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GEOGRAPHIC INFORMATION SYSTEMS: RESEARCH ISSUES

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Abstract: GIS research has evolved by trial and error. We need to think more systematically about GIS research. New technology and societal needs are important determinants of issues that govern GIS research strategies. URISA has a stake in fostering GIS research, particularly research that is applications driven.

INTRODUCTION

Geographic Information Systems (GIS) are used for the analysis of the spatial distribution of resources. At a global scale the boundary layer of countries is used to determine the spatial effects of pollution, say acid rain or variations in industrial output. At the local level, the land ownership (or cadastral) layer is used to determine more localized spatial effects, such as the source of soil erosion or the locational consumption of public services. Driven by this broad range of applications, and subject to the rapid rate of computer technology developments, the field of geographic information systems needs a systematic articulation of research needs. Organizations such as URISA ought to be prominent in the development of an agenda for both basic and applied research, URISA is particularly suited to the articulation of applications driven research needs.

This paper argues the need to understand how the GIS field developed and what we have learned from the process and apply that learning to future applications of GIS concepts of technology. Similarly, we need to understand how technology and social transformations take place. Then we are in a better position to understand issues and approaches that need to be addressed. This paper attempts to develop these threads.

UNDERSTANDING THE EVOLUTION OF GIS

Without a formal research agenda and a program for research in GIS, the field has evolved by trial and error. Often this trial and error has resulted in expensive mistakes and the loss of credibility for GIS, because research has had to be done in the context of implementing systems for operating agencies. This has resulted in cost and time overruns and shortfalls in performance. The lack of a systematic framework for GIS research will be addressed by the development of a National Center for Geographic Information and Analysis (Abler, 1987). However, this center will focus on basic research and applied research needs may not be fully met.

The early evolution of GIS concepts of technology was assessed by Dueker (1979). He examined five systems that were developed in the late 60's and early 70's -- the Canadian Geographic Information System (CGIS), the New York State Land Use and Natural Resources (LUNR) system, The Minnesota Land Management Information System (MLMIS), the Polygon Information and Overlay System (PIOS), and the Oak Ridge Regional Modeling and Information System (ORRMIS). These were largely independent discoveries and consequently a wide range of approaches were employed for the capture and structure of geographic data. Scanning, digitizing, and manual entry of data using grid and vector formats were employed.

Dueker identified that premature reliance on fully automated systems resulted in delays and performance shortfalls, while more modest automation efforts achieved initial objectives, but were not flexible enough to meet new requirements. More importantly though, the early stage of development of GIS concepts and technology required the conduct of research and development within their implementation process. There were not research results to draw upon and the communication among the efforts was minimal. They did not learn from each other.

Subsequently, we saw a convergence of approaches away from manual entry and scanning to digitizing, with more attention to topological data structures for quality control of geographic data. Yet, manual entry and grid-cell systems persisted due to lack of fully operational vector-based systems (Dueker, 1979). In the late 70's GIS development floundered, as their efficiency and effectiveness could not be demonstrated, and GIS research was not being supported. The advent of affordable technology, in terms of microcomputers, and interactive graphics, has had more to do with the rising interest in GIS than has conceptual advances. Now we are in the position of turning to research on GIS to take advantage of the computer and information technology advances. But we need to think more systematically about research. The National Center will facilitate systematic basic research, a similar systematic approach to applied research is needed.

TECHNOLOGY AND SOCIAL TRANSFORMATIONS

Before examining GIS research issues, attention to technology and social constraints to the diffusion and adoption of research results is addressed Niemann et al (1988). Niemann has adopted a paradigm developed by Mayo (1985) that identifies society's "pull" for technological innovation and a "push" from technology. Mayo points out that the pull and push operates as "gates", thus the flow of innovations into society must be both technologically feasible and societally acceptable (see Figure 1 for Mayo's presentation and Figure 2 for Niemann's adaptation to GIS). This paradigm is useful for the clarification of technology versus applications research (see also Kraemer and King, 1985). Kraemer and King argue that automation in local government is too driven by technology and more attention and research is needed on the applications side. "What is needed", rather than "what is available" kinds of implementation research is called for.

Societal needs are more likely to be addressed from an applications-driven research approach, whereas societal impacts will emerge from a technology-driven advances, such as the automobile and photocopy machine, have to be accommodated and cannot be ignored.

Nevertheless, we cannot ignore technological advances. Major ones will continue to drive or pull us. Global positioning systems (GPS) and optical compact disks are "killer" technologies to previous positioning and storage devices that will revolutionize GIS.

Clearly, new technology and societal needs will impact the GIS research agenda. Both are important determinants of issues that govern GIS research strategies.

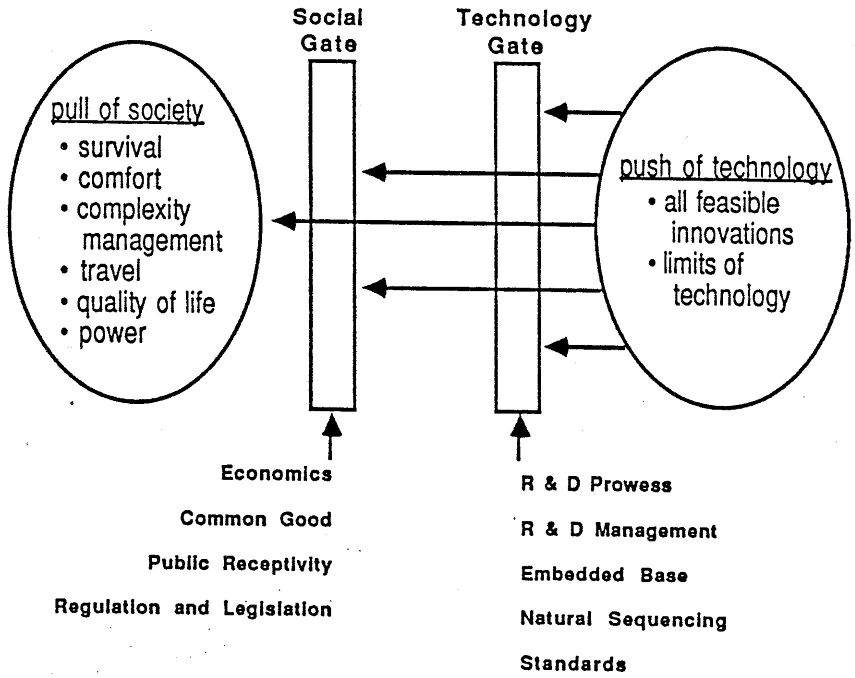

FIGURE 1 THE FLOW OF INNOVATIONS INTO SOCIETY (Mayo, 1985)

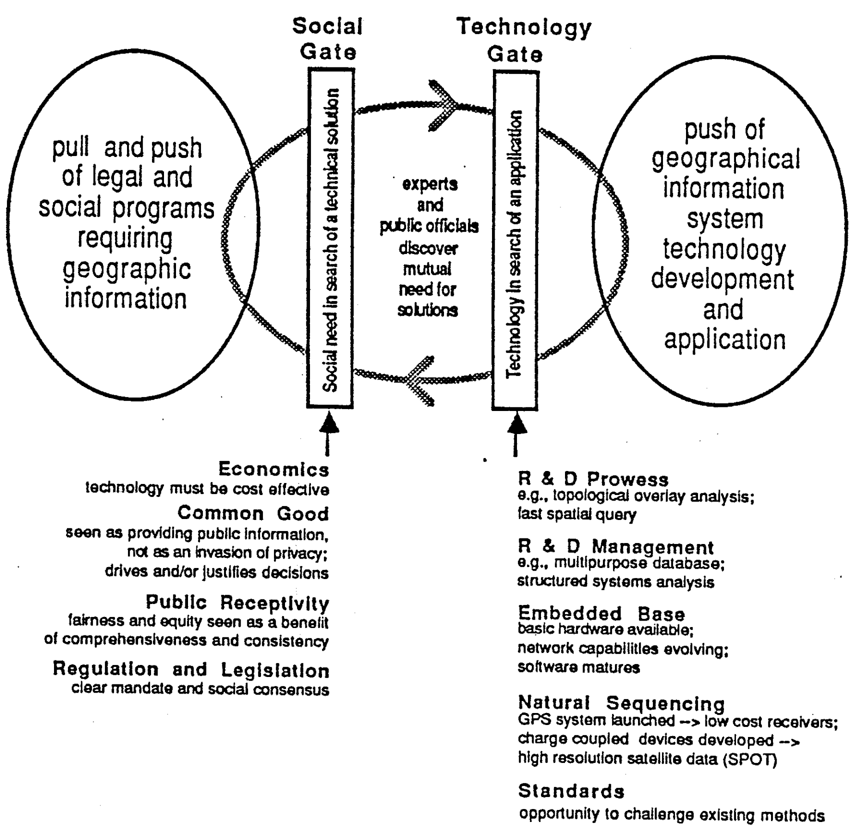

FIGURE 2 THE SYMBIOTIC RELATIONSHIP BETWEEN TECHNOLOGY AND SOCIETY (Niemann, forthcoming)

PERSISTENT GIS RESEARCH ISSUES

There are a number of issues that persist on the GIS research agenda. These are categorized in the same manner as GIS is categorized for stages of processing -- data acquistion, data management, data analysis, and data display. We continue to seek improvement in the capture and editing of geographic data. Data acquistion continue to be a source of problems and a fertile research area.

Similarly, data base management issues require continued attention, both the management of attribute data and improved spatial operators for locational data of spatial objects. As data volume increases, more attention to spatial data partitioning is needed for efficient search and retrievel. Continued refinement of spatial data models are leading to improved representation of features in terms of complex sets of spatial objects.

Improved data analysis in GIS is dependent on incorporation of or linkage to improved models of spatial analysis. "Spatial analysis is undertaken with the aid of statistical or mathematical techniques embedded in models that capture the essence of the pattern and process" (Nyerges and Dueker, 1988). Research is needed on improved spatial analysis technique <u>and</u> their linkage to GIS.

Data display persists as an area of research. Too much of the previous attention has been on using the computer to generate conventional map-like products. New forms of output are of increasing interest.

These issues persist, largely, because of the historic lack of a GIS research program. Consequently, progress has been slow, via trial and error. Vendors of GIS software, responding to client complaints, have been the primary source of GIS research and innovation. This is far from satisfactory though. The bother and cost to clients of GIS technology is substantial.

SYSTEM DESIGN ISSUES

The design of GIS is more of an art than a science. At the heart of the design is the relationship of: 1) user need for generality versus detail, 2) aggregation versus disaggreation or level of detail needed by users, and 3) the cost of computing power for increasing volumes of data. Making correct design choices in the option space is the GIS design problem. Dueker (1988) argues that applications cluster into three groups or levels: 1) planning, 2) management, and 3) engineering design, and that volume and cost increase by an order of magnitude between each level.

There is also an order of magnitude difference between each level in terms of scale and resolution. A need to scale from detailed to general identifies a major research issue -- entity generalization/aggregation relations. The need for generalization and aggregation is greater than what is offered in current systems. Consequently, we see separate systems at each level of application -- planning, management, and engineering design. We do not have single systems that can span these applications.

Another major GIS design issue relates to GIS functionality. GIS functionality consists of:

-geographically structured data,
-linkage of locational and attribute data,
-analytical map overlay.

Geographically structured data consists of point, line, and area spatial objects plus the relationships among them, i.e. topology. Locational and attribute data are stored separately in most GIS for two reasons: 1) coordinates need to be assessed rapidly for display and 2) attributes of spatial objects need to be modified rapidly. Analytical map overlay of separate map data can be used to identify spatial relationships between data layers (Nyerges and Dueker, 1988).

Research is needed to better integrate these three functionality areas. Currently, they are largely separate domains. For instance, the map overlay problem is handled by grid cell models and or geometric processing of polygon sets. The real world relationships among layers is not used.

These GIS system design issues serve to illustrate research needs. These needs are examples that drive research. Much of the progress in GIS has resulted from this type of applications-driven research.

RESEARCH APPROACHES

The above discussion helps to illustrate the breadth of GIS research issues. This section focuses on a promising approach to a narrower set of GIS research issues being pursued by this author and colleagues. New spatial data models are being developed to rapidly or dynamically generate views (or maps). We are attempting to model the processes that generate the maps, rather than modeling the map itself (Kjerne and Dueker, forthcoming). An object-oriented language approach is being employed in the modeling of processes of cadastral mapping. The determination of the global location of an object is the result of applying some measurement procedure to a set of reference objects.

Related research deals with the problem of spatial data models that retain the real-world relations that are currently lost by storage of data themes as separate layers. For instance, common boundaries are lost and come back to haunt analysts as spurious polygons due to digitizing inaccuracies. What is needed is a data model that handles multiple theme connectivity and relates complex features to primitive topological elements (Friedley, 1988).

This search for a more robust spatial data model is an on-going process. Our applications-driven research heritage has forced repeated returns to theory whenever we encounter a new problem that the old data model cannot handle. The best example was the "discovery" of topology by the U.S. Bureau of the Census and the development of GBF/DIME to solve the data quality problems inherent in the address coding guides that were used to assign street address to census geographic areas in 1970.

IN CONCLUSION

URISA is an organization concerned with the application of information technology, particularly GIS. Without the benefit of formal and basic research programs in GIS, the organizations concerned with applications of the technology have often found themselves on the research frontier. Their unsolved problems have generated complaints to vendors and long delays awaiting "enhancements". Consequently, URISA has a stake in fostering GIS research, particularly research that is applications-driven, i.e. solutions to immediate problems. It would be desirable to be one step ahead though and do a better job of anticipating problems, and thereby reduce the cost of delays while solutions are being sought and enhancements produced.

Similarly, basic research is needed in pursuing the robust spatial data model that will enable large leaps forward, than will occur from sole reliance on applications-driven research.

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