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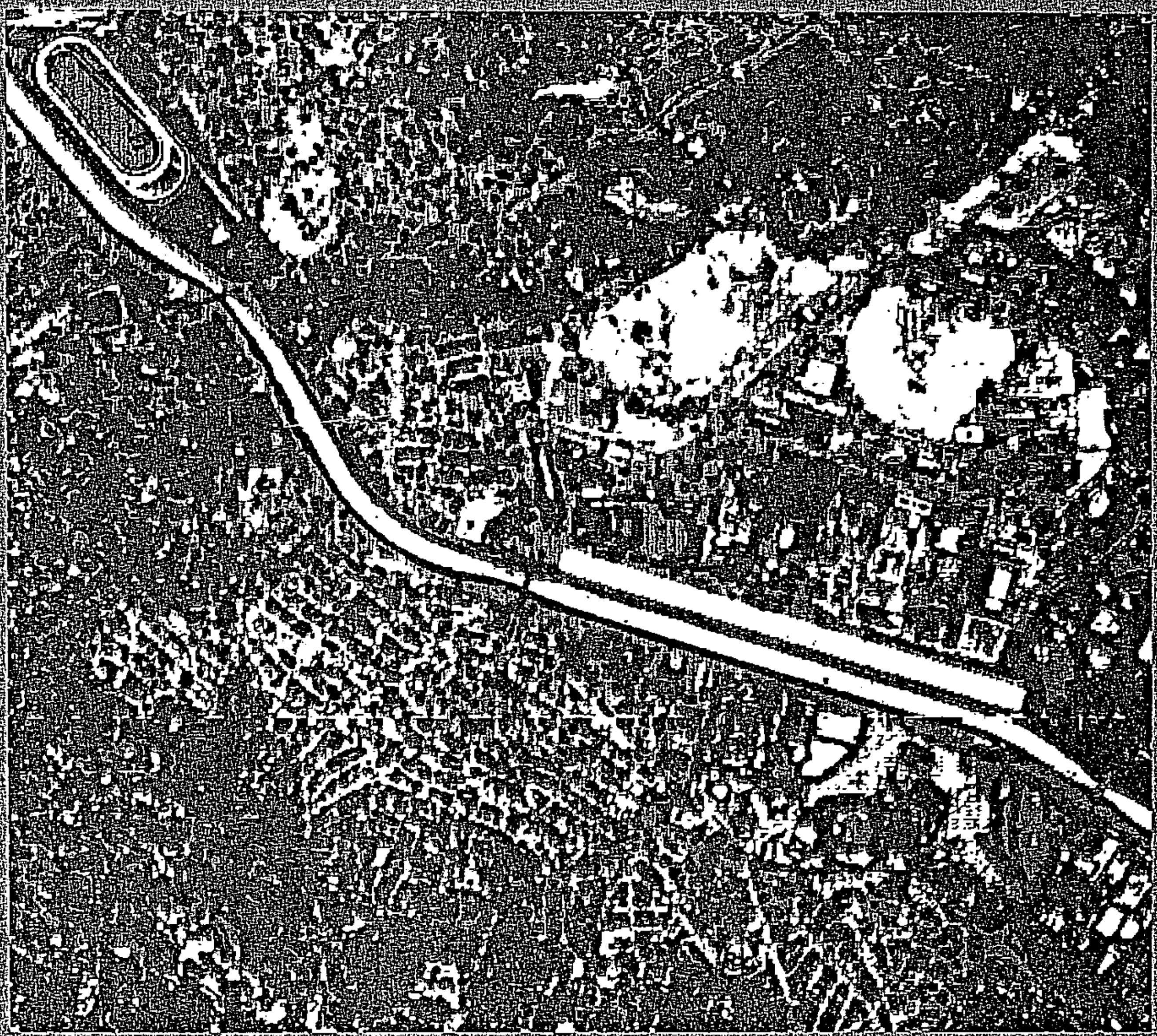

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PROSPECTIVE VIEWS OF GIS TECHNOLOGIES AND APPLICATIONS

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ABSTRACT

Information technology is a rapidly changing field and its innovative ideas and accomplishments will affect the design and use of future spatial information systems. In order to make some predictions about GIS technology within the next decade, the development of new technology must first be assessed. The analysis shows that we tend to underestimate the development of new computer hardware. On the other hand, our expectations about improved software systems are higher than what industry can deliver.

The important problems lie with the adaptation of organizations to this new technology and to identify new ways of using them early. We elaborate on some possible changes for GIS itself and draw some conclusions for its use. In this analysis we try to take into account the differences in access to technology between highly developed nations and developing countries, such as Brazil.

The real challenge is how to make most effective and efficient use of this new technology. It is particularly difficult to understand which kind of information users need. The key question is how should spatial information be presented to users so that they can best exploit it and what quality is necessary.

1. INTRODUCTION

Geographic information systems (GIS) are an innovative technology. They allow users to organize tasks in an innovative form and to solve new problems. GIS relies on the rapid development of modern technology. At the same time, GIS technology itself moves ahead.

GIS is an extremely useful technology. Its application ranges from cadastral systems to resource management. Particularly, in South America with vast areas yet to be developed, GIS may be used as an instrument to achieve rational use of land. In times when management and use of land is becoming more and more important, humans need appropriate tools to handle spatial data about their environment. GIS as is used as an instrument to assist humans in difficult decisions about land development, planing, etc. Frequently, decisions have to be made quickly and reliable and accurate information is needed. Traditional manual methods to produce and use spatial information cannot cope with the rapidly changing environment and the large amounts of data we are collecting, e.g., by remote sensing. With the advent of computerized information systems, new dimensions have been opened, such as

- the integration of information from a large variety of sources,
- access to spatial information for a multitude of users, and
- consistent updates so that data collections can be reasonably kept up-to-date.

Spatial data handling has become an area of general interest. Most national agencies run one or the other GIS to understand and guide the rapid development and changes of our society. The impact of systems, helping humans to analyze geographic data, is important for individuals as well as the whole society. Within the last decade, GIS has matured from a nice idea to an entire industry. Some indicators for this development which takes place in the market, companies, academia, and the professions:

- A great number of system installations has been reported.
- Sales figures of GIS-producing companies have risen.
- A growing number of regional, national, and international conferences focusing on GIS

applications, some on advancements and the theoretical foundation of GIS.

- An increasing number of professional journals publishing articles on spatial information systems, some even adopting the term GIS or LIS into their titles.

- A multitude of disciplines — geography, engineering, forestry, computer science — emphasizing GIS aspects.

- Several universities offering courses in GIS and a boost of students' interests in GIS.

- Finally, national GIS research centers have been established, e.g., in U.S. and in England.

Obviously, the development of GIS has reached a significant turning point. In this paper, we attempt to predict changes in GIS technology — or at least tendencies — within the next decade. After a short overview of our view of GIS and the related terminology, we assess the past development of hardware, software, data, and institutions involved in spatial data processing. Our predictions of future GIS technologies are split into quantitative and qualitative changes. Their impact on prospective users is discussed form three different perspectives: data quality, user interfaces, and cost-benefit analysis of GIS. We close with a summary of our predictions and stress the necessity to thoroughly understand the society's needs for GIS and how GIS is used.

2. GIS, LIS, AND SPATIAL INFORMATION SYSTEMS

2.1. The Notions of GIS, LIS, and Spatial Information Systems

Spatial information systems (SIS) are used here as a general term describing a system for the storage and management of spatial information. A spatial information system can contain a variety of spatial data and be used for a multitude of applications. While other (conventional) information systems, such as office information systems, deal with business data, the data represented in a spatial information system are closely tied to some location in space. The software system must then provide the appropriate methods to analyze and manipulate these spatial data.

Geographic information systems (GIS), land information systems (LIS), and automated mapping and facility management (AM/FM) can be seen as subgroups of spatial information systems suitable for specific spatial applications. LIS is most commonly associated with legal information about ownership of land, records of deeds, and multi-purpose cadastres, while AM/FM systems are tailored for mapping and managing the infrastructure of public utility companies, such as utility or phone nets. GIS is a frequently used term for small-scale systems covering a larger geographic area. They are most often used for planning and resource management, while LIS and AM/FM are primarily used for administrative tasks.

In all cases the major goal of the information system is to maintain a set of spatial information such that they can be used for decision making in different situations and by different organizations. One tries to connect systems together and link their information to gain insight into the complex spatial reality and hence improve the decisions one makes.

2.2. Components of a Spatial Information System

A spatial information system consists of four major parts. In order to predict future developments, it is beneficial to examine the development of each as well as their roles within a GIS. The four major parts of a spatial information system are:

- the institution — people, their management organization and methods — using the information system;

- data describing some part of reality and stored in the information system;

- programs to manage data and derive the desired information; and

- computer hardware to store, process, and represent data.

The order of the components is worth noting: beginning with the organization and the people who actually use the system and ending with the tools necessary to produce the desired information.

3. TECHNOLOGICAL (R)EVOLUTION

3.1. Hardware

New hardware is being produced at a high speed. The trends commonly observed and agreed-upon are: CPU speed doubles every year, memory capacity — both primary and secondary — grows at a similar pace; at the same time, the physical size of a whole system shrinks. Eight years ago, computers needed dedicated, air-conditioned computer centers with specialist staff. Nowadays, everybody can have them sitting on an office desk, and they are about 10 times faster. Currently, there are neither physical nor practical indications that the climax of this development has been reached.

The availability of new hardware technology is clearly first in the producing countries, primarily the USA and then penetrates to other markets. From the announcements of a new product to its use by a small, advanced user group more than a year may pass. It may take up to two or three years until a product penetrates the U.S. market and not much longer to reach other countries.

One should note that not everything mentioned in a trade journal is actually available. New products are often quite incompletely developed and very expensive to use — in terms of time and effort. Usually, it is beneficial to stay with the known and tested product and not to switch to new versions offering only minor improvements.

3.2. Software

Software development is expensive and time consuming. Unlike the development of new hardware, the production of complex software systems is still a major problem. Recognizing the growing gap between improvements in hardware and software during the last decade, the problems of the current software crisis have been widely discussed. Costs of software systems have dramatically grown. A study of software systems produced for the Department of Defence (DoD) in the USA revealed that only 10% of the software systems could be used as delivered, and over 50% were never used at all — even after costly revisions.

What are the reasons for such poor "performance"? Compared with hardware developments, innovative accomplishments for software engineering have been rare and most of the concepts and ideas used today are quite dated:

- The programming languages currently used in industry, such as COBOL and FORTRAN, are almost 35 years old. The popular "new" languages, such as Pascal and C, have been around for 20 years and are slowly taking over. ADA, developed as the language of the future 10 years ago, has found little popularity outside of DoD contractors.

- A similar observation with operating systems: one of the the motivation for cryptic short commands of UNIX, the "latest" standard, has been to reduce typing when slow teletypes were the common character input device.

- Innovative ideas, such as parallel programming, are not yet ready for commercial programming, despite tremendous research efforts. The hardware is available, but the necessary software tools to exploit the innovations are missing.

Compared with the progress of hardware development, today's software engineering systems are antiquated. They result ir programs which are "almost" complete and wil appear "REAL SOON NOW." When finally receive — after much delay — they will lack a usabl manual, and have many "bugs."

During demonstrations, these systems loo perfect and prospective users hope that the perform exactly the jobs they expect fro them. Impressed by hardware performance an nice pictures presented on the screens, we d not see the actual problems with using thes systems. It is generally assumed tha customizations and modifications should b simple and quick. Unfortunately, it is th opposite and we tend to be too optimisti about how easily adaptions can be made or the vendors will come out with new versior solving all the problems. They will not.

3.3. Data

The economic life cycle of hardware nowadays about 3 to 5 years and softwa systems are used for 7 to 15 years. Da managed and processed by such systems persis for a much longer time. In a GIS, data may kept unchanged for several decades. F example, think of parcels in a rural area a how often they are changed. At the same ti we observe the enormous costs for collecti spatial data and keeping the collections up date. Over the lifetime of a GIS we observe approximate 1:10:100 ratio between the cos for hardware, software, and dat respectively. In order to reduce the costs a GIS, one should concentrate on improvi data collection and maintenance — even more hardware and sometimes softwa modifications are necessary.

Our attention must be focused on t maintenance of data collection, their lor term usability. Loading data into a system the first time may initially appear to be key impediment; however, such a collect without updates will be quickly useless.

3.4. Institution

Introducing a new technology in organization requires that the organizat adapts to it. From our daily experience know that organizations are very difficult change and react very slowly to orders change. Typically, one automates a gi function of an organization with information system. The new system complet and exactly replaces the previously man task. This causes least disruption, but a makes the least use of the potential of new technology. It carries forward all constraints the previous technology imposed the organization and to which it adapted o the years. New technology should lead systems which improve the quality of the w done. Particularly, for GIS this means information to make spatial decisions sho be improved. In many cases jobs can be done which were previously impossible. All these are the desired effects and do not lead to resistance.

Problems with the introduction of innovations, and GIS is certainly an innovation, result — among other things — from

- the fear of existing personnel that they will not be able to cope with the new technology, and

- the fear that the new technology will reduce work and make positions redundant.

Both are quite unfounded, but nevertheless very important psychological problems: general experience is that GIS does not lead to a reduction in the workforce and with appropriate training efforts, current personnel continue with new job descriptions. In most cases, where a careful plan for introduction was followed, personnel are very proud of the increase in quality of their work due to the GIS system.

A second set of problems results from the fact that "information is power," even within a single organization. The introduction of information technology is clearly changing the access to information and thus reduces the perceived power of those that have access today. The larger the realm of integration of spatial data in a GIS, the more difficult to deal with. GIS are often planned to collect and combine data from different organizations and agencies, even from different government bodies (nation, state and towns), which did not cooperate in the past. There are no easy and simple solutions to these problems. We can only be extremely careful not to have the technical solution dictate organizational arrangements which require extensive organizational adaptations. The technique is a tool and is flexible enough that it should be shaped to fit the organizational needs and not the reverse.

4. CHANGES IN INFORMATION TECHNOLOGY

4.1. Quantitative Changes

The rapid increase in hardware technology causes both quantitative and qualitative changes. Certainly, we will see an increasing number of computer equipment in our offices to perform traditional work faster. At the same time, this technology boost will enable its users to develop new methods to attack old problems, but also to investigate and solve new problems. Where do we expect changes?

First, some estimations about the quantitative development within the next decade:

- CPU power will continue to grow fast. "Twice the speed of the year before" is a likely scenario to be repeated over the next couple of years.

- Prices for main memory will continue to decrease — about 50% bi-annually — and large amounts of main memory for each user will become economically feasible.

- The performance of harddisks will very slowly increase. At the same time, capacity of harddisks will grow and their price will decrease.

- The demand for communication networks, necessary for fast exchange of data, will grow, but at a slower pace than the technology rate, because political and organizational issues are involved.

In the late 90's, we may expect the following specifications for a personal GIS workstation:

- a CPU with 500 million instructions per second (MIPS),

- 500 Megabytes of main memory,

- 5 Gigabytes of storage space on harddisks and additional 50 Gigabytes on optical disk,

- a workstation screen with 2000 * 2000 pixels, and

- a communication device with 100 Megabits/second transfer rate.

Compare these figures with our current workstations: 2-5 MIPS, 4 MB main memory, a 100 MB harddisk, 600 * 900 pixels screen, and a 10Megabits/sec Ethernet adapter.

4.2. Qualitative Changes

This change is not only allowing us to do the same things faster and with less cost, but it can qualitatively affect the way we do things. It is probably the biggest challenge to understand how to use this new potential to our best advantage. It is not only the larger capacity and faster processing speed of devices that change the way computers can be used, but also their physical size and weight. The new kind of laptop computers which weigh less than 3 kg does not replace the standard personal computer, but is used during travel and in meetings. It effectively replaces the notepad and pencil which we all use to carry around—with the addition of access to personal databases, spreadsheets, etc.

One can predict that in the near future, GIS functions will be implemented on machines which can be carried into the field. How will we use them?

4.3. Rapid Change in Technology as a Problem

New equipment is placed in the market at a growing speed in order to replace "old" equipment. This increased turn-around time causes specific problems to the establishment of information systems. Fast growth is the dream of many companies and societies — until they realize the problems associated with it. Some examples:

- The economic life cycle of new equipment is short, because a new device will soon appear to replace it. The market for used computers is volatile and prices paid for used equipment are depressed by the rapid appearance of new models. Equipment bought last year for $10,000 may be worth less than $2,000 this year.
- Maintenance of a computer system has become a major economic factor. Frequently, systems must be replaced even though they are working fine, because costs for regular maintenance are higher than the costs of buying a new computer.
- Decisions to buy a new computer are difficult in the light of new models appearing on the market every 2-3 months.
- The costs of introducing a new system are high. Conversions from one system to another are often not as simple as promised and thus more expensive. Special problems are caused by the transfer of existing programs and data to the new system. Training efforts are necessary as well.

Since the pace and frequency at which new technology is being introduced is so high, it becomes increasingly difficult to make technical decisions. A GIS cannot follow all the small advances of the technology and must have some stability. Otherwise, everyone is working on keeping up with changing from one version to another, learning the changes rather than concentrating on solving the actual problems.

Thus it is often necessary to decide to continue with the established plan, even if it is not the absolutely newest technology. When planning, we should anticipate likely development and never fix hardware decisions earlier than is absolutely needed. This means in actual practice that one starts the purchase process with a functional description and an indication of some product adding "or the best available at the moment of purchase."Otherwise, one may find after a lengthy process of purchase approval, financing, and import licence buying the product which was good two or three years ago, but completely out of date today (and too expensive as well!).

5. CHALLENGE FROM A USER'S PERSPECTIVE

Having discussed the challenges introduced by the fast pace of technology innovation that influences GIS, we want to change our point of view to a user perspective and discuss what affects the use of GIS data by the end user.

A major challenge for the future is the presentation and use of spatial information. A re-thinking is necessary which effects not only the users of these systems, but in addition the technical experts designing and building them. GIS designers should spend more time on thinking how users will actually use their systems and how to get at the desired information. The focus of these considerations is the human being. A GIS engineer's task is more than finding a solution to a problem. Before GIS designers consider and select a particular technical solution, they have to understandwhich problems are to be solved.

In order to describe what we envisage, we have chosen three typical problems in this area. Clearly, there are others of similar importance with which we are less familiar. The three points will illustrate problems related to data quality, user interfaces and cost benefit studies.

5.1. Data Quality

Data is never absolutely precise and spatial data is no exception to this rule. Spatial data records spatial position with a certain error, it may be out of date, or the data collection may be incomplete and some data missing. There is a number of aspects to the quality of data which we intuitively take into account if we use data in a decision process.

A trained expert would never base a map in 1:100 upon coordinates which were derived from a 1:500,000 map. Likewise, rough sketches made in the field will not be "copied" onto a highly precise blueprint. Drawings standards communicate data quality on which users rely.

Using computers, the generation of drawings becomes much simpler so that unskilled persons may produce renderings of high visual quality. Drawings can be easily scaled. Results are always presented with the same graphical quality.

A GIS has much more potential for misuse of data, because the intuitive cues for data quality and the limitations off some data are missing. We can see this as a problem facing users who have to be advised of the data quality and the validity of data in a certain decision process. We can see it also as a liability problem of the furnisher of data who may become liable for damage due to misuse of the data for purposes it was never intended.

It will be necessary to spend some time investigating the quality of data. Humans intuitively handle precision issues, but these processes must be formalized so that they can be integrated into the software systems. We expect that processes are needed that carry forward data quality indications from the source data to the results. Methods must be found to present these assessments to the users concurrently in an effective, unobtrusive way in order to appraise users of the validity of the data.

5.2. User Interfaces

The primary purpose of a geographic information system (GIS) is to provide humans information about land-related data necessary for their decisions in application domains, such as town planning, resource management, and vehicle navigation. GIS users and their analytical capabilities are the focus of these processes, the effectiveness of which depends on how users may request spatial information and in which form it is presented to them.

Anyone who has ever tried to use a GIS will readily agree how difficult it is to "learn" a system. Training takes a long time and is expensive. Experience with non-GIS applications demonstrated that direct manipulation and visual interfaces, as popularized by the Apple Macintosh or the PC Presentation Manager, are relatively easy to learn and that the users' productivity increases at a faster pace.

Unfortunately, the transfer of these innovative ideas around the Macintosh's desktop metaphor to GIS is not straightforward, and is slower and more difficult than one expected. The problem of designing effective GIS user interfaces is not one of substituting typed commands by menus. Such replacements would even increase the difficulty of learning a system. It is rather a problem of finding out which operations a user executes and how they can be logically grouped so that a smooth interaction can be guaranteed and learning is easy.

A considerable part of the responsibility for a smooth interaction with such a system lies with the GIS user interface through which humans request and receive spatial information. As the integrating part of all applications, the user interface should hide internal details — how data are stored, composed, or decomposed, etc. — so that users are able to concentrate on their work. Its design influences how easily users may interact with a GIS and how quickly they understand the results presented. The common opinion that the interface is "something to be done after the design and the implementation has been completed" is fatal. Such user interfaces are cosmetic enhancements which barely help to make these systems "user friendly." The reverse process — first designing the user interface, followed by the implementation of the system — is rarely pursued.

Current commercial GIS have widely disregarded aspects of human-computer interaction. Prospective GIS users need extensive training prior to using a particular system, a dilemma primarily due to the GIS researchers' and designers' foci on functionality and implementation rather than usability. In the past, the design of spatial information systems has been explored in a bottom-up manner focusing on storage of and access to n-dimensional data, data structures for modeling spatial data, and the architecture of spatial databases. At the same time, little attention has been paid to the users' views of these operations. Systems evolved initially from a small set of commands to almost hundreds of features without the necessary considerations of how users learn them and interact with them.

Improvements to GIS user interfaces may be based on the results of interdisciplinary efforts in computer science and psychology which aim at reducing the gap between users and computer systems. Humans are the focus of these studies which intend to match the concepts humans use as closely as possible. Humans should be able to express their needs using concepts and forms of organization which are most natural to their tasks, in lieu of forcing them to organize their thoughts as dictated by a computer system. Principles and methods dominating the current stream of designing human interfaces and visual interaction are direct manipulation, What-You-See-Is-What-You-Get (WYSIWYG), and icons. The use of metaphors has become a central issue to organizing graphical user interfaces and presenting, explaining, and familiarizing new capabilities or functionalities by exploiting the humans' association of an object with a familiar domain.

The closer the interaction between user and GIS simulates the interactions among humans about geographic data, the more natural the use of a GIS will appear to users and the less time necessary to "learn" a GIS. Systems which do not meet user requirements will not be used and are "useless" in the literal sense. GIS user interfaces design need more than just the application of mice, windows, and menus.

The application of these principles has concentrated on popular, day-to-day business applications, such as text editors, electronic mail systems, and simple drafting systems and until recently, only few of these findings have been carried over to GIS. The dramatic difference between human interfaces for such business applications and GIS is that GIS users interact with spatial data modeling real-world phenomena which they have experienced in their lives. They expect the same — or at least very similar — behavior at the surface of a computer screen.

An additional problem that only now comes into focus is the cultural differences between countries. Most GIS software is constructed in the U.S. for the U.S. market (some come from Canada or Europe). It is not only the surface problems of translation of manuals and command languages or menus to say Portuguese or Spanish which is difficult enough to do, but the overall adaptation to deeper differences in culture. We became aware of linguistic differences in the structure of the description of spatial motion between Romance and Germanic languages and wonder if there are other differences which may affect spatial cognition and thus the way people think about space. This would obviously deeply affect the construction of interfaces if not the internal structure of a GIS.

5.3. Cost-Benefit Analysis of GIS

New systems, not only GIS, should not be introduced if we cannot show that they are cost effective in a wide sense — to use modern technology for its own sake is quite unreasonable; however, showing cost effectiveneus of an information system, and especially a GIS is difficult. It is usually possible to establish what the cost of the current system is, even if some hidden cost cannot be assessed. It is also possible to have quite accurate projections of the cost of the new system, taking into account not only the purchase of the system, but also including funds for system maintenance by the vendor, data aquisition etc. thus, finding the cost of a system is quite feasible and this may be sufficient to show that the new system is less expensive to run than the current one and will reduce overall cost. This is often sufficient, but from experienc we know, that this is not the full picture.

In a cost-benefit analysis, we have to compare the cost, which can be assessed, with the benefits a system produces. Even if the system replaces an existing manual system and could be justified on "cost reduction" alone (by constant benefits), additional benefits will be reaped. In nearly all cases known, additional and not foreseen benefits were much more important than the planned ones. A GIS was capable of producing "information products" in formats not currently possible but highly useful for decision making, the GIS is capable of providing information much closer to the actual situation, i.e., with less of a time gap, or can react much quicker to an information demand. As a result of the introduction of a GIS, the response of an agency or organization to its clients may improve greatly (sometimes with reduced cost). The difficulty is, to see and describe these opportunities for new information products a GIS creates, while the current users of the system will most likely not be aware of them. Even if appreciated, they must be assessed and a value — not a cost — associated with them. Only then we have a reasonably complete picture of the effectiveness of a new system.

6. CONCLUSIONS

GIS must be understood as complex systems that are influenced by many factors. We have looked at two groups of them, which we think are the most important ones today, namely the push for development due to the rapid advances in the technology used, and the need to better understand and adapt to the real needs for GIS. The technology used for GIS changes very rapidly. This is both a challenge and an opportunity. It avails us of new methods to deal with old problems, allows us to select better solutions which were not feasible before etc. It is a challenge to find the best way to use this technology, not only to automate current operations but also to create new tools not possible before. It is finally a major challenge to live in an environment where most aspects change rapidly and it is not always possible to go with the "latest and newest." We pointed out, that we usually underestimate the speed of hardware development — new capabilities come faster than we expect — and at the same time, are overly optimistic what software could achieve. Programs are often delivered late, with less functionality than expected, over cost and with "bugs." Most of the software engineering technology is decades old and progress is much slower than anybody wishes.

On the other hand, we stress that GIS must not be pushed only by what the technology makes possible, but by understanding what society needs and how the GIS is used. We have addressed three subtopics in this area and have found that

- GIS must appraise users of the quality of the information products such that users are not mislead. This is an issue of fairness and affects usability, and in the end, may become a major liability problem for the provider of the data.

- Interfaces to GIS must become simpler to use and easier to learn. Interfaces should be constructed from the users perspective and not reflect the internal implementation detail. Interfaces must be adaptable to other languages and it is not yet clear to what degree other cultural differences affect GIS use.

- In order to show cost effectiveness of GIS, there is usually not too much of a problem calculating the cost but it may be difficult to assess the benefits. It is clear from experience that GIS produce more benefits than is usually expected, but there are not easy ways to predict and assess them.

We see GIS as a system in a wider social and economical context. It has to provide a useful function to the organization that introduces it and to society at large. In addition, it is influenced by and must react to other changes in society.

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