A Policy for Technology Leadership

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Abstract: *The field of GIS as we know it is threatened even as it begins to enjoy its greatest success. We are faced with the possible "death of cartography." It is increasingly possible that, in terms of dollar volume, the greatest practical use of topological databases by managers and decision-makers will by-pass graphical displays and rely on more cost-effective means of conveying spatial information.*

This article presents this issue by exploring the nature of leadership and technological innovation, with a focus on the way a professional paradigm defines and limits a field. A case study of the development of GIS illustrates these concepts. Current technological and commercial trends are then outlined suggesting that the nature of GIS may change radically by the year 2000. The problem is whether our institutions can overcome their inherent resistance to change, and respond in sync with the speed of technical progress. The question is: What should URISA and GIS practitioners do to be technological leaders in the future?

GIS (geographic information system) is now really getting established. All of us who have been part of the field for the last 20 years can recognize this success. What used to be difficult, technically and organizationally, is increasingly easy and routine. The indicators are certainly positive: the money spent on GIS has been booming, employment opportunities are up, and quality professional journals such as *URISA Journal* are being published. We can justifiably feel that our emphasis on computer mapping has been vindicated.

Yet there may be trouble ahead. We may be facing a serious, fundamental challenge to the concept of what a GIS is and what it should do. The exploding demand for digital cartographic data is increasingly being fueled by business—by managers who have little or no interest in maps per se. These customers want decision-support systems (DSS) that provide useful information fast and cheaply.

For many decision-makers, maps are an inferior way to present geographic information. It may be far more efficient to tell someone where the nearest service is, or how to get somewhere, by using a text print-out or a computerized voice message (such as used by telephone information services in the United States). These alternatives to maps may be much more cost-effective: They reduce costs by eliminating the need for the more expensive graphic terminals and for cartographically trained personnel, and they increase productivity by reducing the response time of the operators of the system.

Consider the following examples of the many significant uses of topological databases that by-pass the use of any map display:

- Major express services (such as Federal Express and UPS) are contemplating national roll-outs of services that allow their operators to tell customers where the nearest drop-box facility is. This

is done via a text message on a screen.
- Major mailing services (such as Donnelly, Metromail and R.L. Polk) not only routinely use geographic data processing in customizing their services, but in fact are investing millions of dollars in digitizing improvements to the TIGER files. Yet their operations may never see a map in practice.
- Several of the "Baby Bell" regional telephone companies are preparing improved information services that would answer questions such as, *where is the nearest drug store that is open now,* in which the operators would never see a text, much less a map.

Computer processing of geographic data may signal the "death of cartography." The map as a vehicle for encoding and transmitting information may go the way of the watch dial and hands. Admirably developed for its time and technology, the analog watch is now more decorative than efficient. Digital watches tell time more simply and directly.

In the words of the National Research Council's 1990 Report on Spatial Data Needs:

The field of digital geographic data processing . . . has grown dramatically, not only in terms of the numbers of individuals involved and the variety of applications addressed, but also in terms of the sophistication of the applications . . . It is discovering new capabilities it never realized it possessed and exploring them with both awkwardness and self-confidence. . . . Perhaps more importantly, the field is now developing a certain self-awareness, a realization that it has a future and one that can and must be directed. (p. 17)

This article is an attempt to stimulate a healthy discussion of the future of GIS. The argument consists of four major sections. First, it discusses the basic concepts of leadership and innovation, with particular reference to the important notion of the professional paradigm. It next suggests that real innovation inevitably clashes with established, successful concepts, and displaces them if the paradigm does not respond quickly. It then illustrates these ideas by a case study of the evolution of traditional cartography and mapping into geographic information systems. It concludes with suggestions of what may be necessary if we wish to maintain technological leadership in our chosen field.

Leadership, Innovation and Paradigms

Leadership

Leadership, at its core, involves two tasks:

1) **Creating a vision** of how things might be different, of a goal to be achieved; and
2) **Motivating and bringing people** to that end.

Much more is also required, of course, as Gardner (1987, 1990) and others point out, but these are the essential elements: the idea for change and its implementation.

Leadership comes in two flavors, differentiated by the degree of change. Using the phrases popularized by Burns (1978), one usually speaks of either *transactional* or *transformational* leadership. The former is the kind of direction normally provided by good managers carrying out their business as usual: They establish goals, such as higher sales or better products, and mobilize their staff to achieve them.

Transformational leadership is more interesting and challenging. It seeks to establish new pathways, new modes of operation; it tries to transform the very nature of the organization, to bring people to achieve quite different goals, by unusual means. Henry Ford, for example, may be considered a transformational leader in that he revolutionized the concept of manufacturing and distributing automobiles. Transformational leadership is truly innovative.

Innovation

Technological innovation is, in many ways, the result of leadership. It is the change achieved by deliberate thought and acts. Like leadership, it comes in two versions: incremental and radical.

Incremental change is the gradual refinement or evolution of a technology. For example, the steady improvements in propeller-driven aircraft between the World Wars represented incremental change. So does the continual development of the DIME files over the last decades. This process results from the steady focus of proven technical skills on a problem, from transactional leadership of the research and development process.

Radical change embodies some kind of technological leap. The switch from internal combustion engines to turbojets for aircraft is an example, as Constant (1973, 1980) describes in detail. So is the shift from manual to computer-driven production of maps. Radical technological change requires transformational leadership; it requires a fundamental redirection of established practice.

Paradigms

Following Kuhn (1962, 1970, 1977), we can recognize that any technological discipline is normally organized around an establishment that defines the standard direction of research or modes of design. This complex of established practice is known as a paradigm.

A technological paradigm is the community of professionals and institutions in a field. It is both the people and their extensions: the technical journals, the societies, the graduate programs, etc. As any community, it is a source of many strengths to its members.

The paradigm first of all defines *who* is a member of the field. A geographer, for instance, is not simply someone who practices what the dictionary might label as geography; professionally a geographer is a person who does what other geographers are pleased to label as such, and is likely to have gone through a specialized education in the field. By defining who is an insider, the paradigm specifies who is eligible for its support. In addition to the encouragement and promotion of one's efforts that comes from a group of like-minded colleagues, this support typically translates into significant material benefits: fellowships for students, jobs reserved for graduates, government grants directed to the profession. For example, when the U.S. National Science Foundation endowed a National Center for Geographic Information Analysis (NCGIA), it was inconceivable that this not be placed in a department of geography, even though much of the best work nationally on database management and information analysis is done in computer science and management departments.

The paradigm also defines *what* is legitimately part of the field. It does this by its norms for training programs, rules for joining professional associations, and editorial practices for its journals. These norms are often quite stringent and may even have the force of law. In the United States, for example, one may generally not even take the bar examinations if one has not been to law school. Likewise, many countries and states have legal restrictions on who is eligible to become a land surveyor. These standards are helpful to a community because they establish a degree of competence and provide legitimacy—and also of course because they limit the supply of specialists and thus enhance their rewards! The drawback is that these rules discourage change, even at the margin. An established community naturally tends to consider change "inappropriate" in that it may redistribute power and status. At MIT, for instance, the faculty constantly worries whether even minor curricular innovations (such as subjects in computer science) would be acceptable to the Accreditation Board for Engineering and Technology (ABET).

A paradigm, finally, defines *how* a profession is to be carried out. Through its education and by example, it defines the criteria for good work. These are useful because they expedite normal practice. Established methods, such as double-blind testing in the drug industry, have proven their efficiency. Clear criteria of performance focus researchers and designers on specific goals and facilitate the comparison of alternatives. In map-making, for example, a principal criterion of quality has been topographic accuracy. For cartographers a key question is: does the map give a precise bird's-eye view of the territory? Do the streets and rivers bend exactly as they should? This focus has certainly led to topographic maps of exquisite accuracy and detail. The drawback has been that this criterion proved to be a major reason for resisting the introduction of computers in mapping.

Paradigms versus Innovation

An established paradigm is the natural enemy of fundamental innovation. Radical technological change, which by definition brings in some kind of reorientation of a field, as the assembly line did in automobile manufacturing and the jet engine did in the aviation industry, forces a shift in the established paradigm. Such shifts are most uncomfortable: Previously valued skills lose importance and their practitioners are set aside in favor of new people with newly suitable skills; established institutions and companies are displaced by up-and-coming, upstart groups. Paradigms will resist fundamental innovation; the more successful the paradigm, the deeper the resistance will be.

Paradigms confront radical innovation in each of the important dimensions of *who* is legitimately involved, *what* is the nature of the task, and *how* the results are to be evaluated. Real technological change will thus be broadly challenged, and must expect a long struggle for acceptance.

Who

The real innovators are typically outsiders, mavericks in some sense. (See the case studies of Doig and Hargrove, 1988, for example.) This is not accidental. The insiders, the persons socialized in the methods and virtues of a paradigm, do not easily see beyond its limits. These experts are so well indoctrinated in their specialty that they have lost their ability to question it fundamentally; they have what is known as a "trained incapacity" for innovation. Each of us probably has some personal experience with this phenomenon. Outsiders, on the other hand, have not learned what "isn't done" or "isn't part of the discipline." They do not have a personal stake in the established processes, and are thus freer to challenge, to experiment, and to innovate.

Right from the start, the paradigm closes its eyes and ears to radical changes enunciated by the innovators. First of all, a mental block goes up. These outsiders, the reasoning goes, cannot understand the real issues because they are outside the field. Furthermore, as outsiders, they effectively have little chance for access to publishing in the journals or to using the other professional platforms of the field. The openness of a field to presentations based on some objective measure of quality is quite theoretical in practice. After some 30 years of successful professional experience, I know very well that the acceptance of research grants, articles and requests for podium time depends upon friendships and position within the professional hierarchy. The paradigm automatically tends to exclude the outsiders and the messengers of fundamental innovation.

The case of Admiral Hyman Rickover, now acknowledged as the father of the U.S. Navy's nuclear fleet, makes the point (Doig and Hargrove, 1988). He was socially and professionally an outsider because of his background and career as an engineering officer. The mainline U.S. Navy repeatedly tried to fire him as he developed nuclear reactors and radically transformed the Navy's fleet. Technical quality of itself was no guarantee of acceptance.

What

A paradigm by its nature has defined the focus of a field. These definitions often close it off from new concepts. An established discipline normally suffers from "hardening of the categories," an institutional form of trained incapacity.

Consider the way the field of cartography thinks of a map as a two-dimensional representation of topographic data, and focuses its attention on this artifact. In so doing, cartography has been very successful: A modern map using conventional, well-recognized symbols can portray up to 70 different categories of data clearly and distinctly.

Yet we must remember that maps are not ends in themselves—only decorators want them on that basis. Maps are strictly intermediate devices; however sophisticated, they are merely a means for conveying geographic information to users. There are many other ways of doing this, however. For example, think of how you tell a friend over the telephone how to get to your house, or consider how Hertz gives directions to common destinations around its car rental agencies by printing out a sequence of instructions. But the discipline of *carto*graphy, polarized around the charts it has developed into modern maps, gives short shrift to means of presenting geographic data that do not involve maps. Think of the last URISA conference you attended: What booths featured displays that did not involve maps? Despite what may be written in some of the forward-looking literature, our paradigm in practice virtually excludes innovations in GIS that are not map-oriented.

How

A paradigm also implicitly defines the criteria for evaluating technology. These reinforce the standards of what is the proper focus of a field, and serve as the technical reasons for rejecting real innovations.

The standard criteria for materials for body panels in the automobile industry, for example, have been those associated with the traditional choices: varieties of steel. The criteria thus reflect strength, resistance to buckling and several physical properties of the material itself; they do not consider other important qualities such as safety or ease of manufacturing. The traditional criteria have been biased against extruded plastics, materials which can be molded into one part to substitute for several steel parts and thus reduce the cost of fabrication. If the automobile industry stays with the traditional criteria, it denies the advantages of really innovative materials, and effectively resists their adoption.

Consider cartography again. One of its prime criteria for excellence in GIS is associated with the traditional map—specifically, complete accuracy of the representation. Contrarily, practical cartography is hardly concerned at all with speed or ease of including corrections (maps of major cities are frequently several years behind in terms of new streets, subway stops, etc.). Yet practical decision-support systems are typically most interested in speed of response, the key determinant of the labor content and thus the cost of operating any customer-inquiry system, and the key advantage of computers. Contrarily, they are less interested in bird's-eye accuracy (when directing a friend to "go straight down the expressway," it is of no importance if the road actually wiggles back and forth). By using detailed accuracy as a criterion for producing maps, cartography effectively delayed the implementation of widespread computerized mapping, possibly by decades. Map publishers such as Rand-McNally still produce their maps in the traditional way, and still do not know how to bring their maps up to date rapidly.

Consequence

The paradigm of any established technology is inherently antithetical to radical innovations, to fundamental shifts in the paradigm. The establishment will ignore radical innovators at best, cast them out and repel them otherwise. It will denigrate their ideas as inappropriate, and evaluate them by criteria ill-suited to the special advantages of the really new technology.

The irony is that, as an innovative technology gets established, it becomes less receptive to fundamental change. This presents no problem if no radical technological change is likely to emerge in the field. But this phenomenon presents an absolutely basic problem if the field is indeed about to undergo basic change. The profession must then either learn how to readjust, or face the real possibility of being displaced.

Evolution of GIS as a Case Study

The history of the introduction of computers into the mapping process illustrates the broad opposition of established paradigms to fundamental innovation. We ought to learn from the experience, so we are not condemned to repeat it.

The idea of the computerized map is now well established, even if it is still very far from being universally used. Yet this has taken over a generation of effort. Why is this? Drawing maps is a tedious, repetitive process. Conceptually, it would seem ideally suited to automation. In fact, the cartographic paradigm has resisted the transition tenaciously.

The details of the "analogue to digital revolution" in mapping are documented in the Special Issue of the *American Cartographer* devoted to the subject (Chrisman; Coppock; Dangermond and Smith; Goodchild; Petchenik; Rhind; Tomlinson; 1988). Carter (1984) explains the technical concepts of computer mapping. Since GIS shares with cartography the idea that a map is the central product, the following focuses on the who and how issues of the development.

Who

Map-makers have traditionally been professional cartographers working with skilled draftsmen and engravers. Major producers of maps, such as Rand-McNally, maintain large, long-term teams of these craftsmen.

The persons who wanted to bring computers into mapmaking did not belong to this tradition of cartographic production. They were pretty much computer programmers in practice, whatever their formal background. In the early 1960s when the move toward computer-mapping began, nothing much happened if you did not spend a lot of time with the machine. Major foci of activity, such as the Harvard Laboratory for Computer Graphics and Spatial Analysis, located in the architecture department, did not reference themselves to maps either by name or discipline. The innovators were clearly outsiders. And as outsiders they were not really welcomed into the cartographic paradigm, which, of course, is one of the reasons for the founding of URISA and why we still feel today the necessity for creating our own journal.

How

The essence of what is done in cartography is, naturally, the production of accurate maps with many layers of detailed data. Once produced, the maps are relatively static: They are printed in some physical form and updated infrequently. This objective is quite distinct from the needs most easily served by computers.

The computer and its peripherals are best at correcting and reconfiguring data. Conversely, a computer system has difficulty with precise drawings because exquisitely detailed resolution severely increases the need for computer memory, slows down production as data retrieval becomes more difficult, and pushes the capability of printers to their limits. Computers, whatever their advantages, could not originally do the job as defined by the specifications of the traditional paradigm. It is little wonder that the early enthusiasts for computer mapping met with incredulity, "facing . . . distinctly unsympathetic and disbelieving audiences" (Rhind 1988).

The criteria for evaluating maps, in conformity with the standards of cartography, were stacked against computer-based products. They weighed precision highly and flexibility hardly at all. A system which generated stick drawings (using vectors) or coarse curves (due to the pixels) was of virtually no interest, however rapid and flexible it might be. Under these circumstances, computer maps could not have much of a future with the traditional paradigm.

Computer maps have indeed been slow to enter practice. Only now, in the early 1990s after a generation of effort, does success seem to be in sight as the estimated market for GIS products climbs above $100 million a year (or more, depending on what precisely one counts in the total).

A New Paradigm

To achieve success, the computer-mappers have had to create their own GIS paradigm. They have done so around the users who particularly require up-to-date geographic data and value the flexibility and speed of computer systems, and who are not especially concerned with the beauty of the graphics. These participants in the paradigm include utilities, companies or towns that need to track the constant changes in their environment: new equipment, market districts or land use.

The GIS paradigm is well on its way to becoming firmly established. It has its societies, such as URISA, its journals and trade magazines, its academic programs and even its own National Science Foundation program, the NCGIA. At present it is still young and flexible, however, and can be responsive to fundamental technical change.

In establishing the new GIS paradigm, the innovators have not really converted the old. So far, indeed, they have barely affected it. An anecdote makes the point. Of the 53 geography departments placing explicit course announcements in the 1987 edition of *Peterson's Annual Guides* to American education, only two (!) cited geographic information systems, two more "computer and traditional mapping," and one more mentioned its "excellent computer facilities." That is, in only 10 percent of the salient academic departments had computers caught on by 1987! This is a full 30 years after I was introduced to the computerized COGO (coordinate geometry) systems as an undergraduate in engineering. Clearly there has been more than a minimal resistance to the technological innovation.

The Next Fundamental Innovation?

The boom in GIS and its prospective adoption for Spatial Decision Support Systems (SDSS) as a standard business tool (Bylinsky, 1989) is certainly most encouraging to all of us in the field. But as we think about how this is happening, there is an irony: Just as we are "winning," we may be "losing." The businesses and operations managers who are fueling the boom have a different view of how geographical databases should be used, and may be leading us to a fundamental reconceptualization of GIS to SDSS. Indeed, a GIS and a SDSS are not necessarily the same at all (Densham and Goodchild 1989; Goodchild 1989). We may be contemplating what some observers call the "death of cartography."

We must expect that the "Golden Rule" will operate as generally for GIS as it does elsewhere: "He who has the Gold, makes the Rules." The future of GIS will depend on what the big users want from it.

First, who might these users be? According to the National Research Council's recent report:

> As one business executive put it recently: "By the end of the coming decade, a large proportion of travel and transport will be regulated, guided, or assisted by derivatives of the TIGER database." (National Research Council, 1990, p. 26)

Indeed, all those interested in transportation, in dispatching deliveries and pickups, organizing service calls, directing customers to stores, and so on may be interested in using SDSS for management of their logistics. Indeed, we are already seeing companies such as Federal Express and UPS, Fortune 500 companies operating their fleets, taxicab management companies, and referral services beginning to use GIS on a significant scale (de Neufville and Vignos 1990).

Note that this community of users is made up of outsiders to the current world of GIS. They have not been trained in geography or land use; they are more likely to be managers or engineers. They do not share the same expectations or norms.

Will these users really influence the nature of GIS? The answer must definitely be yes. A mere 1 percent of their current expenses is a market of several hundred million dollars; they will certainly have a major impact. And they already are major players: Months before the TIGER files were fully released, large private corporations were investing millions of dollars to extend its geographical database for logistical and other commercial purposes. Based on current discussions, we may also expect that in a few years some private companies—acting either alone or as a consortium—will build a DIME-like file (i.e., with address ranges) from TIGER.

How might these users influence GIS? The key observation is that transportation managers want decision support systems (SDSS), want solutions to their daily problems, and have no intrinsic reason to be interested in maps which, after all, only offer limited ways to present data. A map can locate a vehicle on a map, but would be hard put to indicate its status, tell us whether it is full and indicate if it has many more stops on its route, etc. A map can locate a business, but cannot simultaneously display its record of transactions, credit rating, current orders, etc. A map fails precisely in those domains that concern a logistics manager.

Managers of transportation systems can be expected to want to use their SDSS and geographical databases the same way as their other databases. They are used to rapid responses, reports in straightforward language, and the ability to execute structured queries. They cannot be expected to wait for slower displays that use specialized symbols. Their criteria of performance for an SPSS are quite different from those for GIS.

A typical SDSS adapted to operational managers produces text listings when responding to a query on the "cartographic" data. In one application, an operator in a central office handling requests for regional deliveries of pizza will (a) get a listing of franchises near the caller, (b) see if the nearest can currently meet the request, (c) identify the delivery route and (d) check the caller's credit rating (Ferraris 1987; Wong 1987). Similarly, the GeoSpreadSheet prints out data associated with zones, adjusting instantaneously to a manager's "what if" questions about the boundaries of sales or delivery districts (Cooke 1989). The map in such systems is quite secondary, if it exists at all.

These new SDSSs contrast markedly with the prototypical current GIS, such as ARC-INFO, to take a prime example. Even in its PC version, this kind of standard GIS requires highly trained operators, responds slowly, and meshes with difficulty with other business databases. It is now used by businesses (see Bylinsky

1989), but is this map-oriented format the one that will be most suitable in the years ahead?

Consequence

It is entirely possible that the world of GIS will undergo radical innovation in the years ahead. The new SDSS paradigm would feature:

- **Who:** Different kinds of professionals, that is, managers of businesses in contrast to planners for government agencies.
- **What:** A new range of products, notable for the absence of maps and other traditional kinds of graphical displays.
- **How:** Emphasis on speed, legibility and flexibility in contrast to the cartographic standards.

The question for those of us that constitute the GIS paradigm today is whether we can adjust to accept this innovation in geographic data processing? Or whether we will disregard it, exclude it, and fight it? Will we react as the traditional cartographers did to computer mapping? Or will we learn from that experience?

A Policy for Technological Leadership

Those of us interested in establishing and maintaining technological leadership must look for ways to facilitate the process of fundamental innovation. A key difficulty is that such radical change typically faces a long, difficult struggle against established professional groups. Paradigms do not want to be shifted. What is to be done? How can we do it?

The central policy recommendation seems obvious: If the core resistance to real change is that existing paradigms impose perspectives and discourage new visions, the solution is to facilitate the development of the new views. What might this mean, specifically?

Who

The essence of a paradigm is a community of like-minded professionals. Facilitating a new paradigm means creating a cohesive group tied by common interests in the same issues. When an innovation concerns new products, a good way to start a community is by setting up users' or special interest groups (SIGs). These will inevitably form if the new SDSS vision of GIS ever comes about. The real issue is whether the existing GIS community will encourage them. I would recommend that we make a special effort in the direction of the new SDSS users, and actively seek to include them in the fold.

What

A community of practitioners is not an end in itself. It is a means to develop consensus about the nature of the innovation. Judging from the literature, the conference sessions and discussions with colleagues, I see very little awareness of SDSS and of the non-standard ways geographic databases are being used in industry. The GIS paradigm is already becoming set in its ways, and is already adopting the pattern of excluding non-standard views. If the presentation does not fit the mainstream, send it to a different journal, conference or whatever.

The second recommendation follows on the first. The GIS community, its journals and its conferences ought to make a determined effort to be on top of all the developments in the use of SDSS. I am sure we are not at present, because there are big gaps in the literature. If the existing GIS community fails in this task, it risks being overtaken as the new uses gain prominence. The March 1990 NCGIA workshop on SDSS research was certainly an excellent step in this direction. Such efforts must continue.

How

A community of practitioners is also a means to develop consensus about the standards for evaluating an innovation. In arguments about whether a radical innovation is worthwhile, it is crucial that the innovation be judged by criteria which recognize its special advantages. As everyone in the software industry knows, the development of criteria by which products are evaluated are key to acceptance.

The final policy recommendation is that the GIS community should participate in developing explicit standards of performance for SDSS, and for the new, map-less forms of using geographic databases. If we do so, we can also incorporate our own concerns. If we do not, we risk the development of criteria by the new community of producers and users, which will work to our long-term disadvantage.

Conclusion

If we want to maintain technological leadership we must act like leaders. We must not just keep abreast of developments, we must be at their forefront. This may be painful when dealing with radical change. The GIS community certainly cannot expect to be comfortable with an innovation billed as the "death of cartography." But it would seem that if we do not take this development seriously, and position ourselves to shape its future, we risk being eclipsed. So we urge our colleagues and the leaders of the GIS community to participate aggressively in the exploration of the new uses of Spatial Decision Support Systems.

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