FROM GIS TO GEOGRAPHIC INFORMATION SCIENCE IN UNIVERSITY EDUCATION

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Key words: Geographic Information Science, spatial analysis, spatial modelling, GIS software, geocomputation, education.

INTRODUCTION

The relatively short history of GIS has passed the first steps of innovations made in universities and research institutes during the early 70´s, the step of early applications during the 80's mainly in government and military establishments as well as the latest steps applying GIS in private business during the mid 90´s (Longley et al., 2001). GIS seems now to be more or less accepted technology in society and together with the driving force of location based services (LBS) and e-commerce GIS seems to have a promising future in business.

There are also remarkable changes in the academic education and research on GIS technology, however, in publicity, these topics are not treated so often. The development of university curricula and educational contents, are of basic value, in relation to the development in practice. University education should always be showing the way, introducing the new solutions, technologies and also developing the theories. Unfortunately in many universities GIS education seems still to be using of existing, commercial software packages and learning ready-made applications. As Longley at al. state in their recent book (Longley et al., 2001) "a lot of fun and excitement of GIS comes from working on it, the education should be for life and for changing technologies and only fundamental principles tend to persist after software has been replaced by a new version".

The first popular textbooks on GIS were written during the late 80´s and early 90´s. They usually started with a definition of a Geographical Information System (GIS) – typically as follows: "A GIS is a computer-based system that provides the following four sets of capabilities to handle georeferenced data: 1) input, 2) data management, 3) manipulation and analysis and 4) output". Variations of this definition can be read in the beginning of almost every textbook on GIS published during the last ten years, starting from (the quoted) definition by Aronoff (Aronoff,1989) and continuing to the end of the second millennium. The other approach to define GIS was mainly used by the GIS engineers; according to it GIS was seen as an information system consisting of software, hardware, data, users and procedures and specialized on processing geographical data (Artimo, 1994).

In the most recent books the definition of GIS has much more flexible form and maybe not so central position. For example in the "big book on GIS" (Longley et al., 1999) introduces several definitions as well as its paper back students version (Longley et al, 2001).

Definitions vary from “the container of maps in digital form” to “a spatial decision support system” and “a tool for revealing what is otherwise invisible in geographic information”. On the other hand GIS is still very strongly seen as an information system and the technical components – network, software, hardware, data, people and procedures – make an important approach to GIS. – There seems to be clearly two main approaches – and also two main streams of education and research: the analysis and modelling oriented use of GIS and the design and implementation view on GIS systems. These two approaches are represented by different professionals among GIS science and industry; GIS use (advanced spatial analysis and modelling) is mainly represented by geographers, land use planners and landscape architects, geologists etc. and GIS development respectively by engineers, computer scientists and surveyors.

For geographers GIS has always been a tool for analysing and modelling the reality. Since the first GIS systems enabling only simple measurements on map data the potentiality of spatial analysis has always been identified. Map overlay and other graphical analysis functions as well as basic network optimization tasks are the best known analysis operations in GIS. Also more complicated models on geographical data on physical, environmental, human/social and decision making applications are well represented in GIS history. Operations research methods and statistics are the main fields from where theory and solutions were found for the models. This stream has been called as spatial analysis and spatial modelling. Unfortunately in many cases the lack of proper mathematical or statistical tools has rejected the integration of modelling and GIS data sources and GIS functionality. For example spatial statistics has developed somehow as an isolated field among GIS society. In several application areas the need for advanced spatial modelling for decision making and forecasting purposes has been identified. There are many books on spatial modelling describing application fields like urban planning, soil erosion, atmospheric models (Fotheringham et al., 2000), epidemiology, geology, hydrology, ecology (Fisher et al., 1996) and especially terrain analysis for different purposes (Wilson et al.,2000). Separate models for various purposes are not enough, but the users want to integrate the existing models to available data sources and visualization tools. Also better defined theoretical basis for spatial modelling is needed. Geography studies are not more enough for spatial modelling, more advanced methods are needed and thus also more thorough studies on mathematical and statistical modelling.

For engineers who implement GIS systems GIS has always been an information system specialized to geographical data processing. Spatial algorithms have got support from computational geometry, spatial data structures and topology have been one of the core topics, geographical data management has been an ever-lasting topic for debate all until the last relational data base management based solutions. The last big challenge for GIS engineers has been the Internet and the development of open, standardized and interoperable GIS software. The whole philosophy in GIS software has changed from the monolithic, “secret”, black-box systems with individual development tools to open and documented software products with application programming interfaces easily customized by using standard development environments like Visual Basic and Java. A GIS engineer must nowadays be very well aware and educated on software development, interoperability, distributed systems and modern software architectures and development tools. On the other hand the need for more advanced computational methods is evident. Spatial data mining, parallel processing, neural networks, artificial intelligence and for example cellular automata approaches are just examples of new techniques to manage and handle the vast amounts of spatial data and also tools for the implementation of spatial modelling.

In both streams of GIS a remarkable development has happened during the recent years and will also continue very rapidly. It is important that also universities find this challenge of developing their GIS curricula towards a full scientific educational program on Geographic Information Science.

DEVELOPMENT IN GIS ANALYSIS AND GIS SOFTWARE TECHNOLOGY & BUSINESS

From spatial analysis to spatial modelling

Authors and researchers coming from the field of quantitative and analytic geography, have always seen GIS as **a process model** of some part of the reality. Depending on the application the model is either physical, environmental, human/social or decision making.

GIS as a process model and analytic tool is typically called as **GIS or spatial analysis** in text books and university courses. Main contents of GIS analysis has been on relatively simple measurements and computations of map overlays, buffers, shortest paths and maybe solving of some location problems. Interpolation of curves ad surfaces has always been an important topic in GIS analysis. GIS analysis in this simple form is not enough, when real process models are designed more advanced **spatial modelling** approaches are needed.

Geographical process models can be simple or complex –from analogous models (topographic maps, aerial photos, digital terrain models) to conceptual models (flow charts and diagrams) and mathematical models of different kinds (statistical, optimization). Mathematical models can be deterministic, probabilistic or stochastic. Models can be static or dynamic also dealing with time component. Also models differ in their data contents, in addition to spatial data they can include varying amount of attributes (single attribute, multiattribute) as well as the temporal data. (Wegener, 2000).

If we want to outline the structure of a GIS as a process model – instead of those quite static constructions made of four parts like data collection, management, analysis and visualization - we must analyse spatial modelling applications and their conceptual and software architectural diagrams, as described for example in the description of the atmospheric model (Bernard et al., 2000) or any other application. The structure consists three main parts: the database(s), the application (model, process and numerical solution) and visualization. In a good case the database exists as well as the numerical and visual tools are available. The model and the process is the one that needs to be analysed, formalized and implemented as an application. Nowadays when GIS use is more and more in network the question is not always about one database included in the GIS system, but rather a flexible amount of available databases connected via Internet. Standard interfaces enable data retrieval from several data sources. Applications include the process model: either decision making or optimising, simulation or just computation of some measures. Applications can not be bought as ready made, in most cases you have to customize it. This application is more or less the functional core of the GIS. Tools are the methods for solving the problem – either numerical methods for solving mathematical models or visualization tools. The application is responsible on modelling the problem process, the tools can be used in solving various discrete computation tasks. - The model outlined can be compared with the three-tier-architecture of standard information system terminology: (user inteface), tools (business logic) and data server (data management) (Longley, 2001).

In order to establish a real GIS application for spatial modelling, we need, rather than a computer and some GIS software, first a lot of understanding of the process itself as well as a lot of knowledge on how to formalize the process and the problem as a model and finally we need the method to solve the problem – and this is in most cases a software tool and a computer. In using the model for simulation, optimisation or just for exploring we need data, and for this we can use the enormous geographical data bases which have been collected during the recent times and are available in many countries. Data bases as well as the implementation of the models make the important link between spatial modelling and GIS system development.

From stand alone GIS systems to distributed geoprocessing

By the GIS engineers GIS has been treated as an information system and the main focus has been of course in **the design and implementation of GIS**. Geographical data base management, spatial data structures and algorithms, spatial programming and computation, visualization applications with 3d modelling, animations and virtual realities are the main issues. This is an important sector in GIS technology and also in GIScience. However, the structure of a GIS is no more a stand alone system with individual, tailored data base and data input, analysis and output functions, but an open system where GIS application can retrieve source data from several data bases via Internet and use the power of **distributed geoprocessing** in general. The most important feature of a GIS data base or application seems to be the standard interface API. Without mentioning it is self evident that all types of location based mobile applications have created a big challenge for system developers: new equipment and software environments, new users and very high demand for openness and standardization.

Geographical data bases are often called as models, and the different forms can be found as follows: analogous logical data models, conceptual models (conceptual schemata), data base descriptions and finally the implementation of the data base. If the data base is implemented by an object-oriented way, the models not only include static spatial data and attributes but also the behaviour of the object. This seems also to be a link to implementation of spatial modelling.

The user is, of course an important part of the system. He or she might take part in data collection, in application customization, anyway, he or she is the one who is interpreting the results received from the application. In the usability of the system both spatial modelling and system development have a challenge. The users must know the methods and understand the limitations of the tools, otherwise he or she can not use the results. So, if the user is just an end user, also the tools must be either very deterministic or simple, also the user interface must be easy. When the user is a professional, also more dynamic and interactive models can be used as well as more complex theories under the tools, the user interface can be also more complex. The usability of the system is from the users side the most important feature.

Needs for development in education

The main problem today in using GIS in spatial modelling is first, the lack of GIS-integrated modelling tools and second, the users´ low level of theoretical understanding of the use of tools. On the other hand the problems still exist with data integration (standardization) and user interfaces.

The development from GIS to Geographic Information Science in university education needs development in both of the fields discussed above: spatial modelling and system development. The new scientific topics which have been introduced during the recent years like geocomputation, seem to touch both of these areas. Researchers´ interest to mathematical modelling and new computation methods is raised up, approaches like cellular automata and fuzzy modelling, new programming approaches for computation like parallel programming and genetic programming are the new approaches and technologies for spatial modelling and model implementation. The vast amount of spatial and related data bases in the network require more efficient tools for queries like spatial and visual data mining technologies. Multimedia and virtual realities bring GIS to the cyberreality. (Openshaw et al., 2000). And finally we are not allowed to forget the development in GIS industry – to be able to be successful among LBS and e-commerce providers GIS professionals must be very aware of the value and fundamentals of spatial thinking and behaviour to be able to develop and offer the right products for service markets.

RESEARCH AGENDA FOR GEOGRAPHIC INFORMATION SCIENCE

US University Consortium for Geographic Information Science (www.ucgis.org) has published in 1996 a list of 10 research challenges for Geographic Information Science. The topics are as follows:

- cognition of geographic information
- spatial data acquisition and integration
- spatial analysis in a GIS environment
- interoperability of geographic information
- distributed computing
- future of the spatial information infrastructure
- GIS and society
- uncertainty in geographic data and GIS based activities
- extensions to geographic representations
- scale.

Geographic Information Science has been defined as a field of information science specializing on the fundamental issues arising from creation, handling, storage and use of geographic information (Longley et al., 2001). We can then say that in the research of Geographic Information Science the following topics should be specially emphasized today: the spatial modelling processes, the theories of the mathematical, statistical and computational tools, the management of the geographic databases and the development of the applications. The main fields of research in GIScience thus seems to be:

- analysis and modelling of spatial processes and problems
  - analysis of applications
  - mathematical modelling
- tools for solving the formalized mathematical problems
  - basic calculus, differential equations, linear algebra and vector calculus
  - spatial statistics and probability theory including the issue of accuracy
  - spatial optimization and graph theory
- tools for computation
  - "traditional" numerical methods for computation
  - fuzzy modelling, neural networks, fractal theory, cellular automata
- advanced software development and customizing
  - geographic data management, spatial data queries and geographic data mining
  - fundamentals of interoperability: standards, interfaces, software architectures
  - advanced visualization of geographic information: animations, VR, multimedia
  - interfaces and geographic information cognition
  - advanced programming, algorithms
- automation of data collection, hardware technologies.

Modelling the problem should be the main problem also in the university education. Geographic Information Science teaching should be emphasised on the theoretical abilities in modelling. Instead starting the lectures with introducing the big three – points, lines and areas and the topology between them, like the building bricks of a GIS – we should introduce use of mathematical functions and statistics in describing the phenomena that actually is the original target of interest.

There is not much use of a huge municipal data base if no applications use the data – administrative use is not enough to make profit on the costs of data collection. Also, collecting a national topographic data base only for map production is not sensible – but in order to use the data in spatial modelling the analysis applications should be taken into account already in the data base design stage. If the database has not suitable conceptual structure the data can not be used to the applications. Anyone who is responsible on GI database projects should also be able to think the use of the data more widely than only from the administrative or specific application point of view. The big task of giving this wide understanding is of course universities.

And finally comes the business: GIS applications are not made for fun, somebody must have profit on them. We are a small group in the big economical game and if GIS professionals are not capable to offer applications required on the market, there are a lot of other professionals to do the job. LBS is one of the most acute examples.

DEVELOPING THE GIS CURRICULUM

The core question in the design of a curriculum is the goal of education. In some previous articles (Artimo, 1992) the author has outlined three educational goals which at least can be identified in teaching Geographic Information Technology. The goal of the student who learns GIS and Geoinformation Science can be:

GIS user, the person who only uses GIS systems in his or her daily work, probably in quite fixed and simple tasks, no problem situations occur in the use of GIS, no need for understanding the information system in detail

GIS developer, the person who has on overall understanding of the GIS system as an information system as well as the design and implementation process of a GIS application, he or she is able to act as a project manager but still he or she is not very deeply aware of technical solutions; GIS developer is also able to work is a spatial modelling team, he or she has the basic understanding of GIS analysis and the idea of modelling as well as the basic principles in different solutions

GIS engineer, the person who is able to design and also implement technically a GIS application, he or she is specialized in data management, spatial programming and also spatial analysis and visualization from the software tool point of view; he or she must have the last knowledge on software development technologies.

This three level structure is very much GIS development oriented and information system oriented. A fourth profile should be added, i.e. GIS analyst. A **GIS analyst** is a person who knows spatial modelling and the mathematical and computational solutions for the problems.

In addition to these very GIS oriented profiles we could add some others that are necessary in many development projects. The first is the cartographer. The **cartographer,** who also could be called as a **GIS visualizer** (but because there already exists such an traditional and good name for this professional we do not want to replace it), is specialized in geographical data visualization in different media: paper, screen, Internet terminal as well as modern mobile terminals like smart phones or personal trusted assistants (PDA). The cartographer manages the creative design including colours, symbology and typology. He or she is also familiar with the map production process including printing and other output methods. Visualization professionals are needed in every GIS. In most universities teaching geography or surveying Cartography has traditionally been one subject. Cartography and cartographers should also remain and not be "embedded" in Geographical Information Science (Virrantaus, 2001).

THE EDUCATIONAL CONTENTS FOR GIS USERS, GIS DEVELOPERS, GIS ENGINEERS AND GIS ANALYSTS

As mentioned in every education design project it is necessary to define first the educational goal. We have now defined four profiles: GIS user, GIS developer, GIS engineer and GIS analyst. In the following we try to outline the educational contents of these learning profiles.

GIS user

- main goal: to be able to use a GIS as a tool in his/her professional everyday work
- basic understanding of computers, software, data base management, data models
- basic understanding of GIS architecture, scanners and other input and output devices, as well as GPS
- fundamentals of GIScience, concepts, terminology

GIS developer

- main goal: to be able to apply GIS technologies and approaches in new environments, work as a project manager in a GIS development project
- understanding of GIS design process in principle: feasibility study, definition of a GIS, costs and benefits of a GIS, data management possibilities
- understanding of the principles of spatial modelling and spatial problem solving
- managing also the supporting subjects like geodesy and photogrammetry, positioning and remote sensing as well as visualization

GIS engineer

- main goal: to be able to develop and customize new GIS systems and applications
- understanding the entire software development project from the problem to an implemented system: feasibility study, definition, technical design, programming/customising, special questions of data base management and interoperability, testing
- design of interfaces
- knowledge management
- GIS hardware, networks and telecommunication

GIS analyst

- main goal: to be able to make spatial analysis and spatial modelling
- knowledge of mathematical modelling, simulation and numerical methods
- understanding of different application areas: physical, environmental, human/social, decision making processes
- understanding of GIS software technology
- knowledge of existing source data and the data quality.

HOW TO KEEP THE CURRICULUM UP-TO-DATE ?

As mentioned earlier in many universities still at the moment the GIS education only produces GIS users. The situation should be so that every geographer, surveyor, land use planner, landscape architect and civil engineer specialized on infrastructures or environment should be on the GIS user level.

GIS developers are required maybe most in practice, so all the major/minor students in Geoinformation Science should have these capabilities.

Both of these profiles need to be updated regularly. It has shown up that a university course of GIScience , either basic or advanced, must be updated at least every second year, and completely reorganized every fifth year. All the time the level of theoretical studies must be raised, the educational material from advanced courses must be shifted to the basic ones.

The university has to make the decision whether they go deep on GIS engineering or GIS analysis. In our university, Helsinki University of Technology, Department of Surveying , we have until this been completely specialized in GIS software engineering (Vrrantaus et al., 2000). However, the identity of Geographic Information Science being clarified, we have also found it necessary to update the educational goals and create another specialization stream, GISAnalyst.

In our educational program we already have the profile of a GIS Engineer and we teach courses which cover the educational goals listed in the previous chapter. It must, however all the time be updated. New software technologies, distributed processing, standards, programming technologies, new computational approaches, data warehouses and data mining (Virrantaus, 1999).

To create a completely new profile in education is a big project which can not be performed in one-two years. For example in creating GIS Analyst profile we first update the basic courses on this issue, so in the introductory courses we give some lectures on spatial analysis and spatial modelling. Then the next step is to add some more specialized lecture to some existing course, like we have already a course on GIS Analysis, the contents of this course is changed and at least half of the lectures will be on modelling. The next step is to make a new course on Spatial modelling and finally add problem based learning course (Virrantaus,2000) in which students have to make a spatial model for some application area. At the same time the students have to learn more mathematics, so those selecting this profile in studies must at least, in addition to basic mathematics, learn courses on mathematical modelling, optimisation, numerical methods and spatial statistics.

CONCLUSIONS

When a university department starts the development of GIS curriculum the first task is to define the level of the educational goal: do we teach only GIS users, or is our goal to make them into engineers who implement GIS systems, or is the goal even higher and we need to produce real specialists who are able to make spatial models for various purposes.

Typically a new curriculum starts with the goals of GIS users, but even then the core idea should be the understanding of spatial processes and the use of spatial data in problem solving. How deeply the students go in analysis and modelling and how individually they must be able to develop applications, is an individual decision in every university. As mentioned earlier the biggest need in practice seems to be for GIS developers, the project managers whose knowledge is quite wide.

If we look to the global future the need for both very qualified GIS engineers as well as GIS analysts is evident. The environment need to be analysed, global climate, forests and oceans need to be analysed, we need integrated models of the whole human demographic and economical as well as ecological system. - Military is always several steps in front of civil applications and we have witnessed in the near past how a war can be won by having largest amount of information and knowledge. Fortunately we can use information and knowledge also for civil and peaceful purposes. - We can save human lives and make the life more happy, healthy and successful by offering better geographic information and better spatial analysis technology for our decision makers.

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BIOGRAPHICAL NOTES

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