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Geographical Information Systems in Action

by

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Abstract

Geographical Information Systems (GIS) are becoming more and more important to solve problems and tasks of all disciplines within the geo-sciences. Looking back to history of about three decades GIS technology of today is highly developed; it has reduced acceptance thresholds being a barrier for a real breakthrough in the seventies and the beginning of the eighties.

Meantime Geographical Information Systems – also called *Geo-Information Systems* – have been acknowledged to be efficient tools in mapping and inventory of spatial data. Therefore, its spectrum of application is very broad ranging from data management only to comprehensive data analyses and visualizations. However, critical points of acceptance are furthermore complex user interfaces and the lack of knowledge representation in GIS technology.

The paper starts with the state-of-the-art in GIS technology and demonstrates diverse applications in ecology, digital mapping and digital planning. It is shown that the systems in action are capable to solve manifold tasks even if some deficiencies are known. The second part of the paper gives an outlook on new developments and how to integrate them into the existing systems. In particular networked GIS are the system architecture of the nineties – therefore data quality, data exchange, data conversion and data compatability become more important than ever before.

1 Introduction

The fast developments of information technology have influence on all the human actions in business and private spheres. As far as research and development is concerned about 14.000 publications are given every day on technical and scientific aspects which should be read by the experts to keep them updated in their profession. However, it becomes clear that such a flood of information cannot be processed although we can observe a trend to more and more specialization in most of the disciplines involved.

These informations are stored in large databases. Its access and proccessing led to developments which can be cited in headings without being comprehensive: parallel computing, optical storage, distributed databases, local area networks, viewing systems, neuron networks, and artificial intelligence. Computer science of today has become a basic discipline; it should solve heterogeneous problems resulting from different applications – the linguist uses object oriented databases for investigations on *dead* languages, and the engineer proves environmental correspondance with planned new highways.

Even if developers of information systems at university and vendor level may follow the progress in technology, the practitioner is not able to do so because his field of activity does not allow for a comprehensive assessment on systems offered today. He has to choose a system capable to run his applications more efficient than before. For that reason, he has carefully to select hard- and software components from an offer of **one** vendor what lead to an alliance for a long time period. This is not an easy task: looking into the documentations and advertisements of the vendors one can say that (almost) everything is being solved.

When history is reviewed in terms of *big steps* in computer science architectures we can see some positive *lights* within the information dschungel. Summarizing the decades beginning with the sixties – the decade in which Geographical Information Systems (GIS) has been introduced by R. Tomlinson in Canada – the following developments went simultaneously with GIS

- 1960 – 1970 centralised computing at computing centers, data processing in host systems
- 1970 – 1980 introduction of minicomputers, distributed computing power at decentralised institutions in combination with computing centers, data processing in host and satellite systems
- 1980 – 1990 continuation of decentralisation, desktop computing – introduction of personal computing (PC) for simple data processing; workstations dissolve minicomputers
- 1990 – 2000 networked computing of host, workstations, and PC; distributed databases, integration of artificial intelligence into data processing, realisation of standards for soft- and firmware.

Further developments in information technology should concentrate on soft- and firmware; meantime hardware has obtained its own dynamics and cannot be influenced by application oriented disciplines. What we as engineers can state are big gaps between hardware offers and software products – this gap is once more obvious when costs of these components are compared. While hardware is becoming cheaper with increasing efficiency, software remains an *unknown* especially when no general purpose components may be used. GIS are one special *node* within information technology; its components make the evidence clear to problems and solutions of a modern computer driven society. However, the priority of GIS starts not with hardware although it cannot run without it – the data is the most important part with a life span of about 50 – 100 years. Therefore, the following information technology model is valid for a GIS:

- data (priority 1)
- user interface (priority 2)
- soft- and firmware (priority 3)
- hardware (priority 4)

2 Potential of GIS

The main advantage of Geographical Information Systems is the link of thematic data of arbitrary nature with geometry; this link is the true indicator for the term *geographical*. A better name would be *geo-referenced* or *spatial*, but this will not be discussed here.

The models for this link are twofold which might also be combined with each other. At the beginning of GIS technology this link was performed by the geometric position x, y. We can observe this link in most of the GIS on the market – it is well-known and called *the layer principle*. The layer principal overlays different thematics simply by its geo-reference. Every layer is to be considered independent from another one. Therefore, no flexibility is possible, for instance, to combine a hydrographic layer with a political layer in the sense, that the river Rhine simultaneously represents the state frontier of France and the FRG.

Research in the end of the eighties has shown, that the link of the layer principle is very static and not well-suited for object oriented data handling of geometry. For that reason, the more flexible approach is the feature oriented link wich led to the *objectwise* or *object oriented* data model.

Figure 1 demonstrates the two different approaches; the system philosophy of today uses both models to increase the potential of GIS. Following this philosophy geometric data of surveying, planning, remote sensing a. o. can be combined with attribute data from statistics, geography, geology, ecology, and further disciplines involved with thematic mapping and inventory.

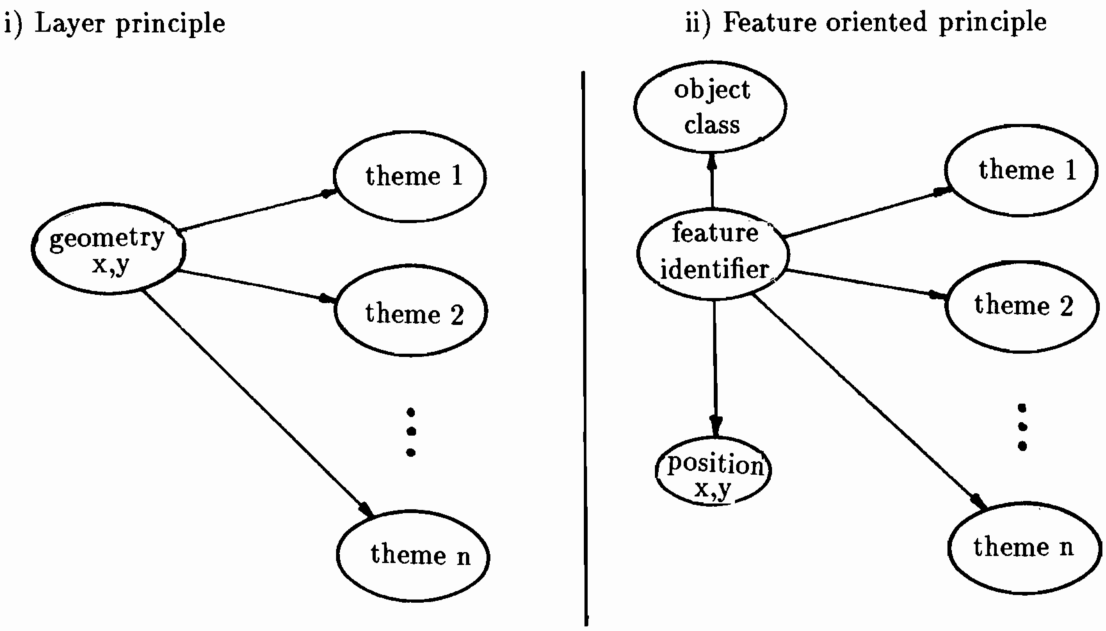

Fig. 1: Models to link different thematics

3 Applications of GIS

The GIS applications can be classified according to the five sectoral GIS which we know from market analyses (Fritsch, 1991a). These sectoral GIS are not independent from each other – some of them integrate very strongly data of the others and are therefore interrelated with each other. Thus, we can say, that the most important aspect of GIS is data exchange; what means to have a bidirectional data transfer for *import* and *export*. This problem will also be covered in the conclusions

Figure 2 shows the sectoral GIS resulting from a study carried out by Schilcher/Fritsch (1990). The *utility information systeme (UIS)* were and are the most progressive sectoral GIS with a percentage of about 47 %. These systems are mostly vector oriented at large scales – some special applications integrate scanned photographs to detect damages or to provide for fast local orientations when field work has to be done.

At the same scale we find the *land information systems (LIS)* of the mapping disciplines. They represent a small group within the GIS family (about 8 %). Also these systems are vector oriented; special solutions in particular for updating in medium scales use raster approaches.

At medium scales we find the *spatial information systems (SIS)* of geographers – these systems are mostly called *geographical information systems* although they represent only a sectoral GIS with a percentage value of about 15 %.

The *environmental information systems* can be found at all scales – in large, medium and micro scales according to local, regional and global investigations on our environment. At large scales the environmental goodness-of-fit of man-made constructions is one problem to be solved more and more by GIS technology. This question integrates also CAD modelling into GIS. We found out, that the percentage value of EIS is about 15 %.

The fifth group of sectoral GIS are the *auxiliary information systems (AIS)* which are under establishment for special applications such as flight, car and ship navigation. Another big market for AIS is telecommunication. Not the whole part of telecommunication may be found in AIS; also UIS can be the adequate sectoral GIS. The remaining percentage value for AIS is about 20 %. Figure 2 gives an overview on the sectoral GIS.

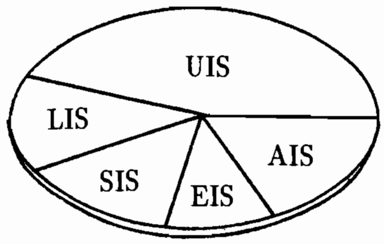

Fig. 2: Grouping of geographical information systems

According to the sectoral GIS above the applications can be grouped – it is interesting to see which underlying geometries are used. Table 1 gives a classification resulting from Schilcher/Fritsch (1990). This classification is updated in particular when local images are integrated. It should be noted that the applications are not complete, because the spectrum of using GIS is growing very, very fast.

This grouping led also to an estimation of the ratios of vector, raster and hybrid graphics. While vectorial data is used in about 2/3 of all GIS applications, raster data have only a small percentage value. But the combination of vectorial and raster data – being called *hybrid data* is increasing. The following figures for the ratio vector : raster : hybrid were estimated in 1990

65 % : 8 % : 27 %

It is expected that hybrid geometric data will increase during this decade leading to percentage values of vector : hybrid in the year 2000

50 % : 50 %

Table 1: Grouping of GIS applications

vector	raster	hybrid
energy (UIS) sewer (UIS) telecommunication (UIS)		sewer control (NIS)
cadastre (LIS) municipal surveying (LIS) rural land reallotment (LIS)	photogrammetry (LIS)	photogrammetry (LIS) cartography (LIS) rural land reallotment (LIS)
civil engineering (SIS) urban planning (SIS) infrastructure planning (SIS) geography (SIS) geology (SIS) water management (SIS) resources documentation (SIS)	remote sensing (SIS) geography (SIS) resources exploration (SIS)	transport management (SIS) environmental goodness-of-fit (SIS) infrastructure planning (SIS) remote sensing (SIS) geography (SIS) geology (SIS) water management (SIS) resources exploration (SIS)
environmental documentation (EIS) biotope mapping (EIS) climate research (EIS) forestry (EIS)	environmental exploration (EIS) climate research (EIS) forestry (EIS)	environmental exploration (EIS) climate research (EIS) forestry (EIS)
car navigation (AIS) flight navigation (AIS) ship navigation (AIS) military vehicle navigation (AIS) telecommunication (AIS)		car navigation (AIS) flight navigation (AIS) ship navigation (AIS) military vehicle navigation (AIS) telecommunication (AIS)

4 Future developments

The decade of the nineties seems to be very important for further developments in GIS. We have learned that data should be stored in a geometric-topological model as far as geometry is concerned – the thematics is linked through feature identifiers to have the most flexibel data access. But what about object oriented databases? Fits the geometric-topological model into concepts of object oriented programming using $C++$, Smalltalk, and other languages to provide for inheritance and encapsulation? To which levels of activity image data can or should be integrated into GIS? Is there a need for 3D data models? These questions are only a sample of open problems to be solved in near future.

4.1 User interfaces

The important key factor to accept GIS technology is the human interface to the GIS. This interface should be as easy as possible and it should allow also non-trained personnel to communicate with the machine.

The fast developments in computer science helped to create standards for interfaces. Meantime, it is quite clear that *graphical user interfaces (GUI)* offer the easiest access to the system. Starting from a standard GUI the user is able to define its own icons and object links embedding

(OLE) , therefore he can create its own interface which fits best to his applications. GUI's are supported by X Window and OSF/Motif within UNIX driven workstations and PC – PC AT are dominated by MS Windows which will be the standard for the whole decade of the nineties.

Character user interfaces (CUI) will disappear although they provided fast system response in particular when well-trained personnel communicates with the machine.

4.2 Hybrid GIS

The integration of image data demands for different levels of data activity in GIS. At the lowest level image data can be used as background information to provide for the orientation of vector data. Already at this level the image should be geo-coded to avoid time-consuming transformations and to make overlaying as simple as possible. Two different approaches exist for image data rectification: the use of control points and polynomial modelling which can be used in medium and small scale mapping, and digital ortho projections with digital terrain models as control information for large scale applications. Both methods have its roots in photogrammetry and remote sensing, thus, photogrammetrists can help a lot in further developments of hybrid GIS. But what about the digital terrain model? Where does it come from? Can it automatically be derived from aerial images or by Spot imagery? What about its accuracy? Once again, these questions can only be answered by photogrammetrists. As far as data structures at the lowest level are concerned, the images are pixel oriented with a matrix topology. But, already here is some room left to solve the problem of *packing* and *unpacking* the image data. Which methods can be applied? Could orthogonal transforms such as Fourier, Hadamard-Walsh and others be used to compress the images without loosing to much details? Or should image data compression be solved in the signal domain?

The next level should handle object oriented raster data. This data set consists of homogenious areas also to be called *chorophlet maps* which result from semi- or fully automated classification techniques. Once data are classified also compression and decompression becomes easier. Compression ratios of 1/100 and more can be reached, for instance, when quadtree data structure are used. Also intersections can efficiently be handled.

The highest level raster data may reach in a GIS are topologically and semantically structured vector data. But today we are far away to solve this question. Which is the best approach to convert non-classified raster data to vector data? What can be expected by bottom-up and what by top-down procedures? It seems, that binary raster data may be transformed to a high degree by bottom-up techniques – some vendors offer software packages for line following and vectorisation also in an interactive mode. Percentage values of 80 – 90 % are proposed when using these packages for large scale scanned maps. But what about the remaining 10 – 20 %. What time effort has to be paid to identify very critical regions and cells? It would help very much if vendors might give realistic figures to the GIS users.

4.3 Height integration

The geographical information systems of today use two-dimensional geometric data x, y for the geo-reference of thematic data. Within NIS height values z attribute planimetric data and led to 2.5 D geometry, which only indicates the density of 3D data distribution. In the recent past investigations were made to integrate digital terrain models into GIS (Fritsch, 1991b). This is only a first step to establish fully 3D geometric data sets in GIS – a long time investigation has to prove whether it is sufficient to separate into 2D planimetric and 1D height data or to concentrate on fully 3D data. But what about the spatial analysis? Three-dimensional intersections are much more difficult to solve then in two dimensions. Which algorithms should be used here? Is the effort to be made worth while to extend GIS technology to three diemnsions? Should we also integrate time as it is necessary for environmental monitoring?

4.4 Geo-SQL

Query languages are another key factor for an easy access to a GIS. Up to now the *structured query language (SQL)* of the relational database management systems (RDBMS) can query the thematic data. Questions as follows can be answered:

1. inventory questions – *How many ..., Where is (are) ...*
2. positional questions – *At which position ...*
3. combination of inventory and positional questions – *How many ... are located at ...*

But there is no possibility to query the geometric-topological data model. It is expected, that the vocabulary of SQL is extended to a Geo-SQL. One main objective must be to have the same vocabulary to query GIS data. This leads to a redefinition of the query space. The following questions are of importance when Geo-SQL is to be defined:

1. Which objects should be balanced?
2. Which thematic (semantic) and/or geometric relationships exist between different objects?
3. How should the results be visualized?

4.5 AI and GIS

The integration of the methods of *artificial intelligence (AI)* may improve object recognition and object analyses in GIS. Today we cannot see much progress using AI in GIS. But this may change when a more realistic viewpoint cleares which methods of knowledge representation can be used already and which have to be researched further on.

First AI tools are available for UNIX workstations and PC's – they are in closed correspondance with the objectwise or feature oriented approach. Further systems are to be expected. Towards the end of the nineties it will become clear which role AI will play in GIS.

5 Conclusions

The preceeding chapters indicated the massive influence of current information technology on GIS. These systems are today not only accepted in praxis, but are a necessity in many applications. We can say that very critical and sensitive applications which need data input of different disciplines, such as climate research, planning of big traffic knots (airports, train stations), infrastructure evaluation and densification, cannot resonably be solved without GIS technolgy. Only with the aid and guidance by these systems human society is capable to query fast and reliable information on our planet, to analyse it and to make decisions. Furthermore, the combination of positioning sensors with GIS may help to avoid traffic jams, to guide for convenient travelling, and to react faster in cases of emergency.

However, there are some critical questions which have to be answered: which profits the GIS user of today can expect from this very, very fast progress in computer technology? Should he save money for a new GIS of tomorrow? Which data model will be used in the year 2000 ? What about money critical investments such as scanners, recorders, CD's – may the data they produce and visualize run on future systems?

The answers should be reduced to a simple one: first of all, the GIS society demands for compatibility of hard- and software to run its data also on architectures which are currently under research and development, and which are not yet known today. Secondly, networked GIS may reduce investments in permanent new technolgy. Why not to use a PC GIS implemented on a MAC or a MS-DOS machine for local applications, but to store the data in a large database maintained by UNIX workstations? The network idea contributes to super computing power even if it cannot be used at the same time.

Standards for networks, databases, GUI's, graphic data representations and others may contribute to general compatibility conditions. However, the main critical point is that GIS vendors should care for bottom-up compatibilty of GIS data structures. The user is not willing to have a data loss when changing the GIS platform. Therefore, there is a high need for data standards in GIS – meantime the conditions are well known, why not to fix basic rules which can be valid to the year 2000 and further decades? Only when this question is solved suffiently data conversion and data exchange becomes transparent also on an international basis.

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