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GIS IN THE YEAR 2000 *

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Abstract

As indicated by current growth rates GIS has enormous potential. It promises better information through integration of data based on spatial location and at the same time cost savings through sharing of data used by more than one organization. A review of the major technological developments expected over the next seven years indicates areas in which improvements of current GIS will become possible. Comparing the 'social pull' from the GIS user community and the 'technology push' from computer science, one can predict with some likelihood the development of GIS in the next 7 years. Areas where a technical development meets a current impediment to wide GIS use are likely to develop. Other technical improvements, even important ones, may not match a demand and thus have very limited influence. Future developments due to general advances in technology and the development based on particular GIS research and development are assessed.

At the end of this paper a number of futuristic GIS scenarios are developed and the development necessary to realize them is indicated. They stretch from use of virtual reality technology for finding public utility lines to substantial integration of datasets for environmental protection. In the conclusion, some of the impediments that will hinder GIS use even in the next millennium are discussed and the need for more basic research in geographic information to address these issues is argued.

1. Introduction

GIS were invented in the '60s when it became apparent that computers could be used to treat spatial data and produce maps. After several years of experimentation in

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the '70s, when software development and application were often in the same hands, an increasing number of GIS projects were undertaken in the '80s and a commercial GIS market became established. Today GIS is booming and new applications of the base technology are discovered every day.

This is an appropriate moment for pause, to contemplate where we are and where we are going. Understanding the major reasons for GIS growth, assessing the impediments that limit growth today and thinking of future uses of GIS is a worthwhile effort. A clearer view of the future helps to make better decisions today, but it also influences the ongoing development.

This paper attempts to predict the future, by observing user needs and technical developments. It is based on personal experience and is therefore a very partial assessment of the situation. The predictions are based on the best information available to me – but I cannot assume any guarantee, legal or otherwise, that the future will be exactly as predicted. Indeed, I hope for some surprises.

In this paper I will first discuss why the GIS is growing and list a few of the social demands that affect it. I will then argue, why, how, and to what extent we can see what the future will bring, before I assess the major effects of technology development over the coming years. In section 5 the prevalent use of GIS is described, as a backdrop for the discussion of improvements due to technical advances. Improvements due to specific GIS research and development are mentioned in section 6. Section 7 lists some scenarios for future use of GIS and leads to a discussion of remaining impediments to the use of GIS after the end of the decade. The conclusion summarizes the predicted development and argues for more basic research in GIS to overcome the remaining impediments.

2. GIS Responds to Social Demands

In order to understand the development of GIS, one must not only consider the technical development, which seems to fuel the growth of GIS, but one must also consider the 'social demand' for this particular technology. The best technology could not be sold, if it were not fulfilling a social need. There are three societal needs, that propel GIS:

- the concern for the environment,
- the increasing demand for information, and
- the need for savings in public administration.

GIS promises to fulfill all three of them.

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GIS as a technology makes the promise, that all information regarding a piece of land can be coordinated and brought together, both on a local and a global scale. Most people will be familiar with the 'layer model' of GIS, which suggests the ease of integrating information from different sources. Data that is already available can be combined spatially. In principle, such integration of data from different sources has been possible before, but now it can be done quickly and economically with computer assistance.

2.1. The Concern for the Environment

The environment is currently a major societal concern. After realizing 'The Limits of Growth' in the 70s and now the observation that human activities are on a scale with natural processes and influence climate locally and globally, society is sensitized to the environment. The influence of nearly all decisions on the environment is scrutinized. It is demanded, that all the information available are brought together and additional data collected in order to predict better the interactions of new developments with the different parts of the natural system.

Most human activities use space. It has been observed, that most decisions in public administration and also in private companies, depend on spatial information and affect space. They would benefit from GIS, because GIS has the technology to deal with spatial information. GIS is the primary method, to collect, store, manage, process and present spatial information, and should therefore become integrated in most decision processes.

2.2. Demand for More Information

In general, our society seems to demand decisions that are rational, based on facts and require the consideration of all aspects of a problem. This trend is implicitly based on the assumption that more information will lead to better decisions – an assumption that has to the best of my knowledge never been tested empirically. GIS is part of the information technology in general, which all benefits from this trend.

2.3. Economy of Public Administration

GIS promises to reduce the duplication of effort needed to collect spatial data and therefore to lead to cost savings in public administration. Data once collected can be distributed to other users. It has been observed that different parts of administration all need similar data (for example data concerning land use, buildings and occupants), and all of them collect and update the same data at great expense. GIS promises to reduce this waste of public funds, and to make public administration more effective.

All these reasons make GIS an attractive technology responding well to current societal needs. In this decade, no public administrator will be criticized for introducing a GIS. As an effective method of data collection GIS is booming and will continue to have large increases for the next years.

3. Limits to Predictions

It is difficult to make predictions but not impossible. The future can be foreseen, at least to a certain degree and for a limited period. The future will be mostly the same as the current situation – this is certainly not correct, but a good first assumption. To make a better prediction, one has to look for reasons for change. I will consider here two areas: development of the base technology, i.e. computer systems, and the major impediments to full use of GIS. This combines the effects of the 'technology push' which propels the functionality of the systems offered, with the 'social pull' that demands certain developments to make the systems more responsive to their users needs.

The development of technology for the next 7 years is relatively easy to predict. Based on the understanding of what is happening in the research labs today, one can foresee what new offers may reach the market within the next decade. It takes typically 2 to 4 years for research work to be completed, another 2 to 3 years for the development of a research result in a product and 2 to 4 years to bring a product successfully to the market. Very little will reach the market in 10 years, which is not yet studied in a research lab.

On the other hand, not everything that is subject of a research effort today will be a successful product in 10 years. Some research will not reach its goals, many results will not respond to the needs of the users, and others will not be brought to the market for commercial reasons. To predict what will not be successful is therefor much more difficult. Consideration of the user's needs and the current impediments – paired with some assessment of market forces – may help to assess likely avenues of actual development.

4. Development of Technology

One part of the forces that will shape the future of GIS is the development of computer technology. This is surveyed in this section, whereas the next sections will then assess how the opportunities provided are actually used in future GIS products and applications.

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4.1. Hardware development

Despite the fact that hardware today is only a small part of total expenses for a GIS, it is still a primary focus of discussion. Prediction of hardware development is relatively easy and the next 7 years will be mostly a continuation of the current trends. The most influential of these trends with respect to GIS were: the move from mainframe to personal computers and the reduction in size and weight, resulting in systems that one can carry around all the time.

4.1.1. General Trends

The development of hardware will continue with the speed we have observed the last 10 years. It is surprising to realize, that nearly everybody always underestimates the speed of hardware improvements: it is faster than anything we dare to expect. The speed of development itself is a cause of some problems. Administration has difficulty in coping with it. Consider for example the procurement process: the time necessary for the administrative decision making are sometimes longer than the time a product is actually on the market and occasionally by the time an agency has permission to buy a system, this specific system is not sold anymore.

There are no reasons to assume that development will slow down; no physical barriers are visible that will stop the trend within the next 10 years. In particular:

- processor speed will continue to double every two years at the same cost, making processing power essentially free of cost;
- storage capacity will increase and prices decrease, but there is no expectation of substantive improvements of the access time for large amounts of data (and the GIS data collections will grow fast enough to assure that they remain 'large' and require disk based storage);
- screens based on the current CRT technology will not improve substantively but other methods (LCD, active matrix etc.) may become viable in a few years, possibly providing screens with substantially higher resolution than the current 1000 by 1000 pixel standard.
- plotters giving high quality graphic output for large format and extremely high precision (cartography) will remain slow and expensive;
- scanners will become less expensive and high precision (few microns) will be available.

4.1.2. Every User His Own Processor

The development in the past, in particular the reduction in price for complete computer systems, has lead to a major shift in the way a computer is used: 20 years ago, a large number of users were connected to a single processor, using time sharing. Now, every user has his own, personal computer. This has revolutionized the use we make of computers and also, the number of people who can use computers. It might be true, that cost per user has remained essentially the same, but that is not relevant.

4.1.3. Computing on the Go

The major effect on GIS — and on many other fields — is the 'form factor': computers do not only become faster and cheaper, they also become much smaller. For most users, the current generation of laptop computers contain all the computing power they need in a machine the size of a large book, weighing 3 kg. Such a computer can be carried all the time and allows the user to have the 'whole office' with all the files always at the tip of the finger. Expected development will lead to lighter, faster systems, which the marketers call 'Personal Digital Assistant'. Interesting studies are underway to keep such mobile computers connected to the world wide network, so databases, printing services, electronic mail, etc. are always available.

These later two hardware developments, —first the personal computer and then 'really personal' computer that one can carry all the time, — have profound effects on how one works with a computer, and for what tasks the computer is used. I speak from personal experience, having moved from a very comfortable mainframe to workstations and personal computers, one at work, one at home and one for traveling; now I have only one machine, which I carry nearly all the time.

The rapid development of hardware, in particular processor speed, should change our focus from considering minimal requirements to achieve a task to considering what all this computing power can do for us.

4.2. Software

The development of software is much slower than that of hardware. It is — contrary to the experience with hardware — slower than one would expect. We all overestimate the speed with which advances in software are making an impact. For example the 'new' programming language C is about 20 years old, the object–oriented paradigm of software engineering at least 10, and everybody has some experience of how long it takes for the next release of a product, which is nearly finished, to arrive on his desk.

The two major developments I see are in the comprehensive use of database management systems for GIS and the use and distribution of data and services on a network.

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4.2.1. Databases

In the next 7 years, databases will become much more flexible and easier to extend for special requirements of particular applications like GIS. The existing solid experience with the implementation of current relational databases will help the emerging object–oriented DBMS to become the leading technology. They will provide the flexibility and opportunities for extensions to make them usable for GIS. Database technology offers two aspects important to GIS, namely data models to support modeling of the data from the application area, and transaction management to safeguard data during changes.

Database Management Systems force the database administrator to describe formally the data that are relevant for the application area. DBMS are primarily differentiated by the tools they provide for this modeling effort. Currently, relational databases which require the structuring of data in relational tables, are most widely used. The new object–oriented database provide a more flexible way of structuring data, which includes identified objects with the related operations. Database management systems will also include support for time related data, at least for the most fundamental models of time as they are used in administration.

Databases offer 'transaction management', i.e. comprehensive set of methods that permit the secure use of the data by several people at once. Four aspects are usually stressed:

- atomicity: every change is either completely done or not at all; the database is never affected by partial changes;
- concurrency: parallel users are isolated and their changes cannot interfere unexpectedly;
- integrity: changes must achieve a consistent state with the database or they are completely rejected; this guarantees that the database is always in a consistent state;
- durability: any change that the database accepted and confirmed will never be lost, despite technical problems.

Most GIS applications require at least these services and will greatly benefit if all the data are stored in a database which automatically provides these functions. Future DBMS may offer provisions to manage versions and tools to structure updates that take a long time (i.e. days to weeks) to complete into transactions.

4.2.2. Specialized Support Packages

Not only databases, but also other specialized functions will be provided as a commercially available package, which can be combined easily with other packages and application specific software like GIS. Primarily the object–oriented paradigm and the client–server architecture makes it possible to separate large, connected groups of functionality and package them, in such a way that they can be integrated in other programs. This is not only beneficial for software production, but allows the integration of GIS with other application packages.

Packages for data storage, graphics, user interface, communication, word processing, spreadsheets, networking, desk top publishing etc. will all provide methods for their integration in the overall work flow of an organization. The necessary base services for their interconnection are currently built into the operating systems and much more elaborate methods are to be expected (the Macintosh OS or Microsoft's new NT may serve as a current example).

4.2.3. Networking

The most important change is 'networking', i.e. connecting personal computers in a network, that reaches from the office to the world (comparable to the phone system). The ability to connect computers and to exchange data quickly and easily is technically available now, but often the software, e.g. a database program, is not capable of using this facility intelligently. It is predictable, that networks will be the regular computing environment.

Users will have access to a worldwide collection of databases, public or private. There will be access to particular servers, that provide specialized services – from high quality cartographic output to super computer performance for complex calculations. Not everything will be done on the personal machine, but somewhere in the net and it will not be relevant for the user, where.

4.2.4. Artificial Intelligence Methods

Methods from Artificial Intelligence will be increasingly used and the barrier between database and expert system will soften. The increased processing speed will allow the use of the more powerful inference methods of AI which are much slower to execute than current database queries.

In particular, logic based concepts will be integrated in the databases. They will provide 'triggers' to start certain actions if the set conditions are met, they will also manage constraints and other information that describes the base data stored (so called meta data). Artificial intelligence will also develop usable methods to deal

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4.2.5. User Interfaces

User interfaces will be mostly menu based, with much more standardization of structure and symbols, to provide a consistent interface that is easy to learn (similar to the Apple Macintosh today). Pen based interfaces are a new development that will be used in some special applications, and similarly, speech recognition will be used for some others. Most user interaction, however, will remain with keyboard and mouse or trackball.

5. Improvements in GIS due to Technical Advances

New technology becomes relevant to a GIS only if it is available within the program. For example, the fact that a computer is physically connected to the network is only valuable for a user, if the software permits its use. For networking, this is easily achieved with a program to move files between computers and the GIS can then access data from source after they have been moved to the local storage. This however is not a very effective use of a technical development.

This section starts with a discussion of current use of GIS technology and then details the technical advances that meet a current restriction of GIS software to fulfill the GIS promise.

5.1. Current Use of GIS

GIS is widely used today but often its capacity is only partially tapped. GIS is a very powerful tool for the management of spatial information and its analysis. It promises that for every task that requires spatial information, this information can be provided in exactly the right format at the right time. This is however not always the case, as GIS are often used to maintain map data or GIS are used by specialists, in both cases the effective users see only the paper maps.

The GIS is used to collect spatial data, store the data and produce cartographic output. These maps produced by the computer are then distributed to the users (or first reproduced and then distributed). The information product is a standardized output, of the which does not necessarily respond properly to the specific needs of the task a user works on. It does not contain exactly the information required – there may be some additional information that needs to be filtered out, or there may be some missing, which the user must collect and add to it. It is also produced ahead of time and not on demand, so it is not up to date. Last but not least, the representation is also standardized which sometimes makes it difficult to extract the necessary information from the map.

GIS experts use the GIS to prepare material for the decision makers dealing with particular spatial problems. They explore various alternatives, document the most important ones and put together a plan of action. This material is then provided to the decision makers, the politicians and the citizens affected. It would be much more effective, if these decision makers could access the GIS themselves, explore the alternatives they are interested in and see the rational choice by interacting with the system.

For a number of years the trend in the use of GIS has been away from mere maintenance of maps which are then distributed to the user, to the provision of information directly to the user when it is required. Users who are accustomed to their personal computer for text processing and spread sheets will demand interactive response from the GIS and will not be satisfied with regular updates of their paper maps.

5.2. General Trends

From the hardware developments discussed, we may immediately find two advances in technology that have only a limited, quantitative effect on GIS:

- processor speed will improve performance of complex operations, but will mostly be used to improve the user interface, to produce better graphical renderings and to use more sophisticated analytical tools;
- larger storage devices assure that the growing amount of data collected can be dealt with and we will even be able to keep 'old' data in the GIS to allow time related analysis.

Many minor aspects of technical development will remain irrelevant for GIS. I do not think that the RISC vs. CISC issue is relevant to the GIS, nor is the programming language used for writing the GIS program. Unfortunately this will not hinder some of the vendors to use these arguments in the debate and confuse some of the more naive buyers. I do not expect that parallel computing will have a substantive impact on practical GIS work within this decade, nor do I think that neural computing will be of importance for the practitioner.

5.3. GIS Become Fully Based on Databases

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met by the commercial DBMS then available. In most cases, at least the geometric data is stored in specially structured files.

GIS will increasingly use standard DBMS for storage of all data. In particular the new object–oriented DBMS now appearing on the market seem to be well suited to GIS requirements and simpler to integrate with an existing GIS. This will make transaction management, even in improved forms, available to GIS users. Current GIS require other methods to avoid problems due to concurrent users and to assure data against loss. High–level, vendor independent data description languages and facilities for heterogeneous, distributed databases will simplify the exchange of data between GIS from different vendors. Methods to protect confidential data eases the cooperation between different users and sharing of actual, regularly updated data.

5.4. Provisions to Connect to Data Stored in Other Databases

GIS will make network services available to their users, without resorting to the transfer of the data as files. Data that is stored and managed at other sites may be used at remote sites over the network, without the user having to understand the details of the network or the organization of the remote site. It will become possible, to connect the GIS to the data in remote databases using database and network services.

This will eventually allow organizations to provide data, which is kept up to date, for a fee over the network. Similarly, multiple organizations working for the same area may decide to share data and to assign responsibility for data maintenance to only one agency.

5.5. Integration of GIS into Work flow

The current GIS provide most functions a specialized user needs to work on a project. Their limits are felt, when the results of a study should be integrated in a report produced with a desk top publishing package, or a map should be sent away by electronic mail.

GIS will make increasing use of the existing, standardized packages for graphic layout, word processing etc. It will then become much simpler to integrate the GIS and its products into the work flow in an organization.

5.6. User Interface

The commercially available, standardized packages for user interface development will be used by the GIS software vendors to build their products. If this is done methodically and according to the rules for interface design established for these 'graphical user interface styles', then learning to use a GIS will be somewhat simplified. The generalized services integrated in future operating systems to support the work flow will be the connecting 'glue'.

6. Developments of GIS Software

Not all the developments of GIS will be due to advances in general information technology, but some will come as a result of GIS research and development proper. This concerns primary areas, where GIS has specific demands.

6.1. Analytical Functionality

GIS users need a large choice of analytical functions from spatial statistics. The current trend to integrate these into the general GIS and make them available to all users will continue and a large set of sophisticated spatial analysis tools will be available to all users. By the end of the decade there may some tools, to assist the user when selecting these analytical functions and to warn against the most obvious misuses.

6.2. Models of Space

Current GIS provide the user with vendor specific tools to model the spatial situation. These models are motivated more by implementation considerations and less by the requirements of the applications. Sometimes they are well adapted to one application area but not to others.

GIS will include support for raster and vector data and allow presentation of data in both formats concurrently. For analytical operations, the most suitable conversions will be selected to hide most aspects of data conversion between different models from the user. By the end of the decade, some standardized models for vector data may develop and have widespread use, thus simplifying the exchange of data between different systems.

6.3. Models of Time

To the best of my knowledge, no commercial GIS has explicit support to deal with temporal data. On the other hand, support for temporal data is required by a large number of applications. Planning needs the analysis of time series to understand the development of a town, archeology wants to represent location of finds and the epoch from which they date.

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7.1. Virtual Reality

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The simple models of time that DBMS will provide are designed towards administrative uses. Time in geographic data sets needs some adaptation which are currently researched. It will also be possible to document all changes applied to a dataset over time, so their justification can later be assessed.

6.4. Data Quality and Error

All data describing reality is only an approximation and contains inevitable errors; these errors are caused by

- the measurement process (precision),
- the time delay between data collection and use of the data (temporal update level),
- the classification method applied, i.e. how many classes of land use are differentiated,
- the consistency of the data collection, i.e. are the same rules always applied,
- the completeness of the data.

Data quality influences very directly the cost of data collection. An organization will therefore request the data quality necessary for its task. If the data is then shared with other agencies, other requirements may be imposed. There is the danger that data is used for tasks for which it is not suitable, because the quality is not sufficient. Of course, this is not limited to precision alone, but applies also to all other aspects, e.g. completeness or update level. For companies providing data for a fee this opens the question of exposure to liability for errors made by the user.

At the end of the decade GIS will have some (simplified) methods to manage data quality and advise the user about it.

7. Some Futuristic Scenarios

7.1. Virtual Reality Helmet

Virtual reality is combining advanced, realistic graphics to render a 'realistic' environment in 3D built into a helmet coupled with sensors to determine the position of the user and his hand gestures. It is mainly used for amusement and allows people to walk in a 'virtual reality', which they see and in which they can pick up and move objects — but which is virtual, i.e. exists only in the computer and is shown to them through the eyepieces in the helmet, but not visible to anybody else.

This technique could be used for maintenance crews of public utility companies. The foreman can don a helmet in which he sees at the same time the real world overlaid with the maps of the pipes. The ground seems to him then 'semi transparent' as he can 'see' the pipes buried. If a hole is dug and the real pipe is not where it should be, he can grab the 'virtual' pipe and move it to the place where the real pipe is – automatically updating the database.

Technically this is feasible today, it requires GPS (Global Positioning System) to sense the position of the person, virtual reality software and a wireless communication link between the helmet and the central database. The hindrances are probably more related to

- whether or not the system is physically robust and can survive in the harsh environment of maintenance crews, and
- whether or not the crew can be trained to effectively use the system.

A similar system could be used for environmental impact assessment. Decision makers, politicians and even ordinary citizen can done a similar helmet and see the current situation and the proposed changes, together, in 3D. Evidently this does not create new information, but information presented in this form becomes much more convincing, much more emotionally engaging.

7.2. Electronic Town Map

A centrally maintained town map, which is kept up–to–date and includes all information that is necessary for effective navigation by car, has many potential uses and a very large number of potential users. Such systems must be more complete than current town maps, as they require complete information about one–way streets and all limitations to turning at intersections.

Such systems are offered experimentally in some big cities. Sometimes they are specialized for emergency services – often augmented with the information about buildings etc. that are relevant for these services – to help emergency vehicles arrive more quickly at their destination. Sometimes they are sold for use in ordinary cars to assist drivers in finding a desired location – a serious problem in fast growing urban areas and of extreme value to service personnel who have to make many 'house calls' in unfamiliar locations.

Not only in big cities, but also in rural area car navigation poses a problem for all but those already familiar with the area. For example when emergency services are provided from central locations, understanding where they have to go and finding their way is a problem.

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The same data can be used to optimize the distribution of goods with trucks. Many companies have fleets of trucks, from breweries to the refuse collection service, and school buses. Optimization of routes is possible and is already cost effective today. Future GIS will provide more functionality in this area, not only to determine effective routes, but also to present this information in the format preferred by the user.

7.3. Simulation of Urban Development

GIS is the most appropriate tool for urban planning. The integration of data from different origins and the visualization of different trends and possible future states is extremely useful for planners. Current GIS lack the dynamic aspects, but that will be changed.

A GIS for urban planning will resemble a dynamic simulation system much more than today's static map oriented system. The simulation will use all information about the current situation and will also use the comparison of past and current states to deduce trends and rates of change. The planner will be able to make some key decisions and then see how the development forces urban growth, land use change within the city, traffic, etc. to change over time.

Such a simulation – albeit extremely simplified – exists already as a game: SimCity. It is a realistic simulation, based on some standard urban development theories and the methods from 'urban dynamics'. The player can determine zoning, build roads and railways and set tax rates and then see graphically, how his city develops year after year (every year takes a few seconds to calculate). It is an interesting game, educational but sufficiently realistic with an intuitive interface, to allow children of 10 understand it and learn from it. A more realistic version specific to a particular town will certainly have planners and politicians understand better the mechanism of urban development in their town.

Technically, this is feasible and the computing power, the dynamic graphical presentation and the user interface are all available in principle. The problems arise when building spatial and temporal modeling tools that are sufficiently powerful to integrate the different aspects of urban dynamics.

7.4. Integration of Data for Environmental Protection

This scenario addresses the needs of environmental protection for integration of data and visualization. Agencies dealing with environmental protection and management of natural resources are among the most important class of GIS users today. In the future, they will have access to all sorts of spatial data, collected by their agency and other agencies and some private firms, and be able to combine these data. They will be able to use not only environmental data, but link in the real estate information from tax registries, economic and social data, traffic and accident statistics etc.

This is already familiar to the technologist. All of this is possible today, except for some 'minor' problems, for instance;

- establishing the communication links between agencies in countries where the telephone companies apply absurd tariffs or other restrictions to data communication on telephone lines;
- connecting computers from different vendors that are involved;
- converting data from one database to another database; and, last but not least,
- resolving all the administrative, legal and political issues restricting sharing of data.

7.5. Workstation in the Field for Data Collection

The small portable computers with graphics screens are optimal to support data collection in the field. There is already a package on the market today for collection of 'ground truth' for remote sensing, combining a laptop computer with a Global Positioning System receiver. Thus the user is always appraised of his current position with respect to the remote sensing image and can add the 'ground truth'. The system also informs the user where to move to for the next 'ground truth' point.

The same workstation concept can be used for large scale, primary data collection as it is currently done by surveyors, e.g. when they measure property lines and other detail. Keeping good notes in the field, with all measurements properly encoded is a problem. Analyzing the notes in the office to draw the map is expensive and fixing the errors requires a trip back to the field. This process can be greatly simplified and streamlined by constructing the map in the field. It requires the combination of GPS to determine a point of origin for a local survey, an electronic total station to measure bearings and distances, all linked to a CAD package to construct the map.

7.6. Public Access to GIS

Many have demanded that the general citizenry gets access to all the data that flows into a public decision. The laws in the U.S. but also in some other countries provide for 'free access to government records' (provided there are no more compelling reasons to keep them confidential). It is observed that citizen without access to data cannot effectively control government activities.

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Providing environmental and other spatial data at locations where citizens have easy access to them, e.g. public libraries, seems to solve this fundamental problem in today's democracies. Besides the technical problems of providing the data – which is at least in principle solvable – there is the problem of making the system so easy to use that ordinary citizens can use it effectively. Some experience exists with 'public access' interfaces to some small database (e.g. time tables for trains) but nothing comparable to a complex system like a GIS.

8. Remaining Impediments to Widespread Use of GIS

Not all the impediments to widespread use of GIS will be remedied by the end of the decade. There are a number of problems that will impede the widespread use of GIS by the end of the decade. Some of the impediments are technical, some of them are related to the organization of the data, some to the structuring of the data and to the understanding of the meaning of the data, and others are related to the integration of GIS in existing organizations. The most substantive restriction however will be the complexity of the user interface, that restricts GIS users to a small group of specialists, fortunate enough to spend several months in training to master the 'art'.

It also seems very unlikely, from today's perspective, that computer hardware will limit the uses of GIS, and I think that most of the requirements of a GIS will be met by the base software, from networking to database and user interface tools.

8.1. Integration of Data

GIS are supposed to facilitate the integration of data from different sources. This is technically easy, and arbitrary combination of input data can be computed. Even if the input data was all meaningful and valid, the result can be utter nonsense. Firstly, inevitable errors in the input data may combine to make the result meaningless. Secondly, the specific meaning of the data does not warrant the type of conclusion to be made.

An effective and comprehensive management of data quality will still be a problem. As stated before, data quality is more comprehensive than just the precision of the spatial data. Data quality often determines if a data set can be used for a specific task or not, because error would be too large or too numerous. Very little is understood how traditional systems manage data quality in the work flow, but it is evident, that the solution is not to require generally higher data quality during data collection. Increased data quality requirements slow data collection and exponentially increase cost.

Data collected by an agency may seem to be generally usable and other agencies may ask for copies to be used for other applications. Sometimes also the office of 'Budget and Management' will complain that there is 'obvious' duplication of effort and require cooperation. Unfortunately, data that is correctly collected and encoded for one application may not suit another one. For example, in the U.S. the 'owner name' data for real estate property in the tax assessors office cannot be used by the registry of deeds, even if it seems that 'owner name' for a piece of land is a well defined and unambiguous data element. The difference is that the tax assessor is not determining ownership but is content with finding a presumptive owner who is willing to pay taxes on the piece of land. This does, however, not constitute proof of ownership.

Another example is the definition of the width of a road: for a traffic engineer it is the width of the area of unobstructed traffic flow, for the hydrologist it is the blacktop area from which water is collected in a sewer, for the legal department, it is the width of the right of way — all of them reasonable definition of 'width of the road', but using one in lieu of the other leads obviously to wrong decisions.

8.2. Integration into the Organization

A GIS, as any new technology, affects an organization that adopts it. It promises benefits to the organization but it also changes the way the organization works. In a first attempt, organizations adopt technology that replaces one to one existing processes, for example a GIS is used to support the work of the mapping department. The GIS produces the same map that the manual processes produced before, perhaps at a lower cost or faster.

Only in the second phase, is the full potential of GIS discovered and attempts are made to integrate it into the organization. Current commercial GIS hinder this integration, because they were designed to support a single professional in his work. Support for multiple operations by professionals in parallel within an organization must be built into the GIS and then automatically enforced.

8.3. Assessment of the Value of Information

The potential for exchange of data and sharing of data between organizations will create a market for geoinformation. We have no idea how one could measure the utility of geographic information and how one should set prices for geographic information. It is not even clear, which units should be used: should one measure kilobits, or is the square inch of map or the square kilometer of area covered an appropriate base for assessing value and price.

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GIS today are complex programs, some with thousands of commands, that require substantive training during several months before they can be used effectively. This effectively limits the number of people that can learn to use a GIS and thus the potential user community. Many potential users do not have the time to go to training courses or to read through multi–volume manuals.

Word processors and spreadsheets became widely used when they became simple, so that after a few hours of instruction a user becomes adept at simple tasks, and can learn the more complex aspects on the job. If use of GIS by a larger community is desired the interfaces must become as simple as those of a word processor. There is a large group of 'spatially aware professionals' – geographers, planners, surveyors, ecologists etc. – who all would like to use a GIS, but cannot learn today's GIS user interface. The ultimate challenge is the user interface for the 'minister of the environment' – a user interface enabling him to access prepared databases and explore alternatives for a decision after a maximum of 30 minutes of instruction.

9. Conclusion

We have shown first the expected development of the base computer technology for the next 7 years and found that for the current methods of GIS usage, hardware will not pose any more problems. The challenge for the hardware is to find good uses for the increased processor speed and the opportunities that become available, when each user has his own computer linked in a network. The ability to bring substantive computing power to the field opens new avenues for distribution of work between field crew and office staff and opportunities for new products.

For software, we predict that most GIS will be using standard database management systems with the appropriate additional modules, that user interfaces will all be menu based and that networking will be widely used to share data collected by different agencies. GIS will go further in the integration of vector and raster data and will add sophisticated functions from spatial analysis. GIS will relate better to other programs, e.g. desk top publishing and the work flow in an organization can be improved.

We have also found a number of areas where GIS will still be hindered at the end of the decade. They are mostly related to the semantics of the data, description of data quality and thus to the problem of usability of a dataset for a specific task. We have also found, that GIS are currently used primarily by specialized users, but to achieve their full potential, many more people must become able to use them effectively. This requires improvements in GIS user interfaces and the methods we use to teach GIS to technically naive, but otherwise sophisticated users. The ultimate challenge is the user interface for politicians or the common citizen, allowing them to explore spatial databases with minimal training.

GIS development in the past 30 years was not very fast. Current use is still mostly map maintenance and distribution of paper based information products. The most widely used commercial GIS package was designed about 15 years ago. With considerable delay GIS makes use of technology that was developed for other application areas. Not much computer technology was developed specifically for GIS, given that there are other and more lucrative markets.

There has also been very little research in geographic information and analysis. GIS vendors spend little on in house development and have hardly any research staff. With a single exception, GIS vendors do not support basic research at universities (except with gifts of hardware or software). Public funds for GIS research are also very small. The only effort solely directed at basic research is the U.S. National Center for Geographic Information and Analysis, funded by the National Science Foundation and located at the University of California Santa Barbara, New York State University Buffalo and the University of Maine. GIS centers in the U.K., the Netherlands, Canada, Australia etc. are directed towards basic research and application, with application oriented work usually winning.

The effect of the lack of research are very clear: commercial GIS software lacks today features that were determined as necessary several years ago, but nobody was funded to do the research work. This hinders effective and successful application of the technology.

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