

From GI Science to GI Engineering

Andrew U. Frank

Technical University Vienna
frank@geoinfo.tuwien.ac.at

Abstract

GIS and newly GI is a rapidly growing business. The quick pace of change in the new economy forces a change in the university. GIS is not the magic wand it used to be, many people routinely use it. This creates a demand for well-reasoned, practical education at many different levels.

In addition to a continuation of the scientific efforts, which have made the advances in the use of GI possible, a systematic engineering practice to translate the scientific results into usable rules is necessary. This paper discusses in detail the important changes in GIS as the major focus moves from the construction of software systems to systems to produce and market Geographic Information.

Science is exploring the new and unknown. Novel methods must be devised to answer new questions and the outcome is uncertain and sometimes surprising. Engineering uses reliable methods based on scientific results. The methods are tried and follow established practice. The results can be predicted and surprises are undesirable. Take as an example the design of a bridge: design rules allow to determine the characteristics of a bridge before it is built and surprises – bridges that crash – are very seldom. No equivalent design rules are available for GIS today and occasionally projects go over budget, deliver late or fail entirely.

The need for a 'reduction to practice' of the results of GI science from the past decades becomes evident when one considers the expected growth of GI applications. The potential of future applications can only be realized if competent specialists can construct such systems following tried rules with certainty in reaching the desired goals. This requires the development of GI Engineering as a complement to the emerging GI Science.

Introduction

Geographic Data is crucial for the economic development of a country, it is central to the protection of the environment and it contributes to a democratic society. Most geographic data is acquired by people living in their environment and used daily without specific consideration. Technology constantly changes our world, two changes affect the way we handle geographic data in particular:

- Transportation technology – especially cars, but also air transportation – has increased people's mobility. We find ourselves more often in places we do not know and depend on the availability of geographic information to find our way to the hotel, to the station etc. The adaptation of cities to individual transportation with cars has reduced our abilities to find

our way using simple concepts and increased our reliance on outside providers of explicit geographic information.

- Information technology makes it possible to collect, process and deliver information in ways not previously possible. Information is valuable to improve decisions and decision makers in public and private request more information. As many decisions are related to space, geographic information is desired.

From Batch processing to Interactive and Network computing

GI today has evolved through three phases to reach the current situation. It is useful to understand this succession to plan evolutions.

Isolated systems

Most countries have National Mapping Agencies and other similar agencies that collect geographic data systematically and make them available in map form. Originally, maps were produced with manual methods and paper maps printed to distribute the data to the users. Since the early 1970's, mainframe computers have been used to assist with map production methods and we can see a first phase of GIS as a tool to produce maps, which are then distributed in paper form. This applies equally to National Mapping Agencies producing topographic maps, cadastral offices producing real estate maps and public utilities maintaining their paper maps of their pipes and cables.

At about the same time, regional and town administration used computers to map their areas for their purposes, but also discovered the use of computers for spatial modelling and analysis. All their queries were provided by invisible computers and only the products (paper maps mostly) communicated to the users.

Interactivity

Interactive, multi-user computers with small networks of directly connected terminals provided the technology to produce geographic information on demand: instead of producing geographic information as a map and distribute it to all potential users which consult the map when they have a need for geographic information, users were directly connected to the database and could pose their questions when they arise and get immediate answer in form of a cartographic sketch.

Integration

The advent of the Internet and mobile communication technology, where essentially every user is connected to every computer in the world opens the path for the delivery of geographic information to whoever needs it, exactly when it is needed and in the form most effective for the decision to make.

Technology Push versus User Demand

To understand the trends in GIS which are opened by technology changes one has to compare the possibilities the technology opens with the demands of the users: a wide variety of users in many different situations could use very different forms of geographic information.

The value of geographic information is the improvement of the decision it contributes to. The cost of acquiring the information reduces its value and must not be larger than the value of the information – otherwise the user is better off making the decision without geographic information. The cost of acquiring the geographic information consists of the payment to the owner of the information, but includes also all investments in time, learning and equipment the user must have to access the geographic data. Unless geographic information is very simple to get, it will not be used in many instances.

The early GIS and especially the early adapters of GIS in the 1970s and 80s were mostly fascinated by the technology and used GIS because it was possible to make maps with computers. The benefits of the GIS were often described summarily and cost-benefit assessments were not often made carefully. In consequence many early projects failed to complete technically, some were technical successes but failed to find the users of the products and a substantial number had difficulties to maintain organisational support and appropriation of resources, because benefits to the organisation could not be demonstrated.

GIS based on Cost-Benefit Assessment

GIS projects today must be based on a careful assessment of the benefits the GIS brings to the organisation. The information the GIS produces – what we call the ‘geographic information product’ – must be assessed for its value to the business and the overall contribution geographic information makes to the business goals must be evaluated. GIS that do not substantially contribute to the strategic goals of the organisation and are not cost effective should not be started, because they will eventually fail (this does not exclude that projects are made for demonstration and experimentation – the value of the experiences made is the benefit achieved and must be compared with the cost).

Distributed GIS

GIS are connected to the web and can be distributed: servers provide data that is used by many clients. In this sub-section we discuss aspects that relate to ‘close user group’ (or intra-net) solutions: data are collected and used by a small number of organisations. Contractual arrangements for protection of data, compensation, liability etc. are set up initially and cover a multitude of interactions.

Today, providing GIS data to a large and initially unknown group of users is possible. In such cases, contractual arrangements are set-up for each use. We treat this case in a later subsection under the heading of ‘E-commerce with GI’.

Technology

Today's web technology permits the connection of a user with any computer on the web. This is of great benefit to GIS, as it permits to integrate and use in combination data available at different places. The promise of spatial integration of data from different sources according to location can be fulfilled without the physical centralisation of data in a single location. Today's technology does not justify physical centralisation. Technically it is sufficient to connect the different data holdings logically using a distributed database system.

The design of new GIS applications must always consider the Internet as a means to distribute the data storage and thus resolve organisational problems of data ownership, and a means to deliver the results to a larger number of potential users.

Logical connections between data bases

The logical connection between databases permits us to treat the data found in multiple data collections as if they were a single logical data base and ask questions about the compound holding. This requires the construction of an integrated database schema, which indicates how the different data are brought to a common interpretation on which the query processor can operate (Devoegele *et al.* 1998).

No fully automated approach for schema integration is known today and often no complete integration is necessary. It is typically sufficient to identify the data which should be shared and describe the common semantics. This is best done in face-to-face discussions of the people responsible for data collection and data use.

Organisational aspects of distributed GIS

The potential of connecting the data holdings of different organisations and use them jointly, overcomes the reluctance of independent organisations to give up their ownership of data and bring them into a central pool. Organisations often believe (mistakenly) that having the data gives them power and do not understand that in today's competitive but co-operative world, sharing of information benefits both sharing partners. Technical means today permit to resolve all questions of data sharing – if a clear policy is agreed upon, the technical solution can be constructed, usually from standard components (Onsrud and Rushton 1995).

Data that is maintained by one organisation but made available to others can be protected such that only the first organisation can update it but all others can read it. A recent EU project has developed automated mechanism, which permits the co-operating organisations to propose updates to the data and send them for validation and integration to the 'keeper of the original' (Frank 1999).

Compensation for data use

Questions of compensations between users of data and the providers are difficult to address. Traditionally the discussion is oriented by the effort and the cost invested in the initial collection of the data and the cost of maintenance. It is recommended that the value of the data to the user is also considered (Krek 1999).

Metadata and Open GIS

Investigations in the potential for re-use of geographic data have shown that most users who would need geographic data do not know that others have collected them already. Advertising the availability of data is an important first step to realise re-use. The information that describes the data available is called meta-data, data that describes the data.

Standardised formats for metadata have been established. They help providers of data to collect necessary data in a uniform format, which can be inserted in a database and queried automatically. Unfortunately, the current metadata standards take mostly a data producer perspective. They describe in detail how the data was collected and treated. They do not respond to the user's questions about what the data could be used for (Timpf *et al.* 1996). The potential user must have extensive and detailed knowledge about data collection technology to deduce which data is usable for his application. Metadata are very important for the knowledgeable users, but they are not the answer to a widespread use of GIS.

Once data is localised, the transfer of the data and the conversion between the formats the data are stored in to the format in which they could be used is necessary. Widely used commercial data formats and standardised transfer formats are the condition to use off-the-shelf data translators.

The Open GIS concept brings interoperability into the area of the web: in stead of transferring complete data sets as files from computer to computer, the user can access the particular data she is interested in. The advantage is that the data accessed is the current, up-to-date version, not the version that was acquired and transferred a few months ago. To allow this, the client software on the computer of the user and the server software on the computer of the organisation maintaining the data collection must communicate the users precise need for data and communicate back the data required in agreed upon formats.

Open GIS makes it possible, that GIS software from different vendors can co-operate: it is not important that the same vendor provides all the software under which the data are collected and stored, different systems can be used and be accessed from software from various other vendors. From the user's perspective this avoids the trap of having the data in a proprietary format of one vendor and not being able to use software from other vendors or to incur high cost, when changing from one vendor to another one (Varian 1996).

The Open GIS consortium is an industry group, which sets the standards required for this interaction. It follows a layered approach. The same Open GIS standard can be implemented on various Internet interoperability standards and corresponds to the spatial extension of SQL.

Small, Business-Oriented GI

GIS in the past decades was mostly built for public administration to help them with the collection and management of spatial data for complex planning and administration purposes. A single organisation

managed the data and used them. IT, especially the web, has opened new opportunities: the use of GI in business.

New opportunities to start a business are created: Companies can collect and maintain data or assemble data from other sources into useful packages and make the data available for others. This makes a GI business possible, where the single user cannot cover the cost of collecting the data for the occasional use she has – but a multitude of users together create a viable business.

For example, Business geography – the use of spatial demographic data for business, in particular marketing – is a very rapidly growing field. Large companies acquire data sets and software for their marketing divisions to plan publicity campaigns, to identify regions where there is potential for increased sales etc. Small companies use geographic data not often enough to warrant acquisition of the data set. In a current EU project Small and Medium Enterprises are given access to the same geodemographic data and application software on a ‘pay per use’ concept¹.

These new opportunities to provide various business processes with the necessary geographic information in a cost-effective manner are very large: they are given in real-estate marketing, tourism, travel, road navigation, etc. One can assume that the volume of these businesses is in total much larger than the current GIS business, which is mostly addressing the needs of large, public organisations. In this ‘small GI’ business, each transaction is small, the amount of GI provided is small and the value is limited, but the number of transactions is very large. Consider, for example, a business to provide the nearest taxicab for each request for a small fee – once set up, a fully automated money-maker!

GI and Telecommunication

The past few years have seen a change in the telecommunication industry: the wire-based telephone system has changed to a wireless telephone and, correspondingly, the wireless broadcast radio and TV move quickly to a cable-based system. The potential for every person to reach and to be reached at any place by phone is very attractive. Diffusion of the GSM technology for telephones is extremely quick and the next generation of UMTS communication systems is planned as we write this. In some European countries, 70% of the population has GSM phones and the numbers are growing everywhere.

The ability to communicate person-to-person by voice telephones and between computerized systems is a major new factor for GIS. GIS is built on the promise to produce and deliver geographic information where it is needed and replaces the previous paper-based maps, where geographic information had to be produced ahead of times and distributed to all potential users who then had to extract the information they were needing – reading a dense topographic map and drawing the right conclusions is quite difficult! With GSM or UMTS a person in need of geographic information can connect to the GIS and get exactly the information needed at this moment. This is further simplified by the fact that the position of a GSM phone is known and can be used to select the information of interest for the user. Most obvious are examples from transportation, where a user can ask, “which

¹ For examples of geomarketing see: www.gismo.nl or www.wigeogis.at

street at this crossing leads to Hotel X”, or applied to users of public transportation “which bus will take me most quickly to Hotel X?” and “where is the bus stop?”

Technical development occurs not only for processor speed, disk capacity etc., what is widely advertised by the computer manufacturers, but also in the *form factor*. IT devices become smaller and therefore portable. Communication technology does away with cables and allows wireless communication. This makes it possible to carry computers and communication devices together with GPS receivers around. Manufacturers are working on integrating these – there is a palmtop cum GSM phone combination on the market and prototypes of GSM phones with GPS antennas are shown. Researchers discuss “wearable computers” (see MIT Media Lab - <http://www.media.mit.edu/wearables/>). The difficulties are technically with batteries and foremost with usability: constructing user interfaces for very small and powerful devices with many functions is a major challenge. Most users of GSM phones restrict themselves to a small percentage of the total functionality offered (very similar to VCRs) (Norman 1988).

This breakthrough in technology (communication, portability and integration of devices) relevant for geographic information opens the door for new services and therefore for new business opportunities. It is most likely that these services will be offered by independent private companies and it is, in the current political climate, not expected that governmental agencies will enter this market. Services could be

- emergency services for road side assistance, as well for persons travelling in cities by foot or using public transportation,
- information about the best mode of travel to a destination and then continuous information along the path (<http://gi13.geoinfo.tuwien.ac.at/users/winter/ss00/MobileNav.html>),
- information about services, from nearby restaurants, hotels and museums to general information based on ‘yellow pages’ helping people to find any business, or
- information for tourists about sights (e.g., information about special events and locations).

In each case, a potential provider has to evaluate carefully what the value of his service is to the customer and how many customers he may find to assess the economic viability of a business idea. Clearly, all these ideas require the availability of the base geographic data, e.g. topographic data, street network etc. and investments today in improving the quality of this data and the access to the data will pay off in the future fostering such new GI businesses.

GI Engineering

In order to systematically create the systems to produce the Geographic Information many users want, an engineering practice must be created and thought about. Only if the technology can be designed and created within predictable limits of resource utilization, the inspiring picture we have presented before can become reality.

The base technology to make it happen is available. Rules for its use – primarily software engineering and system design rules – emerge in Computer Science. The principles for the design of GI must be derived from GI Science (Goodchild 1990) and a GI Engineering discipline created.

Acknowledgments

This text is based on a contribution I made to the Panel-GI project coordinated by GISIG and funded by the European Commission. The international cooperation in this project and the many contributions from partners both from EU and outside have been helpful for me to understand the very complex situation better.

References

- T. Devoegele, C. Parent, and S. Spaccapietra (1998) On spatial database integration. *IJGIS* 12(4 - Special Issue): 335-352.
- A. Frank, M. Raubal, and M. Van der Vlugt, Eds. (1999) *Multi-Agency Databases to Manage Geographic Information*. GeoInfo Series 16. Dept. of Geoinformation, TU Vienna, Vienna.
- M. Goodchild (1990) Spatial Information Science. in: K. Brassel. and H. Kishimoto (Eds.), *4th International Symposium on Spatial Data Handling*, Zurich, Switzerland (July 23-27, 1990), pp. 3-12.
- A. Krek and A. Frank (1999) Economic Optimization of Quality for Geoinformation product. in: *AGIT 99*, Salzburg.
- D. Norman (1988) *The Psychology of Everyday Things*. Basic Books, New York, NY.
- H. Onsrud and G. Rushton (1995) *Sharing Geographic Information*. Rutgers: CUPR Press.
- S. Timpf, M. Raubal, and W. Kuhn (1996) Experiences with Metadata. in: *7th Int. Symposium on Spatial Data Handling, SDH'96*, Delft, The Netherlands (August 12-16, 1996), pp. 12B.31 - 12B.43.
- H. R. Varian (1996) Differential Pricing and Efficiency. *First Monday*.