New Technologies for Spatial Information Management

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Abstract

Rapid development of technology, primarily hardware but also software, produces new business opportunities. In this paper new technologies are considered for their impact on spatial data[1] handling with special attention to their usability. Two milestones for the development and use of new technology are presented:

1. A new technology is sufficiently developed for widespread use if it is able to reproduce the products of the traditional technology.

2. A new technology is accepted if it is integrated in the organisation to the extent that the business cannot continue without the new technology.

Current use of computer cartography, the Global Positioning System (GPS) and new surveying equipment within the surveying and mapping community is simply to replace an existing technology with another one. Productivity gains in a specific work area are considerable, but overall productivity of the surveying and mapping sector is not much affected. Enabling technologies like computer storage, electronic communication and database management systems have potential for creating much greater productivity gains. But realising these gains requires more adaptation of the organisation. The adoption of such enabling technologies, all of which are proven today, depend on support for their integration in the organisation. Emerging technologies like work flow management support, simplified user interfaces and object-oriented design methodologies address some of the pressing needs in handling of spatial data.

The new emerging technologies address organisational issues through:

- organisation of flow of data and work in an organisation;

- support of cooperative work in a team;

[1] Spatial data is a term widely used in North America to describe any data which contains 'location' as one of its components. Thus data for statistical or administrative areas, information related to points (such as water quality sampling points in streams) or data related to networks (such as traffic flows along roads) are all spatial data - as is topographic data. Geographical Information Systems (GIS) are a set of tools for dealing with any spatial data. In Europe, the term 'Geographical Information' is becoming more widely used than 'Spatial data' to mean the same thing: 'spatial' has different connotations in French.

- modelling of data and processes in terms of human cognition, including data quality models; and
- modelling of user tasks and interfaces based on linguistic traditions.

Tools which address these issues make the new technology useful and propel new business opportunities for the computer-based handling of spatial data. Technology alone does not lead to effective adoption of new methods: they must be useful in a organisational, social and economical context. Development in this more comprehensive sense does not proceed in a smooth linear fashion: it happens in bursts, when new methods become useful and become widely and quickly adopted.

1 Introduction

The last few decades have brought very rapid development of computer technology. It is a commonplace to note the rapid increase of computer processor speed, the increase in storage capacity and, last but not least, the enormous decrease in prices. Extensive publicity is fuelled by frequent 'break throughs' in technology; users spend much time in keeping up to date with new technology, assessing new developments and procuring some at least of the rapid succession of new products.

At the same time, we observe a stagnation in productivity in the office and management sector. Despite all the new tools, overall productivity in public and university administration, and in business has either not increased or the increase is very small. The European Union has geared its research programs in information technology and telematics towards more 'usability' to overcome this limitation. This seems paradoxical because advertisements appear daily stressing the great 'usability' of the existing telematics.

This paper considers the effects of new technology on handling and management of spatial data, i.e. on Geographic Information System (GIS) technology in a wide sense. It does not take a technology-centred point of view. Rather it considers how technology can improve the business of spatial information handling. It focuses on use of spatial information and its production. The goal of the paper is an assessment of technology - in particular new, emerging technology - for its effect on productivity. The point of view is 'business-oriented'. This includes private and public administrations which are increasingly forced to take a 'business' attitude. The goal must be an effective and economical usage of resources to produce products which are highly satisfactory for the clients, independent of the organisational structure.

The term 'GIS' is used as a generic term to include all aspects of management, storage and presentation of spatial data. This includes traditional mapping activities and their computer-assisted modern equivalent. But it also includes the management of spatial data for public utilities (so called AM/FM, i.e., automated mapping and facilities management systems), for parcel registration, for resource management and for marketing.

This broad focus is justified as these different aspects of spatial data management are linked together by a common theory, namely spatial information theory. They all use a common translation of this body of theory into computer programs. Moreover, they have been the subject of common research effort in spatial analysis and geographic information both in North America and Europe.

Any comparison of current enabling and emerging technologies with the extent and value derived from their use shows that they are typically used independently. A major thesis of this paper is that their integration must lead to a 'quantum leap' in productivity and a very rapid adoption of GIS technology in many fields if the current limitations can be overcome.

2 Overall Assessment of GIS Technology

Today we observe a very rapid development of computer hardware. At the same time, we see how crucial software is for effective usage, but software improves very slowly. Programming languages are typically 20 years old. Most of the well known large commercial GIS software was designed 15 years ago. Despite the impression that 'it is only a small matter of programming', software advances are much slower than anybody is willing to admit.

The GIS community seems not to pay much attention to the decrease in the size of computers which has happened over the past years. This so called 'form factor' is widely underestimated in its influence on work organisation and its potential for sweeping changes in the distribution of tasks.

Technology is only of value if it can be used in such a way that it positively contributes to the goals of an organisation. To achieve this requires that the GIS technology is integrated in the work of the organisation. To be effective, this normally requires some adaptation of the organisation - less if the new technology replicates the product of an older technology and more if the new technology opens new opportunities. It must be stressed that changes in organisation are extremely difficult to achieve and few effective methods to introduce them are known. Changes in organisation are under all circumstances very slow and take several years to complete. In the worst cases, only retirement and natural fluctuation of personnel can move organisations forward.

The combination of hardware, software and organisational factors ensures that adoption of new technology is a multi-step process and not a continuous one. Rapid and widespread adoption can however occur if multiple new technologies become available.

2.1 Milestone 1: The Replication of the Products of Old Technology

Morrison has recently discussed the development of GIS technology. The development of GIS technology started in the late 1950s but only in the late 1980s did it became capable of replicating, effectively and economically, the products of manual cartography. This milestone is significant since it separates early usage, often experimental and tentative, from regular usage in a business. The milestone marks the end of the first stage of the introduction of a new technology: the quest to replicate the results of previous technology. It opens the door for the integration of the technology in the organisation of the business.

2.2 Milestone 2: Dependency on the New Technology

Organisations adopt a new technology for many different reasons, not all rationally related to the business goals. Early adoption is often tentative, geared towards learning about the new technology and assessing its impact on the business. Typically a few projects are carried out with it to gain experience but the technology is not integrated in the regular flow of business. A second milestone is achieved when a business integrates the new technology in its daily operations. This means that the technology is seen as sufficiently reliable to be dependable and, indeed, that the business cannot function without the new technology. Only after achieving this milestone does the adaptation of the organisation to the new technology normally start. Indeed, it is at this point that a completely new business can start as well as the reorganisation of existing ones to shed the restrictions of previous (paper based) technology.

2.3 Assessment

Not all parts of GIS technology are at the same point in this scheme. But there are also differences between different countries and between different industries. Influences of particular situations, for example, the availability of manpower or the quality of a service organisation, may favour adoption of a technology in one place and not in another. Differences in the requirements of the industries may not allow the use of a technology at an early stage e.g. parcel registration is much more demanding in some respect (but not in others) compared to the application of GIS to rural planning. Last but not least, the quality of the leadership of the organisation makes a difference.

At the international level, the level of usage of the new technology is quite comparable in various parts of the world: the use, for example, of CAD or GIS systems is - based on a my own partial observation - quite similar. All over the world, though, there are still many manual systems in use. Where computer-based systems are in use they are quite comparable: even if the hardware is somewhat more advanced in some places than in others, the functionality which is actually used (not the functionality offered by the system) is often essentially the same.

3 Insular Replacements of Spatial Information Technology

New technology - after having passed the first milestone - is often used as an insular replacement of the previous technology: the inputs and outputs of the process are the same. Only the tools are changed. The most widely used example is the replacement of typewriters with computer-based text editors: computers are widely used for editing letters and other documents but the end-product remains a printed letter put in an envelope and transported by regular mail. The new technology forms an island in the otherwise unchanged business organisation and therefore productivity increases are slim. The same happens with some new technology in surveying. Two examples are given here.

3.1 New Surveying Equipment

Global Positioning System (GPS) and other modern surveying tools (e.g. fully automatic total stations) are widely replacing the traditional methods of triangulation. They replace previous equipment and are used in the same way: they produce the same results but operate faster and with less effort. The results from these tools remain angular and distance measurements for the total station and coordinates for the GPS. These are then used to produce maps or are analysed with the same statistical tools as previously.

3.2 Automated Cartographic Drafting

Computer use for the production of cartographic drawing, engineering drawings etc. is widespread and generally accepted as cost effective. Indeed, it is very often the only technology left, as draftspersons who are skilled and experienced with pen and ink technology are no longer available. The result of the production process is a map or drawing which appears essentially identical to the one which such a skilled traditional draftsperson would have produced. It is drawn with ink on paper and its further use is the same as that of the traditional product.

3.3 Assessment

Replacing one technology with another one and producing the same results carries little risk: the interface with the remainder of the organisation remains the same. It also carries only limited potential for improvement. At most, the whole effort for the previous technology can be saved. More fundamentally, the cost of drafting (not design) or the cost of taking the measurements are only very small parts of the total cost of the whole project in the two examples cited above. Productivity gains with insular replacements are therefore very limited. This is especially true for GPS and computer cartography, as the following real example shows. A GIS project for land registration had a total budget of $400,000. Of this, $100,000 was for photogrammetric base mapping. GPS was used for the determination of control points, reducing the cost from $50,000 to $20,000. This resulted in an overall reduction of project cost of only 7.5%!

4 Enabling Technologies for GIS

Information in the past was connected to the paper on which it is written. Producing copies was expensive. Organisations in the mapping industry, as well as in most other information-treatment businesses like insurance or banking, have adapted to this technology. Computer technology lifts the technical limitations and permits organisational and business changes to follow. But the inertia in the legal and social context ensures that development of the cultural framework is very slow and this impedes such changes. The reason for this is not hard to understand: the significance of the introduction of computers is probably comparable to Gutenberg's invention of printing with movable letters and it will take a very long time until all the effects of this new technology are understood and incorporated in society.

In the next subsections, I review a few specific enabling technologies which are crucial for GIS and enable us to perform new tasks or organise them differently. I examine how they affect the surveying business and how they are best used.

4.1 Storage Technology: The Distribution of Data simplified

Computer-produced drawings can be stored and duplicated as files rather than as paper map sheets. This reduces the cost for handling, reduces storage space needed and reduces access time. But there is also potential for overcoming restrictions imposed on the organisation by the inability to duplicate an archive. In particular, there can be an increase in security of the archives and greater protection against accidental or malicious loss.

Surprisingly, the potential of the technology was available for a long time but was not exploited. Tools to create secure file archives were not provided by the computer industry in the early days; the general impression was perhaps that standard file systems with their protection mechanism would be sufficient for all applications. Some authors have argued that the business opportunity to develop a protected file archive - comparable to the map archive of a mapping organisation - was only discovered recently. Marketing people probably thought that the integration at a more detailed level using database management systems would happen much more quickly than it actually did and render superfluous the development of file-level tools. Moreover, a storage system could easily be designed as an insular system - the paper drawings are delivered, scanned and stored in electronic form. For output, new paper drawings are produced close to the point of use. Investigations showed that this was a feasible option for some administrative applications such as drivers' license documentation, bridge management and possibly also deed registration.

Dependency of the business on such a storage subsystem for drawings would be total. The technical solution must guarantee uninterrupted availability, security against unauthorised access and protection of the data against non-intentional changes and loss. A probable reason why such systems for mapping were not built years ago was the perception of computer systems as a fragile technology which often breaks. Thus a logical priority for further development of the technology was not so much faster CPUs but rather a more dependable and reliable system, comparable in reliability to the service levels given by a manual 'map archive'. This has been partially achieved today - the base technology is reliable if sufficient redundancy is built in.

Obviously such an isolated solution reaps only part of the benefits. More integration would decrease overall cost: maps produced with a CAD system can be delivered as files and be retrieved as files and the production of paper maps completely bypassed. This requires a higher level of integration between the systems. Communication channels between the CAD systems and the storage system are required; data transfer formats must be agreed, etc.

4.2 Database Management Systems: Structuring and Integrating Data

Electronic storage of data allows presentation of the same data in different forms. Neither the subdivision in map sheets nor the content and presentation style for maps needs to be retained: data can be presented on demand to best suit the task at hand.

Access using different entry points (e.g. the name of the owner of the parcel or the street address of a building) is particularly important for administrative data but the same can also be said for data for environmental planning, topographic data etc. Use of a database allows the use of logical structures in the data. This facilitates organising the data to make it accessible for different uses in different forms using different search criteria. The technology of database management has long seemed applicable to spatial data handling problems and efforts to adapt it have been discussed in the research literature since the late 1970s.

Relational databases organise data in tables, where similar data are collected. Each row describes an entity (such as a land parcel), with the same set of attributes (columns). There is a limited, but powerful set of operations available. Users interact with the database using a query language called SQL. General design rules (so called normalisation rules) divide information into small pieces which can be combined to achieve maximum flexibility.

After some years of development, this database technology is now widely used. Relational database technology has the important advantage that it is already used in many other parts of an administration; its use in mapping therefore permits the integration between data from different parts of the organisation. On the other hand, relational database systems suffer from performance problems when applied to spatial data: database performance depends substantially on hard disk technology. Development in recent years resulted in increased speed and increased capacity at lower prices, but access speed increased only marginally (it doubled in 10 years). Building large databases for spatial objects based on relational database technology therefore remains a difficult issue. A number of proposals have been published; for practical purposes, there is little difference between them.

Structuring data as relational tables works well for highly structured information in well organised administrations. It is working well for property registration, and at least two countries have converted from a manual system to a fully computerised system in the mid-1980s. The technology has been generally adopted by public utilities. Success is assured in both cases, because well defined tasks, carried out within a highly structured administrative processes with a limited geometric complexity, are automated.

4.3 Overlays: Integrating Data according to Spatial Location

The fundamental concept of GIS is its ability to combine data related to a single point in space even though the different data sets may have been derived from different sources. This is a generalisation of the manual practice of overlaying multiple maps on a light table. This process has been used to assemble all the information necessary for the decision making process in natural resource and urban land use planning. The computers have lifted limitations and made the process much faster. It should be possible to ask complex questions, like 'Find all parcels with exposure to the south or south-west which are on a sandy soil, within a residential zone and not further than a 10 minute drive from a highway-exit'. Such structured querying is sometimes called map algebra.

Most GIS software today can handle such problems and produce acceptable answers. The work is carried out by specialists who understand how to integrate data of different quality, in different representations (raster data from remote sensing must be combined with the vector data from the parcel registry) and scales. It is typically done on a project-by-project basis, where each project poses particular challenges. The results of such a study are often fundamental to supporting decisions. Yet their quality or suitability is difficult to assess and depends enormously on the sources of the data. These data are very seldom used later. The consultants who carry out the work rely fully on the GIS technology but the planning agency does not: it uses the results from the GIS as it would use the same results produced traditionally (even if they could not be produced with the traditional methods).

4.4 Communications and Computer Networking

Computers can be linked using services of telecom companies. The technology for computer networking consist of multiple layers of services which, when used together, allow the meaningful exchange of data between different computers. Adherence to international standards ensures this is both possible and reliable. This permits access to data collected in one organisation from others, instantaneously and at a very low cost. It can replace the costly traditional distribution of information as printed materials on a regular schedule and replace it with 'access on demand'.

Wide area computer network technology was for years largely restricted to the academic and research communities in the USA and a few other countries and then spread slowly worldwide. In the past year however, many companies, government organisations etc. have become connected to networks. After the address 'president@ white_house.gov' was published, use of the Internet became fashionable. Widely available software guarantees communication by electronic mail - essentially this is a typed letter, sent electronically and arriving nearly instantaneously at its destination, where the recipient can read, save or print it. The service today is reliable, probably more reliable in some countries than is the regular mail, and much faster - which may be reason for its rapid acceptance in the business community. It is not completely secure but research and development is addressing this issue.

The World-Wide Web is a second widely used service. It allows others to access information one wants to make public. Obvious examples include a telephone directory and a collection of cooking recipes. It is technically feasible for a map publisher to makes maps available for perusal and local printing over the net. Indeed, the US Geological Survey does just that. But legal and organisational issues limit the usage today: a widely accepted mechanism for collecting fees remains the major hindrance.

The use of network services for GIS has been limited so far. In Austria, for instance, the property registry are accessible only to a limited group of authorised users (surveyors, banks and lawyers). The special properties of spatial data pose demanding questions before a logically unified but distributed GIS can be realised.

5 Limitations of Today's Technology

The spatial information industry uses these enabling technologies to varying degrees. The second milestone described earlier has rarely been passed as yet. For example, most companies still maintain map archives and do not rely on electronic storage alone. The issues remaining to be resolved are not directly technical ones:

- reliability of the new technology: how often does it break, how long does it take to fix it, how catastrophic is the loss?
- organisation of work around an 'invisible' electronic product: how can we control progress, the quality of work and completeness of the result?
- installing the software from different vendors: how can we make it cooperate? how can we isolate errors and charge the offending vendor?
- 'know-how' of the work force: how can we educate and train personnel?
- formatting and meaning of data collected in different agencies: e.g. how to translate the concept of a parcel from the registry of deeds to the building permit department? - how can we combine data in different formats and on different source scales?
- copyright and fee collection: how can we make a business distributing spatial information over the net?

6 Emerging Technology

A number of new technologies with great potential to affect the spatial data handling business are currently in research and development or in some early stages of marketing. They are all based on several of the above-mentioned enabling technologies and may help to overcome the current limitations of using computer technology to its fullest advantage. They are discussed here briefly since they suggest in which direction GIS technology may well develop in the next few years.

6.1 Data Flow Control: Automating the Flow of Information in the Organisation

To organise the flow of information in an organisation has become a recognised challenge. It is one to which the computer industry provides solutions. Data are a recognised resource in modern business. Efforts to manage the flow of data in the organisation are following in the tradition of keeping track of money through an accounting system or the practice of keeping a registry of incoming mail. There is already some evidence that much time and effort in many organisations is spent on moving data from one desk to another and to search for data not currently available. Intelligent data flow management can assure that a given decision has the appropriate set of inputs from different services, that the results are circulated to the appropriate people and that responses are received within the deadline set. It makes personnel accountable for their decisions (or the lack thereof) and facilitates auditing.

6.2 Comprehensive GIS or Customised ones built from Modules?

Users very often require integration of their specific GIS software for spatial analysis with other business software such as data bases, electronic mail and report generation in a word processor. In many present circumstances, the data from the GIS must be fed into other applications and the results from them inserted back into the GIS. Initially, GIS software integrated many additional services, e.g. map presentation, CAD capabilities, report generation. Today such services have multiplied and have achieved very high levels of sophistication. To build them all into a GIS is overburdening the system. As a consequence, the favoured approach has changed from one based on a monolithic, all-purpose GIS to having intelligent connections to the specialised software. System integrators have a thriving and valuable business combining different pieces of existing software to suit an organisation's need. The concept of interacting software components simplifies this task.

The object-oriented concept can be carried to the software component level: specialised software deals with maps, electronic mail, address lists, etc. The interactions between these components is standardised, such that the map can be sent electronically, the report from the database merged with a map in a written report, etc. Standards such as OLE and COBRA are emerging to permit this for different environments.

In the future, constructing software for complex business application will consist of selecting the appropriate components and integrating them in a useful application framework. The most complex part of the problem will be the construction of a user interface.

6.3 Integration of Spatial Data based on Spatial Objects

For organisations which do not produce map sheets but manage spatial information at a detailed level, it is natural to organise spatial information in a database. This combines the advantages of structuring of data in a database with the spatial integration of the GIS. For every entity, the organisation is interested in the spatial location and its geometric manifestation is stored together with a set of attributes. This data collection is made available for many different users within the organisation. There is an obvious merit in centralising the data an organisation since this will lead to a streamlined maintenance process: an update must be done only once and the new information is available simultaneously to all users. This is particularly important if one considers that updating a data set is a very high cost activity. It has been observed both that expenses in city administration, public utilities, etc. for the maintenance of the spatial data are high and that the potential for reduction in these expenses is considerable if the frequent duplication of effort is excised.

A concentration on modelling spatial objects and their attributes integrates the database possibilities with the power of spatial overlays. At the lowest level, an integrated, homogeneous representation of geometry is required on which all other layers are built, as originally proposed in a report of the US Academy of Science. Solutions to overcome the difficulty of integrating models of the world at different levels of resolution (the so called hierarchy problem) and different precessions are emerging.

7 New Application Areas for Spatial Data

The new technology not only makes current treatment and use of spatial data more economical, but it opens doors for new uses and therefore new business opportunities. Only two of these will be described:

7.1 Business Geography

In every country, socio-economic data for area units are available from the statistical bureau. The data are sufficiently aggregated to protect the privacy of individuals. The corresponding maps describing the units are often distributed by national mapping agencies. This data can be made very valuable if combined with GIS technology.

Such data is extremely useful to help with business planning or marketing. Decisions about the location of outlets for goods or services are regularly based on the demographics of the area serviced. Business can use these data to find potential markets for their products, to find areas not well serviced by their offices, etc. Similarly, politicians need to combine demographic data with environmental data to develop effective strategies for environmental protection (but also for their political campaigns). Unfortunately, the difficulty of getting the data, transforming it into a suitable format and adapting the software for such uses is too difficult for many commercial users, in particular marketing departments.

If the data is readily available and bundled with the appropriate software in a package which does not require much time to learn how to use, it meets a demand from a large sector. Several companies today offer local data suitably combined with one of the simpler GIS software packages. This is a rapidly expanding business of GIS data packaging, where the value added is in the collection and cleaning of the data, making data comparable and immediately useful with software, selecting the appropriate software for specific uses and instructing the user in how to apply it in his business.

The key to this success has been the combination of technologies discussed before: spatial data stored in computer files, demographic data organised as relational tables, large storage devices (CD-ROM), graphical user interfaces and the integration of software components. It became possible, not by adding more functionality to the general purpose packages, but by concentrating on specific applications and building readily useful systems. Using such data effectively requires a good understanding of the issues and how they are influenced by demographics. Interactive use of data can lead to surprising insights by knowledgeable users. These users are highly trained domain specialists (e.g. marketing managers) but neither know GIS technology nor care to learn much about it. The GIS software must be simple enough to be learned in a few hours.

Unfortunately, most current GIS have very complex user interfaces and require long training periods even for users with a background in geography, surveying or similar. Further research in user interface design will lead to more powerful systems and a decrease in complexity of the user interface. But only the emerging GIS 'data viewers' are easy to learn and simple to use. They are adequate for many of these business applications.

7.2 Navigation

Use of spatial data for navigation is probably one of its oldest uses. Maps were originally constructed for route-finding purposes. Standard topographic maps cannot keep up with the rapid change in our world: street maps of large sprawling cities in the third world (and not only in the third world) are permanently out of date; printed maps cannot adapt to the particular demands of some users and printing more and more different maps is not the answer (maps for the car driver, maps for the bicyclist, maps for the environmentalist etc. etc.). More flexible products can be constructed with modern technology.

Research and development is under way to build navigational aids in cars. The first generation of these devices is now available in luxury cars. Again, packaging of spatial data with the appropriate software to assist the driver is the key to commercial success. To achieve truly useful systems, not only street maps with addresses are required but information about the location of businesses (the so called 'yellow pages') must be integrated with 'smart software' to discover the best way to achieve complex goals like 'visit a bank, a petrol station and a Chinese restaurant in that sequence'.

8 Conclusions

Technology for spatial data handling, and thus for Geographic Information Systems, has made rapid progress over the past 20 years. Substantial software systems exist and most of the necessary technology is available readily. The first milestone: reproduction of the results of past tools, has widely been achieved. Today it is in most cases less expensive, less risky and faster to use computer systems than to rely on manual methods. The widespread adoption of this technology is underway but is still limited to replacement of current methods. The issues that require attention are not so much technical, but organisational, legal and social. It will take much more time to adapt the organisations to the potential of the new technology than it took to perfect the hardware.

A number of emerging technologies exist today which are not yet widely used but show promise for substantial improvements in the organisation of GIS. They are not 'faster' or technologically more advanced but address indirectly the organisational limitations of current solutions.

A combination of the already existing technology with the emerging one can in several cases have a substantial impact on the GIS field. The combination will allow new organisations to emerge and it will help to overcome legal or social problems in existing ones. This can be seen in the extremely rapidly growing industries of 'Business Geography' and 'Navigation Aids'. These markets are very different to the current GIS market: they are true mass markets. Every car driver is a potential customer. This requires a different marketing approach to selling GIS software or data to public utility companies.

Available, proven technology is a precondition for rapid growth in a business or organisation but this is a necessary but not sufficient condition for success. A social need for a product and the economic and legal environment must provide a demand for the product to effectively use the technology. In certain fields these needs already exist. The known enabling technology, together with the emerging new developments, form the technical precondition to enable the demand for more and better spatial information to be satisfied. The transformation of the surveying industry from one based mostly on map producing to a true spatial information industry may happen quickly now.