different interpretations of history.

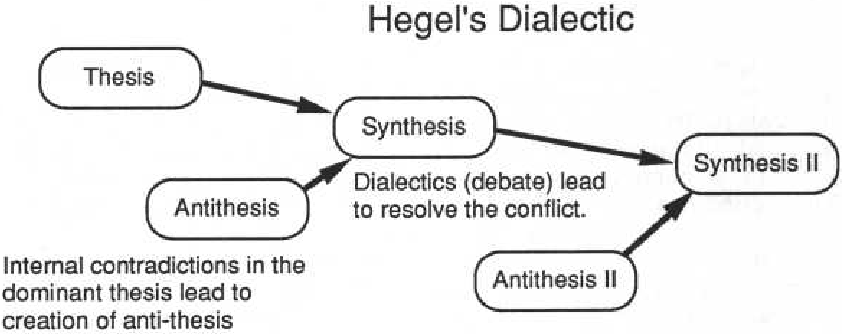

Figure 4: Hegel's dialectic (grossly simplified)

In the field of GIS, there is often the presumption of some basic stages of development, an application of Rostow's paradigm of economic development. There is an assumption that GIS tools all lead in one direction. The differences between raster and vector, and the other technological differences are seen as a part of a universal science

(Goodchild, 1992) that will incorporate the variants under one set of principles. This logic falls into the Hegelian camp.

Reasoning about history is not the same as reasoning about some constructed abstract world with a simple time axis. In historical context, there is no guarantee that the background for each event is unified and coherent. In Usher's (1954, p.19) words, "every event has *its* past." Schematically, this view of history can be presented as multiple "systems of events" or threads of connection that form the historical whole out of parts that may not be inherently consistent (see Figure 5).

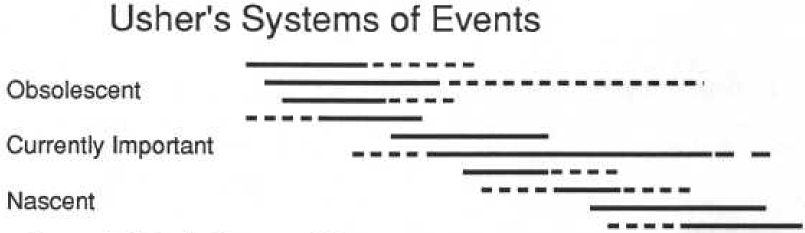

Figure 5: Usher's System of Events (redrawn from Figure 3, Usher, 1954, p. 22)

Each line in Figure 5 can be treated as an orthodox time line with a linear logic. The dashed sections at either end represent the periods in which an idea or construct may be nascent or obsolescent, while the solid portion represents a period of acceptance. Over time, some systems may join as certain concepts become connected. The scheme permits Hegelian synthesis when it actually occurs and recognizes when it may not occur for a long period. Usher's view of historical development could assist in developing the historical elements of GIS.

AN EXAMPLE OF MULTI-THREADED TIME

What does a concept of multi-threaded time have to offer the study of geographic information systems? It provides a framework to understand the ambiguities and conflicts within the technology and the institutions involved. Some of these can be developed by a hypothetical example based on a county land information office, say in the State of Wisconsin. This office has been charged with the "modernization" of the land information in the county, basically a conversion from a preexisting manual system to a computerized GIS. Phrased in these simple terms, it seems to fit the view of progress exemplified by Figure 2 or 3. These models certainly were a part of the political process used to obtain approval in the state legislature and in the county boards. Wisconsin believes in progress. The problem often comes because the vision of progress is different for various participants.

Each discipline or profession can be represented on their own time line (or at least somewhat distinct from their surroundings). In part, these time lines deal with the history of technology as applied by the particular profession. Surveyors have used analytical trigonometry for centuries, so a computer fits readily into the role of the slide rule and calculator. For other people working for the same county, computers were brought in as accounting machines to print the tax bills, so the model of computing is totally different. These time lines were able to persist so long as the surveyors and accountants work at different ends of the building and their efforts were loosely coordinated. Groups with less computing experience, the cartographers who maintained the manual mapping system using drafting tables and pens and the conservationist (trained to map soils and build farm ponds), might find themselves now more central than they were before, as the GIS emerges to coordinate all the county's records in a spatial framework.

Due to the distinct time lines, each discipline may have distinctive expectations about institutional arrangements. Certain mapping professions, like photogrammetry, have seen a centralized, high capital form of technological innovation over most of the twentieth century. The data processing professionals have similar values to centralization based on mainframe computers. These groups will be ill-prepared for a decentralized workstation network that evolves through collaboration perhaps without a rigid hierarchy.

The time lines discussed above deal with the immediate technological expectations of the participants. This range of time covers basically the past century at most and often remains within the work experience of the participants. This is no the only scale of time involved in this county modernization effort. Beyond the history of the technology, the county land information offices connect to a series of historical threads that define the fundamental meanings of their functions.

Many of the high–priority elements of the land information plan deal with environmental regulation, to preserve wetlands, reduce soil erosion, and many other specific programs. These efforts fit into a time line of the environmental movement – a relatively short term affair, though Aldo Leopold, the local saint, wrote his books in the early part of this century. Along this time line, Ian McHarg's *Design with Nature* (1969) creates a close linkage to the time line of the GIS technology. The message of integrating various forms of information was a part of this current of thought before the computer was applied to it.

The time lines of other components in the county land information puzzle are much deeper seated and much less clearly articulated by the participants. The legal structure of the land records is a long and complex history tracing back to Roman concepts of persons and rights, plus medieval constructs of common law – precedents and rules of evidence. These legal schemes came into a wide diversity of form in Europe, and certain elements were brought to the colonies (see Cronon, 1983 and Fischer, 1989). Parts of Wisconsin have the geometric forms of French long lots as signs of the diverse origins (Fortin, 1985). The particular elements borrowed from Britain and France may have disappeared in their original form, due to later events in the history of those nations. The american version of the Enlightenment, with its restoration of certain Roman forms, had a deep influence on the landscape of the

American West. Uniform squares were placed on the landscape far beyond the most grandiose legionary concession. But the time reference is not just to a rationalist vision. Surveyors are enjoined to "follow in the footsteps" of the original survey for ever more. The primitive surveying technology of the 1820's will continue to influence our Wisconsin county.

The Public Land Survey represents an amazing vision of uniformity and rationalism that conflicts with Leopold and McHarg's visions of connection to the particularities of the ecological system. The conflict between a geometric view and an ecological systems view are not resolved by having each one enshrined in statute and ordinances (Sullivan and others, 1985). These differences are not simply about GIS technology, though they will create different views about the capabilities required for that technology. The legal structure of property rights involves conflicting time lines. The basic constitutional structure is built on Locke's theories of government, with its assertions of individual rights. Modern environmental regulations restrict those rights without completely instituting the requisite changes to alternative views of rights and duties (Bromley, 1991). In the matter of wetlands regulations, the time lines stretch back to the medieval common law treatment of water rights, now reinterpreted in a totally different circumstance.

Most of these historical connections might seem remote to the participants, but the origins of their beliefs and values arise from these time lines. The diversity of different traces of thinking will have practical consequences in the implementation and management in the prototypical county in Wisconsin and anywhere else. The set of historical threads will vary, but there will undoubtably be many of them. What seems like inevitable progress to one participant may seem totally incompatible to another. Resolving these conflicts may be solved through the methods focused on individual perception and behavior, but that may only resolve the conflict for the specific participants, not their whole support network of professional or disciplinary background. A long term solution will require confronting the different views of history.

BUILDING A SET OF HISTORICAL AXIOMS

Beginning with Hegel's dialectic and continuing with the Wisconsin example, it should be apparent that sometimes conflicting ideas can coexist. In fact, despite Hegel's grand assertions of dialectical certainty, conflicting ideas can persist over quite long periods. Just because two events occur simultaneously, one cannot infer that the two events are connected in any direct way, or that their resolution is simply a matter of time. Relationships through time do not become instantly consistent. Similarly, some particular element may persist long after the initial reasons for its creation have faded away.

> "(M)any systems have persisted from a remote past, and have lost all significant contact with current patterns of behavior. ... Hunting privileges, for instance, were among the most useless and most irritating survivals of feudalism. The duty of protecting the peasantry and their crops from wild animals degenerated into a

right to preserve game and to hunt over the peasant's crops, to the detriment of every vital interest of the peasant." (Usher, 1954, p. 23)

Another concern in temporal reasoning involves causation. One of the classic flaws in logic is to assert that prior events automatically cause later ones. The flaw is known as *post hoc– propter hoc*. More connection is needed than simple prior occurrence.

To summarize in more succinct terms:

Axiom 1 (multiple time lines): Simultaneity is no guarantee of connection.

Axiom 2 (post hoc propter hoc): A prior event may be totally unrelated to (and uninvolved in the causation of) a later event.

Axiom 3 (inevitable conflict): Since each group in society and each institution has a distinct historical development of their beliefs and values, distinct and incompatible definitions of objects and relationships must be expected.

Axiom 4 (situated definition): Since definitions of legal (cultural and social) rights and responsibilities vary among societies and develop over time, the design of a GIS must be seen as conditional on the context for which it is designed.

CONCLUSION

A model of GIS cannot treat time as a sterile, abstract dimension without losing the historical specificity of its context. Modelling of GIS must extend beyond the data stored in the GIS to include the institutions that adopt the technology and the conversions of the industry that manages spatial information. Once these components are included, a model of time must include specific events and historical processes that lead to meanings of geographic phenomena amongst the diverse participants.

The field of GIS is beset by cultural expectations about time and progress. These cloud the importance of historical context in the implementation and development of these technological changes. Research in GIS should not stop with models of the data inside the GIS. The technological development process itself has historical roots and progresses in paths not entirely picked for the purest reasons. Even more importantly, the meaning of that data comes from the users and from the context of the uses. The context in turn is heavily influenced by the historical processes that lead to this point. A multi-thread model of historical origins seems much more appropriate than the single axis models that pervade the current thinking.

The purpose of GIS remains to integrate information from diverse sources. At the start, simple tricks such a spatial collocation (polygon overlay) could suffice. These tools remain valid if applied within a well-recognized and accepted framework of axioms. What must be designed is a method to integrate totally opposing frames of reference. This will not be carried out simply by mapping objects and relationships between two schema, because the axiomatic structure is the fundamental issue.

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