WHAT IS GIS DOING IN THE ACADEMY? GEO-SPATIAL TECHNOLOGIES IN HIGHER EDUCATION

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BRIEF BIOSKETCH

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INTRODUCTION

A massive adoption of geo-spatial technologies has occurred in universities and colleges worldwide over the past four decades. My first academic encounter with GIS – or automated cartography as it would have been called then – occurred at Harvard in the spring of 1967, when I spent two weeks at a workshop learning the wonders of SYMAP, the state of the geo-spatial art at the time. To current generations of students, the vast majority of whom were unborn at the time, the idea of making a map by overprinting up to four characters at a resolution of 1/10 by 1/6 inch (2.54mm by 4.23mm) seems totally absurd, especially given that the results are only meaningful if one views them from at least 3m away. It is hard now to imagine the excitement over the first pen plotters, which arrived in the late 1960s, and then the first high-resolution raster printers, and the first color displays of maps on computer screens in the late 1970s.

My own reactions in 1967 were decidedly mixed. Cartography was largely outside the academic mainstream, and if a department offered a course in cartography at all it was likely to be taught by an untenured lecturer or technician. It wasn't until 1972, when my first PhD Chip Ross moved to Ottawa to work for Environment Canada, became interested in the potential of the Canada Geographic Information System (CGIS), and started to involve me in his work, that I began to appreciate the magnitude and challenge of some of the technical problems that arise when one tries to do something as conceptually simple as putting maps into a computer. The people behind the development of CGIS in the 1960s – Roger Tomlinson and several very creative IBM staff – had invented and built solutions to many of the most interesting problems, including the first map scanner, the first implementation of the quadtree (the so-called Morton Matrix), and the first arc-node database structure.

By 1975 I had become sufficiently interested to start a course with Ross Newkirk. The course outline and lecture notes make interesting reading from almost thirty years on. Students were expected to program, though only in BASIC, and to code such primitive operations as finding the intersection between two lines, and determining whether a point lies inside or outside a polygon. There was no commercial, off-the-shelf (COTS) software, though a series of packages (SYMAP and its various successors) were available from Harvard, and until the late 1980s many of my course labs were based on code I had written myself (David Douglas once wrote about this as the "hardball" era of GIS, and the later use of COTS in classes as the "softball" era).

Today, of course, GIS (in what follows I use GIS as a convenient shorthand for the complex of geo-spatial technologies) is pervasive in higher education. Every campus has some degree of investment, in courses, staff, programs, or research centers. The lead is often taken by a geography or surveying department, but since geography and surveying are both relatively small and uncommon disciplines, at least in the U.S., there are many other models of academic GIS innovation, including the multidisciplinary service center, and leadership by civil engineering, or one of the geosciences, or even the social sciences. On the other hand, it is by no means obvious why this should be – after all, other IT applications such as word processing or presentation software are widely used in higher education but hardly the focus of courses or programs. Why is there such interest, and where is this interest likely to lead in the next few years?

WHAT DRIVES THE INTEREST?

Many forces impinge on the academic world – funding by governments, student enrolments, job opportunities, the potential for new research discoveries, and legacies of the past, to name only the most prominent – but of all these it is probably job opportunities for graduates that has had the broadest impact on the adoption of GIS. Funding to academic units is at least in part tied to course enrolments, and at some point in their academic careers almost all students are driven to consider their own employability on graduation, and how that is linked to the courses they have taken. A GIS course or two on a resumé is perceived as a good investment.

But that in itself is probably not a sufficient explanation for interest in GIS in higher education. After all, universities typically do not teach word processing or spreadsheets – why, then, is this particular IT application taught at this relatively exalted level, in the third or fourth year of an undergraduate program? In essence, after thirty or more years of development and despite the inherent simplicity of modern user interfaces, GIS remains *hard*. It requires a level of technical expertise that is still problematic for many students, particularly those with non-technical backgrounds. Students majoring in geography, anthropology, or geology find that these disciplines now offer GIS, and perhaps even require GIS for their majors. While many aspects of GIS are being successfully demonstrated in high-school and even middle- and elementary-school classrooms, the kind of expertise that is needed in the job market is probably obtainable only at the college and university level. That is not to say that GIS could not be redesigned to be much simpler, and the central concepts of GIS are certainly understandable at a much earlier age. But for now GIS remains mired in complex conventions and awkward user interface design.

GIS as a potential path to employment is driven by the widespread adoption of GIS in numerous industries. But a second factor driving GIS in the academy is its potential as a tool to support research. Any research field linked to the surface of the Earth, including geography, the geosciences, archaeology, and many others, has to some degree accepted GIS as an essential tool. GIS is first and foremost a research *engine*, a toolbox on the researcher's desk that is capable of doing things that the researcher perceives as too tedious, too difficult, too time-consuming, or too inaccurate if done by hand. GIS in this sense follows in the footsteps of other tools that researchers now consider absolutely essential to advances in science: the microscope, the telescope, the calculator, and of course the computer.

This adoption is far from complete or universal, however. Large areas of the social sciences and humanities have been impacted in the past two decades by what have been termed the *science wars*, conflicts over the potential of science to solve human problems and to lead to advances in understanding. These trends have impacted GIS in those disciplines, including geography, history, anthropology, and sociology, where both camps are present in substantial numbers. On the one hand, proponents of GIS argue that the tool is indispensable for handling, analyzing, and interpreting geographic information. On the other, proponents of critical social theory argue that all knowledge is constructed by humans with diverse hidden agendas, that the concepts of truth and objectivity that underpin science are therefore inherently unattainable, that technologies such as GIS merely reinforce the dominance of the powerful, and that societies are simply beyond the reach of scientific reasoning. Some lively debates have occurred in this confrontation, and it is true to say that both sides are now more understanding of the views of the other.

A third factor driving GIS in the academy is both more fundamental and more far-sighted than both of these. Advances in GIS have relied on a variety of discoveries and inventions, in the form of algorithms, database designs, indexing schemes, methods of analysis, visualization techniques, *etc.* By the 1990s it was becoming apparent that these amounted to something close to a discipline – a science of GIS – and that progress would be much faster if the researchers working on these problems communicated amongst themselves through conferences, journals, and all of the other mechanisms used by scientific communities. Various names were proposed for this new science, including geomatics, geoinformatics, geographic information science, and geographic information engineering, though for convenience I will use GIScience.

GIScience has been interpreted in various ways. It is the science behind the systems, the body of scientific knowledge that is implemented by the systems, and that must advance if the systems are to advance. It is the research field that will determine the future of the technology, by making the inventions and discoveries that will enable the technology to improve. It is also the set of fundamental questions that arise when the technology is used – questions of scale, accuracy, interpretation, and understanding. From the perspective of an educator, it is the set of principles that will outlive today's version of the technology, and thus the set of take-home messages that will prepare today's student for a career with GIS.

GIScience has also been interpreted in a quite different way, as the use of GIS in a scientific context, and subject to the norms of science. For example, it is common practice in science to report experiments to a level of detail that will allow such experiments to be replicated by someone else. This clearly imposes certain requirements on GIS documentation, if a researcher is to be able to repeat an experiment using a different GIS, and to obtain the same results. Calculations of such properties as slope would have to be documented in detail, because there are many possible ways of calculating slope from a digital elevation model. Another norm in science is that results should be reported to a level of precision that reflects their accuracy – for example, coordinates obtained using a GPS that are accurate to no better than 10m should not be reported to three decimal places. Another is that terms should be defined in universally accepted ways, rather than in ways devised by and unique to each GIS software developer.

The emergence of GIScience has brought fundamental changes to the way GIS is perceived in the academy. As long as GIS was regarded as a tool, however pervasive and useful, then its instructors and proponents would rank as second-class citizens, as technicians and tutors rather than as researchers and educators. By making GIS a subject of research and intellectual inquiry in its own right, GIScience becomes the equal of other *substantive* disciplines, a body of knowledge that is potentially as important as any other in the academy. The University Consortium for Geographic Information Science (http://www.ucgis.org), a group formed by a number of U.S. research universities in the mid 1990s, has grown to over 70 institutional members, and has done remarkable work in identifying the basic research agenda of GIScience, its applications, and the fundamental principles that need to be taught in any GIScience program.

Finally, it would be a mistake to ignore another traditional role of the academy, that of reflection. The growth of GIS since its beginnings in the 1960s is remarkable for both its magnitude and its consistency. But the technology has implications that extend well beyond the scope of a GIS project. GIS raises questions of privacy, when high-resolution imagery is capable of peering into every backyard, and when the locations of cellphones, rental cars, and users of credit cards can be tracked to better than 10m positional accuracy. It raises questions of accuracy, when results are presented to levels of precision that bear no relationship to the inherent uncertainties of the inputs. The academy has always played the role of the dispassionate observer, interpreter, and archivist of society, and also to some degree the commentator on society's future. What kind of society is being created by GIS, and what will be the nature of tomorrow's GIS-enabled workplaces and battlefields?

WHERE IS IT GOING?

Just as Thomas Watson famously speculated that the world market for computers might amount to five systems, so no-one in the 1960s could have imagined that today there would be tens of thousands of GIS installations worldwide, or that millions would make daily use of the simple GIS services offered by such sites as MapQuest or in-car navigation systems. Every technological innovation in GIS has led to a new spurt of growth, whether it be the pen plotter, or COTS software, or object-oriented databases, or the Web. The growth of GIS has continued at such a steady rate because the rate of technological innovation has also been steady – if the latter dried up, then growth in GIS would rapidly come to a halt. We are already seeing the end of the adoption process in some areas – in my own department, for example, enrolment in the introductory GIS courses peaked in 2002 and has held steady since then. But interest is still growing in GIS in many areas of human activity. There is still room for massive adoption of GIS in local communities, in business, in health-care management, in insurance, and in any other area where a geo-spatial perspective can lead to better decisions and more effective use of resources.

If technology is the driver for growth, then future growth will depend on a constant supply of new technologies. It is not hard to see what form some of these will take. The vast majority of GIS applications are still dominated by the metaphor of the map – the notion that a GIS is a computer that contains maps and images of the Earth’s surface, and that GIS applications consist of computerized processing of these maps and images. We have scarcely begun to exploit the applications that are enabled by alternative notions, for example by geocoded transactions. These are records of events that are identified by their locations in space and time, and they fall outside the conceptual box of the map metaphor because they are not *mappable*, or easily expressed in the form of a two-dimensional picture of the Earth’s surface from above. Moreover, the process of data production is similarly dominated by the map metaphor, and most geo-spatial data comes in the form of maps and images.

For example, suppose it were possible to perform continuous analysis of geocoded and time-stamped transactions, such as instances of disease, or the locations and velocities of vehicles. Such analysis is already common as a means of detecting credit card fraud, but could be used to provide early warning of outbreaks of infectious disease or traffic accidents. What if GIS could be taken into the field, and used anywhere in real-time to manage emergencies, perform field research, or conduct surveys? Such mobility is already possible in limited form with PDAs, but will be much more powerful when implemented in the next generation of wearable computing devices. What if networks of cheap, ground-based sensors could be deployed in advance of the moving front of a wild-fire, to provide rapid detection of the front’s position? There are good reasons to believe that such devices will be available in the near future for a few pennies a unit, comparable to the RFID transponders already being deployed by major retailers.

A new generation of GIS-based methods of analysis and visualization is just beginning to emerge from the GIScience research community to take advantage of these new data sources, and to provide new kinds of scientific knowledge. New methods are being devised to analyze vehicle tracks, to determine patterns of behavior and gain better understanding of the origins of traffic congestion. New methods are being deployed to explore vast resources of geo-spatial data, to detect patterns and anomalies that exist in both space and time. In many ways the GIScience community finds itself at a comparable stage to that of the statistics community of the 1970s: poised to take advantge of the tremendous power of new technologies and new sources of data, and to go well beyond the limitations of current GIS.

As Michael Wegener once remarked, “Everything that happens, happens somewhere in space and time”. Analysis of the largely static patterns found in maps and images served the GIS community well for much of the past four decades, and led to a host of new insights and ideas. But patterns show only how the world *looks*, and the future of humanity depends far more on understanding how the world *works*. GIS has been roundly criticized in the past for its lack of attention to time, and many factors are to blame. Data on change through time are comparatively hard to come by, and GIS software has not been built for the rapid iterations needed in dynamic simulation. But GIS is in many ways ideally suited as a vehicle for examining dynamic processes, for playing *what-if* scenarios about alternative futures, and for simulating the effects of human activity on the planet. If the next generation of GIS software is the one that finally gets serious about handling time, then we can look forward to many more years of increasing growth.

FIGURES

1. Picture of me, needs no caption

2. Picture of a group of students doing GIS, needs no caption

3. In this visualization of vehicle movements in Lexington, Kentucky, USA, each line represents one track, and the vertical dimension represents time (image courtesy of Mei-Po Kwan).

4. Screenshot from GeoDa, a package designed for the detection of pattern and anomalies in geo-spatial data (software and documentation available from http://www.csiss.org; image courtesy of Luc Anselin).