GIS Education Today: From GI Science to GI Engineering

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Abstract: *Discussions about geographic information system (GIS) education should include content as well as methodology and technology. Currently, the trend has moved from "Big GIS," as built and used by large organizations, to "Small GI" (geographic information) enterprises that sell small pieces of information to individuals. GIS education needs to adapt to this trend by extending its content to include legal and the business aspects of geographic data. A GIS education model based on the three pillars of "Geo," "Info," and "Business" is proposed. It is further argued that education curricula move from a GI science perspective to a GI engineering approach to satisfy industrial demands for the required skills of graduates.*

Introduction

It is critical that educational programs and teaching methods be adapted to the current climate: The methods must use the best technology to help students learn, and the content must cover what graduates need to know. There is extensive debate on the best use of modern technology for education at all levels - for example, various methods from Virtual Field Trips (EUGISES 2000) to distance learning using the Web (Johnson 2000) were discussed during the recent 2nd European GIS Education Seminar in Budapest. Discussion of technology must not distract from the primary concern in education: What should students learn?

Discussion about the content of geographic information system (GIS) education is not new. Efforts include the development of the National Center for Geographic Information and Analysis core curriculum (Kemp 1990), a Delphi study to identify the expected knowledge and skills for GIS managers (Kemp et al. 1993), and a dialogue between potential employers from industry and major user organizations (Timpf 1998). Similar debates have been held in other countries. Based on these discussions, a standard curriculum content has evolved that is covered in most recognized textbooks on GIS such as DeMers (1999), Bernhardsen (1999), Burrough and McDonnell (1998), and Worboys (1995).

The growth of standard GIS applications is slowly approaching saturation; convincing state agencies of the need for new GIS installations is coming up against empty state funds and a general trend toward lean governments. However, interest in using GIS commercial applications is rapidly gaining steam. This new use of commercial GI (geographic information) is - as most efforts in the "new technology sector" - limited by the number of well-educated and competent professionals available.

The main argument here is that the commercial use of GIS has a different quality than the traditional uses that we have seen up to this time. We will contrast the traditional "Big GIS" with the new commercial "Small GI'" and discuss the knowledge and skills of the professionals who will make this new trend a reality.

The Change in the GIS Field: From "Big GIS" to "Small GI"

In the past, GIS was mostly built for and used by large organizations that needed spatial information on a regular basis to make decisions. These organizations collected data, managed them in their own databases, and produced reports and maps for various internal uses. The cost-benefit analysis is notoriously difficult within a single organization; it is difficult to assess the extent that a service contributes. The planning of systems was usually influenced more by internal politics than by deep analyses of requirements or business re-engineering (Hammer 1990). Numerous examples demonstrate that the systems are beneficial to the organization, but often not for the reasons for which they were originally designed. A cost-benefit analysis may typically show benefits in the form of a reduced workforce, but actual implementation later demonstrates that the major benefits are, for example, in better and faster services to the customers.

We want to contrast such systems built for public utilities, towns, and regions for planning purposes, highway departments, etc., with GIS established by service providers who build a GIS and collect the necessary data in order to sell the information produced with the system to many users in small quantities. We call this "Small GI," because the amount of information sold in each case is very small. It is clear that the systems are not necessarily smaller or require less data collection and management than Big GISs. The difference is in the separation between the organization that operates the GIS and the user of the information produced.

Small GI is a commercial enterprise: the service provider is paid to operate the GIS. The income comes from either the users of the GI to which it is sold or by some other organization that indirectly benefits from the information. For example, location-based services, where vendors such as hotels and restaurants are willing to pay a fee to have potential users efficiently informed about their location and offerings; this is advertising in a new, more direct form.

The trend to Small GI service providers is advanced by an increased need to acquire spatial information. In the past, spatial information has been found in the environment when needed, learned over the course of a lifetime, and never paid for. In today's world of high mobility, we often find ourselves in unfamiliar environments. To plan for future activities, we need to acquire the information before actual travel. Consider, for example, a business trip using different modes of transportation, where the traveler needs to know in advance the connection times needed so as to meet for an appointment. At the same time, today's environment is transformed by new construction and transportation technology, which makes navigation more difficult. Commonsense is no longer sufficient, and counter-intuitive moves are often necessary to reach a goal.

Providing spatial information is becoming a business. To estimate the size of the market for GI, one can start with the well-known statement that 80% of all decisions are in some way spatial (Albaredes 1992); this can be combined with the observation that, in all cases, where the benefits of GI can be assessed economically (e.g., in the use of GI for routing), increases in efficiency of about 20% are observed. This suggests that up to 16% of the Gross National Product is created from GI; this is an enormous market potential that can only be realized over an extended period of time.

Small GI produces information for sale to others. The value of the information to the potential clients must be larger than the price charged (Krek and Frank 2000). The use of GI in business has been very difficult in the past. If the only distribution channel for geographic data is in the form of paper maps, a "just in time" delivery of information is not possible. Mobile phone technology creates a channel through which the required information can be transported to the user on demand and just in time. Mobile phones and Personal Digital Assistants are the first steps to computer systems that can be carried around all the time; see also an article on wearable computers produced by the Massachusetts Institute of Technology (2000).

A great number of possible application areas exist: services to inform potential clients of the locations of hotels, restaurants, cultural sites, etc., but also such specialty areas as automatic teller machines (Kottman 1998). The combination of Yellow Page information with location-based technology creates opportunities for businesses. However, services are also available for assisting persons in the process of buying or renting a new home or apartment and for users of public transportation systems. This latter case is used in the next section to give a concrete example for such an application that is technically feasible today.

Information for Users of Public Transportation Systems

The user of public transportation requires surprising amounts of information. Most users are habitual and once they have acquired this information, they use it on a daily basis and are not aware of the amount of detailed knowledge they use. However, when a person arrives in a foreign country, they are painfully aware of the information needs and the effort needed to use the public transportation system - constantly asking for help, often to no avail, because of a lack of knowledge of the local language. Similarly, handicapped persons, particularly those who are site-challenged, have a difficult time using the public transportation system because they cannot acquire the necessary information about the spatial environment through visual perception (Golledge et al. 1998). The following are needs for users of public transportation systems:

- Information must be collected to make a routing decision and to decide which transportation service is used for which part of the journey.
- Knowledge about tickets and reservations is necessary.
- Knowledge of the location of departure points and where to buy tickets and make reservations is needed.

In the world that we live in today, the friendly and usually helpful person in the ticket office is being increasingly replaced by ticket vending machines. This poses such interesting challenges to the user as instructions are often only in the local language; payment is accepted only with a restricted set of local currency tokens.

More user-friendly and therefore better systems are feasible today: Let us assume that a traveler has booked an airplane ticket and a hotel through a travel agent. After arrival at the airport and claiming his or her baggage, the traveler is informed through the Global System for Mobile (GSM) communication phone about the best route to the hotel, and all of the information necessary to carry out this trip is provided step by step. It is not effective to deliver all information ahead of time and in printed form, because this is not flexible enough. New instructions due to wrong actions of the user or changes in the environment (e.g., air planes and trains being late) are not possible; also, the memory of the traveler is not sufficient to take in all of this information, which is only useful for a single decision at a particular moment in time. Only for those trips that we undertake frequently are we willing to invest time and energy in the learning of the route; for all other trips, we navigate as well as we can without learning.

Using the GSM communication phone, the traveler can be assisted with necessary tickets - ticketing using mobile communication is working today with the Austrian Railway System (for further details in German see http://www.oebb.at/special/14.html), and it is expected that ticketing in all forms (e.g., for rail, public transportation in cities, and movie theaters) will be an interesting business aspect of future mobile communication systems.

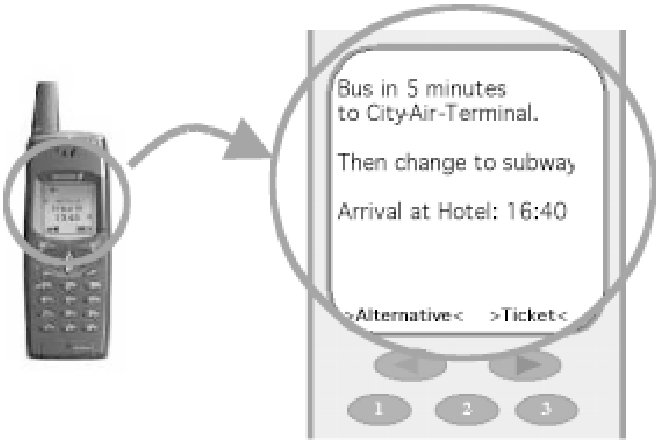

Figure 1: Information on modes of transport through wireless application protocol (WAP) service.

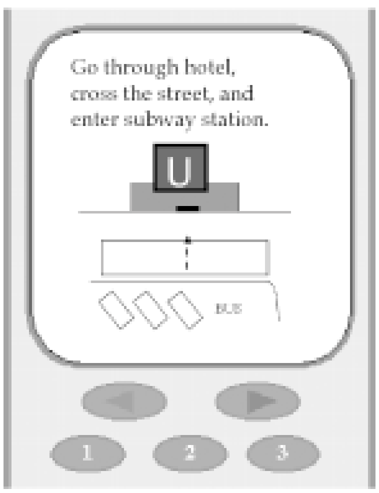

Figure 2: Information on how to go from the City-Air-Terminal to the subway station.

With information technology, it is possible to guide a user continuously on a trip and provide all information just in time and accurately for the situation of the traveler (Figures 1 and 2), even if mistakes are made and parts of the transportation systems malfunction. The traveler can be saved all efforts to collect the necessary information. For a 70-minute trip from Vienna International Airport to a hotel in the city, we observed that a total of 30 minutes was used in information collection (Pontikakis et al. 2000). The value of the information is certainly a reasonable percentage of the cost of the ticket (in this case $6.50) - say $1.00 to $2.50. Every day, approximately 16,400 visitors arrive at the airport; if only 10% use the information service, the service provider's income will be between $600,000 and $1,500,000.

Obviously, many other uses of GI are possible, all leading to the same business structure. A service provider collects data (often, most of the data are already collected or can be acquired from another GIS operator) and provides a pay-per-use service (Wenzl 2000), providing small pieces of information to users precisely when and where the information is needed. The fee must be less than the value of the information for the user. To advance such business, competent GI specialists must establish the GIS, design the user interfaces, organize the business, and be aware of legal issues such as privacy and copyright of data. In the next section, we look at the question of what knowledge and skills are needed by the professionals.

Education Needs

Graduates must be equally prepared for Big GIS and Small GI. The content taught in the past enabled graduates to establish GIS and to collect and manage data for organizations that operate their own GIS. These skills continue to be important for the service providers in the Small GI business. In addition to technical questions, the integration of data from different sources becomes more important, and limits to meaningful combinations require attention. Data quality and the manner in which it translates to quality in the GI produced becomes a central issue in a business, where clients buy information for a fee and expect quality (Goodchild and Jeansoulin 1998). Furthermore, customers may file liability claims if the information is grossly and negligently wrong (Perritt, Jr. 1996).

For such demands, a GI science curriculum is not sufficient. The curriculum content is described in this section, and the difference between a science curriculum and an engineering approach is discussed in the next section. Discussion with industry has led to a curriculum design, which is based on three pillars (Figure 3).

Geo

The "Geo" pillar should provide students with a thorough feeling of how spatial situations can be observed, measured, analyzed, and represented. In addition to the fundamental concepts of physical and human geography (primarily the concept of processes in space), it includes the understanding of spatial data collection (e.g., surveying, photogrammetry, and remote sensing). Not only is it necessary to model and analyze spatial processes, we must also communicate the results. Digital cartography, another component of the Geo pillar, deals with principles of spatial visualization.

Info

Graduates must have knowledge of modern information technology and the necessary skills to use it ("Info"). This includes knowledge of programming languages and database technology, principles of user interface design, and the organization of information systems. Furthermore, students need to learn different aspects of networking and mobile technologies. The special problems of spatial information, such as spatial indexing and computational geometry, must be known. Graduates also need to understand information science - the logical structuring of information, the assessment of data quality, and the problems of inte-

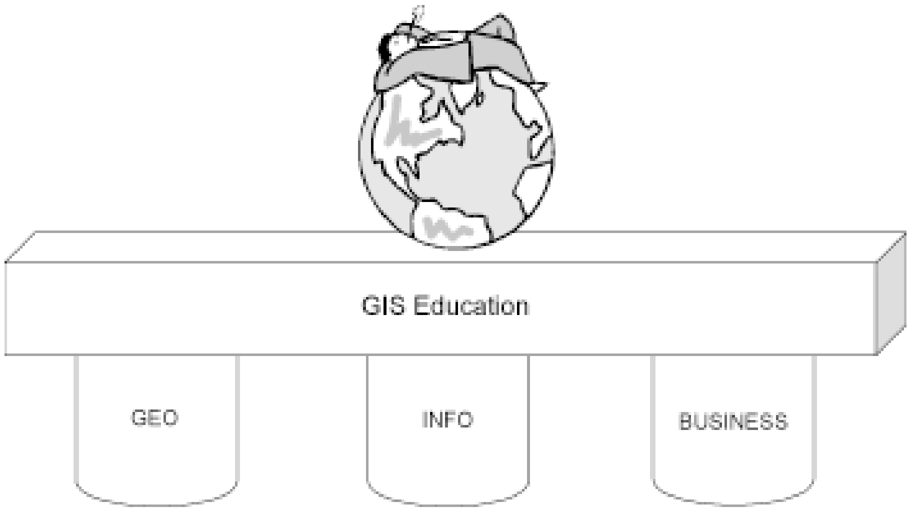

Figure 3: Education of a GI professional is based on three pillars: Geo, Info, and Business.

grating data from different sources and potentially different semantics.

Business

It is not sufficient that today's graduates know how to technically build GISs. The GI professional must understand the principles of marketing, understand the user needs, and see how they can be satisfied. Knowledge about the connection between technology and marketing is vital for the success of a Small GI enterprise. Furthermore, it is necessary to teach students the principles of e-commerce so that they know about such things as the mechanisms for collecting user fees, the organization of help desks and their costs, and marketing.

Legal aspects concerning information systems and data are another major component of the Business pillar. Nowadays, the majority of data are transmitted electronically, collected by one person, distributed by someone else, and used by yet another person. This procedure is very sensitive to legal aspects, such as privacy rights, copyright of data, or legal liability (Perritt, Jr. 1996). Graduates must not only know about the legal impacts on the use of databases and spatial datasets, but also about legal options to deal with conflicts (Onsrud and Rushton 1995).

Figure 4 shows our proposed curriculum in a generic form (details are available at http://www.cti.ac.at/fhk/geo/). It is a "German-style" 4-year program (after high school) and does not contain any general knowledge areas such as are in U.S. undergraduate programs. Students will acquire a practical degree that is comparable to a non-thesis M.S. degree and that will lead them to professional practice. We propose adding a sizable chunk of business-related teaching to the curricula (e.g., business law and marketing) because industry leaders have indicated that successful engineers are increasingly required to understand the business implications of technical solutions or to find technical solutions for business opportunities. Integration is only achievable if one person can oversee the project

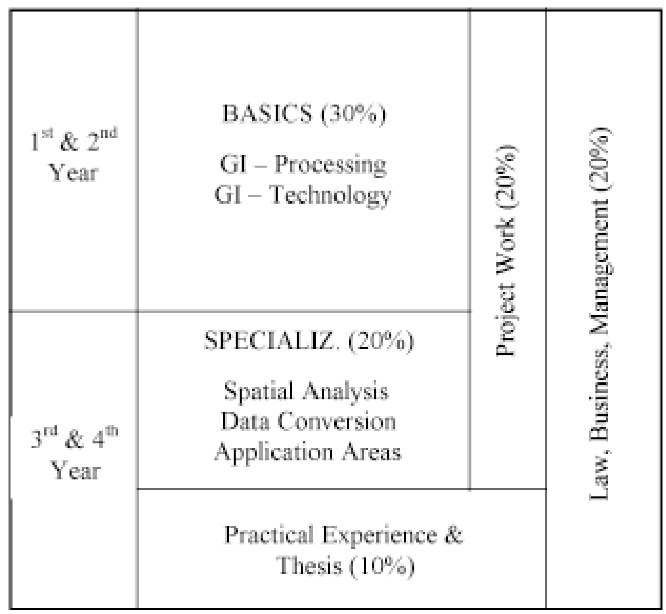

Figure 4: Generic model curriculum.

- possibly asking specialists to contribute their individual pieces.

Education is a "zero sum game." Adding content is only possible if content is reduced at a different front. Industry is clearly telling us that they want "young graduates," and that adding more years to the curriculum is not an option that should be considered! In the next section, we argue for an engineering approach and, thus, reduce the length of the study program compared to a scientifically oriented program.

Form: Engineering Instead of Science

We begin by describing our concept of engineering and science. Science is the search for knowledge (new knowledge, to be precise), and engineering is the systematic application of the results of scientific research to solve real-world problems in a predictably successful way. The outcome of a scientific experiment cannot be guaranteed. If we know for sure what the result will be, then it is not a meaningful scientific experiment. An experiment that does not confirm the hypothesis is as valid as one that does. The outcome of an engineering project must predictably work; engineers build bridges and only very seldom does a bridge fail. Failures are not acceptable and are definitely detrimental to an engineer's career! Engineering "reduces to practice" the results of scientific research. Scientific laws are combined with the results of long-term experience with useful guidelines that codify the state of the art as standards, which engineers follow.

Many GIS courses are situated in the departments of scientific geography or computer science. The primary goal of teaching in these departments, at least according to the theory, is oriented toward the student becoming a scientist. This is obviously not the goal of the majority of students, and curricula have been adapted to provide better service to the students leaving the university after having obtained a B.S. or an M.S. degree. It is suggested that this movement be pushed to a conclusion; that is, separating GI science (i.e., the efforts to advance our understanding of geoinformation in all forms) from GI engineering, which consists of science-based predictive rules on how to build working systems.

In addition to introducing a change in the style of teaching GI, great effort is required to establish a GI engineering science (i.e., the scientific efforts to establish the rules and heuristics which engineers can use to build GI systems that predictably work). The scientific results that we have produced over the past decades are substantial and cover most aspects of GI. However, they are not yet "reduced to practice" to be usable to design systems that predictably work.

Conclusions

A discussion of education must not only focus on the use of new technology in the teaching environment, but must always and primarily consider the substantive issue of what the appropriate content is. Our teaching methods must be technically adequate and follow the development of technology, but content must also track changes in the real world.

As the GIS environment changes with respect to technology, there is also change in the business organization. We have argued that, in addition to the well-known Big GIS installations, which are operated by large organizations and provide various bits of geoinformation to different parts of this organization, we are seeing a Small GI business emerge, where a service provider operates the GIS and sells small amounts of information to various users. These users buy the information as needed and with delivery at the instant they are making a spatial decision. In this article, we have demonstrated using Small GI for step-by-step guidance of users of a public transportation system on their way to their destination ("door to door"), combining spatial information regarding the location of service points, operational information such as train schedules, and the organization of business (such as ticketing).

A curriculum organized to equip students with the necessary knowledge and skills to design, develop, and manage Small GI businesses adds "Business" to the two classical pillars of GI science - namely "Geo" (e.g., geography, surveying, and cartography) and "Info" (e.g., computer science and information technology) - as an equally important part. Understanding the concepts of business from marketing (from product design and user studies) to legal issues is indispensable in this realm. Well-designed systems, where technology and business logic fit together, are only possible if a team leader can see the complete picture.

As we propose to add new content to a GI curriculum, we must also indicate where reductions are possible. The professionals working with GIS processes are closer to engineers than to scientists. They must reliably solve real-world problems and design systems that work. They cannot take a scientific approach, where only novel problems are of interest and hypotheses that cannot be confirmed are as interesting as hypotheses that experiments confirm.

This means that the results of the past decades of GI science research must be reduced to practice and simplified into useful engineering rules. Graduates must understand the rules and the scientific background that has led to them, and they must understand the limitations and the built-in assumptions. They must be GI engineers but they do not need to be GI scientists!

GI engineering is necessary in order for GI to achieve an important place in our world. A large part of the Gross National Product is produced with the help of geoinformation, and future economic growth is best achieved by making business processes more efficient. Geographic knowledge is often the key to this.

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