The Cartography and Spatial Representation Traditions at Penn State

Alan M. MacEachren

It is impossible to specify with any precision when the "cartography program" originated at Penn State. From the department's start in 1945, Penn State geography has been rooted in maps and mapping. Maps have been viewed as both an integral part of the research process and the result of research, rather than simply as a summary of research findings. Recent work using spatial adaptive filtering combined with animated maps to identify and explain spatio-temporal processes in AIDS diffusion and development of a three-dimensional time series for exploring patterns of change in New York City following the introduction of the skyscraper, exemplify the cartographic analysis/visualization traditions at Penn State. The importance assigned to maps as a research contribution is also clear in the four major atlases based on original research that have been edited by faculty in the department, and the USAAtlas 2000 project recently proposed by Ron Aber.

A common thread through the years at Penn State is a concern with the representation of space, not only cartographically, but mathematically, digitally, and cognitively. Rather than building a narrow program in cartography, we have concentrated on spatial representation in its many facets. While cartography serves as a unifying or organizing mechanism for linking varied attempts to grapple with spatial representation, the bounds at Penn State between cartography, geographic information systems (GIS), remote sensing, spatial analysis, cognitive mapping, and scientific visualization are indistinct, as are the divisions among spatial representation and other research specializations represented among our faculty. An active program exists to explore fundamental issues of spatial representation encountered when the environment is captured and transformed by maps, GIS, or the human mind, and to link that derived understanding to other geographic research problems.

Background

By the 1950-51 academic year, four courses in cartography and other aspects of spatial representation were offered at Penn State. Until the mid to late 1960s, the approach was very traditional. For example, George F. Deasy, until his retirement in 1974, forbade his introductory cartography students from using such "innovations" as Zip-a-tone. In spite of being a stickler for tradition, however, Deasy commanded tremendous respect from those who worked with him.

Although Deasy's own research interests were in crop ecology, two cartography Ph.D.s were awarded during the latter part of his career here. Mark Monmonier's 1969 dissertation dealing with application of analytical cartography in crop ecology blended the expertise of his co-chairmen, Tony Williams and Deasy. Although primary stimulation for the work seems to have come from Williams' interests in analytical issues and his role in early computer mapping and statistical analysis developments on campus, Deasy's focus on cartographic analysis in his crop ecology seminar clearly influenced the way in which Monmonier's dissertation was grounded in a specific geographical problem. Deasy also chaired David Cuff's 1972 dissertation, one of the first experimental studies of color on maps. The Deasy legacy continues through the Deasy GeoGraphics Laboratory, created in 1982 by C. Gregory Knight shortly after he was appointed department head.

Starting in the early 1960s, several Penn State faculty began to take advantage of the computer's potential to represent space in innovative ways. Peter Gould (who had spent graduate student days one floor above Bill Krumbel at Northwestern) applied trend surface mapping techniques in his work on diffusion of cotton cooperatives in Tanzania. The department's position in a College of Earth and Mineral Sciences led to one of many cross-fertilizations of social and physical science with the intellectual support Gould received from John Griffiths (now professor emeritus of geology). The freshman-level human geography course that Gould taught from the 1960s through the early 1980s introduced students to computer-assisted spatial/cartographic analysis applied to problems such as location-allocation, diffusion of disease, and prediction of air-traffic flow. The first Penn State graduate research using what would now be termed analytical cartography was Rodney White's 1967 master's thesis in which multidimensional scaling was applied to the relationship between preference and migration. This project, along with Gould's own related work, also marks the beginning of a Penn State tradition in cognitive mapping.

Williams joined the department in 1967. He brought experience with SYMAP and other computer tools (encountered as a Michigan State graduate student in 1965-66) and encouraged Monmonier (then a master's student) to enroll in a SYMAP training course. SYMAP and related tools were soon introduced into Williams' statistics and economic geography courses.

In 1968 the interests in spatial analysis, analytical cartography, and the role of maps in geographic inquiry led to the initial computer-assisted map-animation work at Penn State. Gould and Keith Bassett (now at Bristol University) may have been the first to map some variable other than time onto time in an animated map. Their effort dealt with trying to depict and understand the South as a "socio-economic space." To describe this effort I can do no better than to quote Gould:

Alan M. MacEachren is an associate professor in the Department of Geography, Pennsylvania State University, 302 Walker Building, University Park, PA 16802.
We took something like 1,200 counties of the 'South,' did a bloody great factor analysis on it, and then represented each county as a point in a three-dimensional 'socio-economic space.' We blew a bubble from the center, and recorded, on one of those Bureau of Census blue line maps of counties, when a particular county was captured. The idea was to map the most 'typical' southern county, the one at the center of 'southern space,' and then move out to the least typical on the periphery of the multidimensional cloud. I can remember the university had a photographic lab on College Avenue then, with a 16mm camera held in a rigid frame over a large board stand. We produced the order in which the 1,200 counties were 'captured,' and then we mapped them, one by one, taking two or three frames, and so on. It took us several days, if I remember correctly. The whole thing was very crude and terribly amateurish, for we had no experience of animation at all, and we simply ran out of time and energy to repeat the whole performance; for example, slowing down 'interesting things,' and using other devices to draw the eye to particular dynamic developments.

This effort over 20 years ago has influenced Gould's recent work with Joe Kabel on linking analytical and animated cartographic techniques in their analysis of AIDS diffusion and my efforts with David DiBiase and several current graduate students to identify the fundamental cartographic variables in map animation.

Although computer mapping/analysis had been introduced in undergraduate and graduate courses in the mid 1960s, it was the early 1970s that brought the first major changes to the traditional "cartographic" offerings of the department. In 1974 John Sibert, one of Waldo Tobler's students, joined the department and created the first course devoted specifically to computer mapping. When he left in 1976, Williams took over the course. During the intervening years, its enrollment grew to more than 60 students from departments all over campus. Also in 1974, Abler took over instruction in the introductory cartography course and expanded it to a two-course sequence. This sequence incorporated knowledge of state-of-the-art photomechanical production techniques that Abler acquired during production of A Comparative Atlas of America's Great Cities, Twenty Metropolitan Regions (for which he was co-editor with John Adams). A move to our current facilities in 1977 brought a complete darkroom facility with a horizontal camera built through the wall as part of the "fixed" equipment of the new building.

The focus on cognitive spatial representations, begun in the 1960s, took off as a major research area within the department during the early 1970s. Roger Downs joined the department in 1970 and began a continuing tradition of research on cognitive mapping and the interaction between concrete and cognitive representations of space (i.e., cartographic and cognitive maps). In 1974 Robert Lloyd produced the department's first Ph.D. dissertation dealing with cognitive mapping. In addition to publication of the first edition of Gould and White's Mental Maps (1974), the decade resulted in Downs and Stea's seminal edited volume, Image and Environment (1973), followed by their Maps in Minds (1977). Over the years, close ties have been forged with researchers interested in spatial cognition in a variety of departments on campus, including Down's collaborative research with Lynn Liben (a developmental psychologist) on children's conception of space and maps.

The same year in which Maps in Minds was published, the department acquired its first microcomputer for cartographic work, a Tektronix 4051. The addition of Ron Eyton to the faculty in 1981 expanded the analytical-cartographic/ computer-mapping emphasis in the program to include digital image analysis and digital terrain modeling. A Raster Tech image analysis platform, linked by a high-speed communication channel to the university's mainframe, was acquired in 1984. This combination of faculty interests and suitable computer tools resulted in several master's theses in the 1980s.

Cartography and related aspects of spatial representation have been an active component of the department's graduate research since the early 1960s. Following a single undergraduate thesis published in the 1950s, graduate theses and dissertations in cartography and related topics increased from 8 percent of those completed in the 1960s to 12 percent by the 1980s.

A significant step in the evolution of cartography at Penn State was the creation in 1983 of an undergraduate option in cartography and remote sensing. By 1985 when I arrived at Penn State, this option included about 50 to 60 of our 120 to 130 undergraduate majors. This option, renamed the cartography, remote sensing, and GIS option to recognize the addition of GIS to the curriculum, retains about the same proportion of undergraduate majors.

The most dramatic change in direction for the cartography program happened in 1985. Eyton departed, there was one retirement, and one new faculty position was created, associated with the interdisciplinary Earth System Science Center that had been created in our college that year. In response to this opportunity, the department made a decision to build on its strong base in research and teaching related to spatial representation and a commitment was made to a major graduate level concentration. In that year, I was hired along with Donna Peuquet (GIS) and Robert Crane (remote sensing applied to climatology). At the same time, Lakshman Yapa began two years abroad during which he worked extensively on applications of microcomputer GIS/computer mapping to regional planning in Third World countries.

In 1986 Williams spent a year on a Fulbright in Cameroon, where he helped establish computer-mapping and data-analysis capabilities in the Department of Geography at the University of Yaounde. The following year, when an opportunity arose to add another faculty position, the department selected Deryck Holdsworth who, in addition to his primary substantive interest in historical urban geography and social theory, brought experience with a major atlas project (The Historical Atlas of Canada, Volume III) and a keen appreciation for the role of maps in geographic research (both as sources of historical information and as a way to depict views about a changing social-geographic landscape). Mapping projects are integral components of his urban, historical, and urban-historical geography courses, where students take advantage of the university's detailed Sanborn Fire Insurance Atlas collection and use microcomputer mapping.
software to examine temporal changes in Pennsylvania’s 19th and 20th century society.

In 1988 the College of Earth and Mineral Sciences presented a strong case to the university administration supporting the addition of a cartographer to expand the research and instructional support capabilities of the Deasy GeoGraphics Laboratory. The argument was successful and DiBiase joined us in January 1989 as a geography instructor and associate director of the laboratory. In addition to his official responsibilities, DiBiase is the founding editor and designer of Cartographic Perspectives, for which he has received a design award from the electronic publishing industry. His skill in map design, developed at the University of Wisconsin where he won two national map design awards, has been transferred to students in his advanced production cartography course and interns in the Deasy GeoGraphics Laboratory. Three of his students have won map design awards in the past two years.

The support from the college, indicated by the addition of DiBiase, was not an isolated incident. It is part of an overall college effort to enhance the visualization capabilities of departments across the college for whom spatial visualization tools are increasingly important (e.g., Departments of Meteorology, Geosciences, Ceramic Science, and Geography, and the interdisciplinary Earth System Science Center). This support has helped the department keep up with the equipment needs of a graduate-level concentration in spatial representation. The Deasy GeoGraphics Laboratory, which DiBiase and I direct, for example, now has a Sun SPARCstation2 dedicated to work in scientific visualization and two Macintosh fax (one with a 20-inch color monitor, the other set up as an animation workstation complete with a standard RGB monitor, analog monitor, NTSC output board, video recorder, and sound-dubbing equipment). In addition, lab facilities include two MS-DOS 386-based machines, plus five other Macintoshes. Although the lab also has two complete photographic darkrooms for cartographic work, these are now used primarily for instructional purposes. All projects for laboratory clients are now produced using microcomputer-based graphic design and mapping tools.

In addition to two Sun SPARCstations and a DEC MicroVax in the department’s research lab and an undergraduate microcomputer lab, a cooperative agreement among the department, the College of Earth and Mineral Sciences, and the Center for Academic Computing has recently led to creation of the Advanced GIS Laboratory in our building. This lab, for which geography faculty and students have priority, includes eight Sun SPARCstations and a Sun 4/4905 file server, 4GB of disk space, postscript black-and-white and color printers, and several digitizers. The lab currently has UNIRAS, ARC/INFO, GRASS, and QUILT, as well as other commercial and locally built software available for advanced courses and research projects.

Most computer equipment in the department is linked to the college computer network as well as to off-campus computing facilities, resulting in considerable flexibility for designing multi-platform projects. One recent example is a Deasy GeoGraphics Laboratory project in which results of a global climate model run on a Cray at the National Center for Atmospheric Research were downloaded to a Sun workstation and then to our Macintosh animation workstation. Information was used to create a map movie of simulated Eocene and mid-Cretaceous ocean flow patterns.

Addition of faculty and continual improvement of laboratory facilities during the second half of the 1980s led to a major expansion of the department’s course offerings. At present, six departmental faculty offer 18 courses dealing with some aspect of spatial representation. Three of these 18 courses are specifically undergraduate courses (two in cartography and one in remote sensing), 10 are offered at the 400 level (designed for senior undergraduates and beginning graduate students), with five offered at the 500 level (for graduate students only). The more formalized course work at the 400 level includes courses in behavioral geography/cognitive mapping, computing for the earth sciences, advanced production cartography, computer mapping algorithms, digital terrain modeling, spatial data structures and applications, GIS concepts and applications, GIS applications in regional planning, GIS design and evaluation, and introductory and advanced spatial analysis. The more advanced courses available only to graduate students include work on map symbolization and design theory, advanced spatial data structures and algorithms, GIS design, and digital image analysis, and a seminar in cartography.

The emphasis on formal course work at the 400 level, followed by a small number of advanced courses leading to independent research projects, reflects the tradition of flexibility that characterizes Penn State’s graduate program. Those pursuing master’s degrees here are required to complete 30 credit hours. Three of these credits are fulfilled by an introductory graduate seminar covering a range of issues about geographic research and its role in the wider academic community. Two additional seminars (one of which must be from geography) are also required, as are six thesis credits. The remaining 15 credit hours are selected by the student and her or his advisor. A non-thesis option is also available in which students prepare two research papers rather than a thesis and are required to take 35 rather than 30 hours. No additional specific requirements, however, are imposed on how these hours are selected. For the doctoral program, there are no credit-hour requirements, and no specific course requirements beyond completion of the departmental graduate seminar mentioned above. An effort is made to keep the student-to-advisor ratio low enough that individual studies can be liberally used to tailor a student’s graduate program to individual needs. Course work in other disciplines is also encouraged.

The flexibility of our graduate program, with the availability of laboratory equipment and shared faculty interests, has led to an exciting environment for research on spatial representation and its applications. Slightly more than one-quarter of our current graduate students are pursuing research on some aspect of spatial representation and several others are using spatial representation tools actively in pursuing research on topics such as development planning and climate change. In the past five years, eleven of our current complement of 16 regular and five emeritus faculty have published on some aspect of spatial represen-
in addition to two of the atlases cited above, topics covered by these publications include cartographic database quality, perspectives on directions needed in GIS and visualization research, theoretical problems in GIS design, application of computer mapping/GIS in environmental planning, satellite climatology, map animation, spatial cognition and mental maps, computer representation of spatial knowledge, visualization of cityscapes, scientific uses of visualization tools, historical and cognitive issues in travel mapping, symbol-referent relationships on maps, children’s spatial ability and its relation to map use education, and spatial knowledge acquisition from maps.

Philosophy

The cartography emphasis at Penn State is part of a larger concern with spatial representation. We view the representation of space as a fundamental geographical issue that is typified by, but not restricted to, geographers’ fascination with maps and mapping. Spatial representation is as fundamental an issue to geography as are characterization of regions, understanding of spatial processes, or the many other topics that are considered typical geographic research focuses. Spatial representation is a topic that brings together a wide-ranging set of interests to create a stimulating environment for innovative research.

From the perspective of behavioral geography, there is a concern for how cognitive representations of space influence behavior in that space and with the role of concrete representations (e.g., maps, verbal descriptions, videos, etc.) on those cognitive images. From spatial analysis, analytical cartography, and GIS come concerns with the digital representation of space—what to store, how to encode, how to access, and how to process these digital spatial representations. From remote sensing comes experience with raster representation of space, pattern recognition, and image analysis that we are now beginning to realize might be critical in dealing with other patterns and data acquired in other ways. From cartography comes a long-standing concern with how maps communicate and the growing realization that maps are about more than communication. From science as a whole comes a concern for processing the vast amounts of data that we can now collect and the belief that human vision-cognition is the most powerful tool now at our disposal to grapple with this flood of information. From the perspective of social theory comes a concern with how our representations are “read,” the faith we put in them, and the power they wield.

One result of this mix of perspectives is that the long-recognized, but perhaps little-understood process of cartographic abstraction is coming under increasing scrutiny as we try to meet the informational needs of scientists, planners, and policy makers, while addressing the concerns raised about the power of maps and other graphics and the limiting perspectives they give us on our world.

At Penn State, our basic philosophy is to help students experience the breadth of viewpoints, methods, and techniques associated with spatial representation, and to come away from our program with enhanced critical thinking capabilities combined with the skills necessary to put those abilities to use on significant problems in spatial representation. We assume that technology will continue to change drastically and, therefore, developing abilities to deal with problems critically and adapt to a changing environment are more important to career success (whether in academics, government, or the private sector) than is training in particular software or on particular hardware platforms. Students are not directed down a narrow experimental, numerical, philosophical, or applied path. Course work introduces students to experimental methods in cartography and spatial cognition, to data-processing techniques in GIS and analytical cartography, to the latest map design and production tools, and to philosophical perspectives concerning cartography, geography, and science at large. From this base, students are encouraged to develop their own viewpoints and to pursue research that they find exciting. As at Kansas, where I did my own graduate work, individual/seminar interaction is emphasized as a mechanism to extend from the basic course framework to individualized research topics.

Integration with Geography

As mentioned previously, spatial representation, and with it cartography, is firmly integrated into geography at Penn State. At the undergraduate level, although we offer an option in cartography, remote sensing, and GIS, the degree obtained is a geography degree with a common core of nine courses in human geography, physical geography, human-environment interactions, spatial analysis, and cartography required for all majors. At the graduate level, geography in the title of the degree is taken seriously. Although students are free to do research on topics of their choice, at both the master’s and the doctoral level, breadth of knowledge in geography as a whole is also expected.

Although individual research projects of faculty and graduate students can be narrow in focus (e.g., application of color bivariate mapping methods to selection of soils for lining landfills, the identifiability of pictorial symbols for travel maps, choice of viewing regard for three-dimensional depictions of New York City’s business district, etc.), the overall thrust of our program is to integrate research in spatial representation with other fundamental geographical issues in areas such as climate change, disease diffusion, or historical migration streams.

Future

Lacking a crystal ball, I hesitate to predict the future. Our department is a dynamic one that adapts to exciting challenges. Links between the Department of Geography and the Earth System Science Center, for example, are likely to lead to increased collaboration among faculty and graduate students interested in spatial representation (cartography, GIS, and scientific visualization) and those interested in simulating global and regional scale human-environment interactions. In the short run (three to five years), I expect the following recent developments to continue:

Map Animation

We are currently considering both technical questions such as how to link map animations to models, and conceptual
questions concerning the kinds of symbol-referent relationships that are suitable for dynamic maps. In this category of research, several of us (DiBiase, MacEachren, doctoral candidate John Krygier, and master's students Catherine Reeves and Alan Brenner) are currently developing an animation dealing with predictions about climate change and the impact of that change on agriculture in Mexico. The information we are working with is derived from a research project undertaken by Diana Liverman and her graduate students. One component of this work is the development of a semiologic representation system that incorporates both sound and time. A second component is the development of techniques for depiction of uncertainty in model results (in terms of attributes and the spatial and temporal precision depicted). This and previous work on depicting diffusion of AIDS, and a simulation of a Paleo-climate model, has opened the door to a variety of collaborative efforts that may result in new representation methods, pedagogic tools, and data exploration aids.

Visualization
A related area of development involves understanding how people (e.g., scientists, students, etc.) interact with visualization tools. One research topic in this general area that will be pursued is the potential of interactive computer visualization tools for assisting spatial scientists and policy makers to develop creative approaches to problems they are investigating. Another research project that is just under way is an experiment with visualization-animation tools that help students understand complex spatio-temporal processes depicted by simulation models. As we work out the technical and conceptual questions mentioned above for animation, we also need to consider how these new forms of spatial representation are processed cognitively.

Data Structure and Quality
For any work in scientific visualization or numerical analysis of spatial phenomena, particularly at the global scale being studied by researchers in our Earth System Science Center, representation systems for storing spatial information in digital form are critical. Among the issues occupying recent attention of the faculty and graduate students at Penn State is data-base quality, data structures that allow efficient storage and retrieval of spatial data, the development of a spatial query language, design of GIS user interfaces for access of spatial data, and problems of depicting the quality of spatial data bases and maps produced from them. Some of my own work has been involved with ways to measure and predict spatial data-base quality and the impact it will have on cartographic representations of those data bases. In addition, Williams recently renewed his interest in data-base quality indicators that are embedded in census data bases. While on sabbatical in the Netherlands in 1989-90, he compared U.S. and European policies for dealing with data-base error and the results of these policies in both spatial and aspatial uses of the data.

Beyond data quality, fundamental questions of representation schemes for geographic data are being addressed by Peuquet and her students. The goal of this research is a flexible representation scheme that is inextricably linked with the processes of spatial analysis and modeling of geographic phenomena for which geographic data bases are built. A critical issue being investigated by John Kelmelis (one of Peuquet's doctoral students) involves how temporal information is to be integrated into spatial data bases. Temporal data can involve simultaneous variation of both location and time including such complex operations as one object moving "through" another. Characteristics of spatio/temporal relationships have been derived and future goals include definition of a formal spatial language that can be used to describe spatio-temporal processes, while still incorporating the context-dependencies and inexactness that are often inherent. A strong conceptual link exists between this research thrust and my own work with DiBiase and the students cited previously on the fundamental temporal operators that must be added to our tool kit of graphic primitives as we move from a world of static to dynamic maps.

Spatial Knowledge Acquisition from Maps
Peuquet and her students' work on a conceptual framework for representing space-time relations draws on both geometric and perceptual/cognitive theory. An additional area in which issues of perception and spatial cognition are being addressed at Penn State is in the study of wayfinding and the role of concrete spatial representations, in various forms, as wayfinding aids. My own recent research on the applicability of environmental learning theories to spatial knowledge acquisition from maps suggests several possibilities for the use of sequential information presentation systems that might facilitate the acquisition of wayfinding information by the visually impaired. In addition, several Penn State master's theses have addressed either the process of wayfinding or the impact of symbolization choices on travel maps for wayfinding success.

Design
As technology changes, we are faced with many new options for symbolization and design. Both DiBiase and Holdsworth devote considerable attention to development and application of innovative design solutions to take advantage of this new technology. DiBiase, for example, has recently been experimenting with a new method for depicting bivariate data on black-and-white isarithmic maps and on a technique for schematic terrain shading. This latter method is designed to be implemented with microcomputer graphic design tools by any cartographer with a basic knowledge of terrain, and at the same time to be "lean" in terms of disk space required. With the assistance of one of my graduate students, Matt Tharp, Holdsworth is investigating combinations of three-dimensional perspective and color that allow portrayal of a cityscape that is being "transformed and/or restructured" and in the process produces images that can be seen from many "angles" in both a literal and figurative sense.

Maps as Social Constructs
A final topic that is now actively discussed and will form the basis of at least one Ph.D. dissertation in the next year,
is the overall role of spatial representation in geography, in science, and in society as a whole. Questions concerning alternative, complementary, and competing functions for maps beyond their traditional role in spatial representation; issues related to ethics in cartography and GIS and the power of each; people and organizational issues related to the adoption of automated tools for decision making and shifts in decision-making power that these new tools might bring; and our role as scholars in transforming and restructuring the space we study will continually influence the work of those dealing with "how to" questions. Maps restructure space. Perhaps, as some have argued, cartographers have concealed this fact with accuracy specifications, concerns for map distortion, and four decades of searching for the "optimal map." Restructuring is what gives maps their power. It can convey how an event, technological innovation, migration stream, or land-use change plays out (or might play out) and in doing so can depict topics such as the uneven "contours" of development of capital as easily as it can depict the development plans of a multinational corporation. As we make use of innovative technology for representing space, we need to be increasingly aware that all spatial representations, whether cognitive, digital, mathematical, or cartographic, are representations, and with representation comes a subjective choice of perspective.

It is difficult, if not impossible, to predict the role of spatial representations of any type a decade hence. Maps will clearly continue their role as navigation and measurement tools. What might change is our view of concrete spatial representations in the form of visible maps or digital data bases as tools for problem solving, education, policy formation, etc. Our collective goal at Penn State is to advance the understanding of spatial representation in all its forms while at the same time remaining sensitive to changing societal and scientific viewpoints on the validity of visual/cartographic tools for exploring and communicating about space.

ACKNOWLEDGMENT

I would like to thank Ron Abler, David DiBiase, Deryck Holdsworth, Peter Gould, Roger Downs, Rod Erickson, Greg Knight, Mark Monmonier, Tony Williams, and Wilbur Zelinsky for their comments and suggestions on this essay.