INTERACTION ISSUES AND DECISION SUPPORT IN INTELLIGENT GIS

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Summary

The synergy of commercial GIS packages with other specialist systems and methodologies is usually imposed in order to build systems able to meet the requirements of advanced geographic applications. On the other hand, in order for a computer system to be usable by humans, it should provide an appropriate user interface. Recent experience shows that this can only be achieved if end-users are involved in all stages of the system design process.

The present study examines the issues regarding the connection of GIS to other software systems and with human users, towards the development of more intelligent and usable systems, called Intelligent GIS. Several prototype systems developed for different application domains at variable architectures and user interfaces are also presented.

1. Introduction

Geographic information systems (GIS), as any computer system, do not exist in isolation. They are connected: (a) to other systems and (b) with human users. The connection to other systems will enhance their functionality and upgrade their capabilities, while the successful connection with the human users will render them usable by people.

Current GIS packages, though powerful toolboxes, most with hundreds of functions, suffer from several limitations that render them inefficient tools for spatial decision making. Nowadays, there is a considerable interest in establishing the synergy of GIS with other specialist systems in order to meet the requirements of advanced applications. Systems synergy seeks to fuse capabilities available in the individual systems, leading into new and richer approaches to problem solving with high level of intelligence, namely *intelligent GIS* (IGIS).

The key of success for an IGIS is not only its enhanced functionality. The system should exist to serve human needs. Ultimately, the success of the IGIS rests on whether it can be used effectively by people, and support their decision analysis and making tasks. Recent experience indicates the need to involve users in all stages of the design process. The design process in turn should be iterative and integrate expertise from several disciplines.

The scope of this study is to examine the interaction issues of GIS with two unique and irreplaceable factors: (a) other computer systems and (b) human users. The discussion is organized as follows. Section 2 is focused on the synergy issues of GIS with other computer systems. After the examination of the candidate systems for this synergy, the two alternative configurations systems, interoperability and systems integration, are discussed. Section 3 concentrates on the interaction issues of a GIS with human users.

Specifically, it presents the basic types of interfaces in computer systems and focuses on the GIS interfaces and the operations provided to the end-users for manipulating geographic data. Section 4 illustrates these issues through the presentation of three prototype systems generated by the integration of commercial GIS packages with other systems, and analytic models for the development of intelligent systems to meet the requirements of end-users of different application domains. The interaction issues with both other computer systems and human users are highlighted. Finally, Section 5 concludes the discussion by summarizing the contribution of the study and presenting several open issues for future research towards the development of IGIS.

2. Connecting GIS to Other Systems

In general, there are two ways for establishing the synergy of current GIS and other software systems towards the generation of IGIS: (a) *systems interoperability*, the coupling of existing systems using linkage components—see *GIS Interoperability, from Problems to Solutions;* and (b) *systems integration*, design of a new system from scratch, which fuses all desired capabilities of individual technologies.

There are strong motivations to adopt the first alternative. A major factor is the high cost of building new comprehensive software systems from scratch, particularly when users' expectations for functions are set by the commercially-available GIS, spreadsheets, statistical analysis, visualization, modeling systems, and so on. In addition, these are sophisticated and complex systems, which are being continuously upgraded. Another consideration is the desirability of incorporating systems already in use in an organization and which represent a high investment in training, systems engineering and so on. On the other hand, the (re-)use of existing systems poses particular problems in achieving high performance and establishing a consistent user interface, simply because of the inevitable differences in data models, data transfer formats, and end-user interfaces between components. Hence the second alternative, the design of a new system, should be considered carefully as well.

2.1. Candidate Systems for the Synergy

Depending on the users' requirements and the application domain, different systems may be coupled with commercial GIS packages in order to achieve richer approaches to problem solving. The most commonly adopted systems are:

1. *Database management systems (DBMS)*. A DBMS consists of a set of programs that manipulate and maintain the data in a database. They were developed to manage the sharing of data in an orderly manner and to ensure that the integrity of the database is maintained.
2. *Model base management systems (MBMS)*. A MBMS performs a task that is analogous to that of a DBMS. Instead of handling data, an MBMS manages elements of models. Its purpose, like that of a DBMS, is to use a structure that supports the representation and exploitation of relationships between items and minimizes redundancy of storage. Thus, instead of individual pieces of data, an MBMS contains small pieces of code, each of which solves a step in an algorithm.
3. *Expert systems (ES)*. ES are computer programs that manipulate symbolic knowledge and heuristics to simulate human experts in solving real-world problems. More specifically, ES are capable of representing and reasoning about some knowledge-rich domain with a view to solving problems and giving advice. Thus, ES not only embody expert knowledge, but they also have the ability to recount the steps taken to solve a problem, as well as to gain proficiency at a particular task.
4. *Decision support systems*. (DSS). A DSS is a data processing system that provides a framework for integrating database management systems, analytical models, and graphics to improve decision-making processes. They are explicitly designed to solve ill-structured problems where the objectives of the decision maker and the problem itself cannot be fully or precisely defined.

2.2. Systems Interoperability Issues

The interoperability of GIS packages with other systems has been considered to date primarily through case studies. Early solutions linked a GIS and a single other system through file transfer of data, with the end-user operating both systems through their native interfaces. More recently, advanced systems coupling multiple systems with a common interface have appeared.

The major difficulty in coupling a GIS package with other software systems comes from the differences in their data models and schemata. At this point, the experience in the closely related field of *federated database systems* is of high value. A federated database system deals with the interoperability of multiple heterogeneous database systems that have been independently designed and retain some degree of autonomy in their operation. The differences of the individual systems are accommodated and handled through four specialist linkage operations:

- *Transformation operations*. They map data under one system schema to their equivalent under another schema (e.g., degrees Fahrenheit to degrees Celsius or a data set from an export format to another import format).
- *Constructor operations*. They provide a mapping of commands and data under a schema to a sequence of operations in two or more systems (e.g., the command "show burned areas" in a forest fire management system might be mapped in a constructor operation to a sequence of commands to fetch initial conditions from a GIS, transfer data to a modeling system, predict burned areas by the modeling system, transfer these areas to the GIS and produce a map display).
- *Accessor operations*. They execute a sequence of actions combining operations from two or more systems. An accessor operation might also assemble data fetched from two or more systems (e.g., an accessor operation might join the spatial description of an object, fetched from a GIS, with attribute data, fetched from a relational database).
- *Filtering operations*. They implement constraints on commands and data (e.g., syntax checks of commands, tests of the semantic integrity and checking of access permissions).

These types of linkage operation provide basic capabilities for coupling systems. Combinations and configurations of linkage operations can then be used to identify the major types of configurations of coupled systems, their support for fusing capabilities, and finally their usability. Coupling a GIS package with other software systems can also be supported by customized configurations of the linkage operations, so that differences in the individual models are handled efficiently.

The procedures for coupling individual systems together depend upon: (a) the number of systems involved and (b) the degree of tightness applied, that is, the types of linkage operation adopted. Hence, in a synergy scenario involving *two systems*, the possible configuration types are:

1. *Peer-to-peer architecture*. Both systems exist independently and communicate with each other, exchanging data and control. Only transformation (T) operations are present as linkage operations (Figure 1a). The two systems can exchange data, while the end user must initiate actions on each of the two systems separately. In general, this architecture offers poor fusion of

capabilities and low usability. On the other hand this configuration has typically low cost of implementation.

2. *Embedded system architecture*. One system embedded in another. Transformation (T), accessor (A) and constructor (C) operations are present as linkage components of the two systems (Figure 1b). One of them (the master system) has the capability to invoke actions of the other (the agent system). To the end-user, this capability is conveyed by the architecture as an ability to stay within the environment of the master system. In general, the embedded-system configuration can provide a higher degree of fusion of capabilities and higher usability compared to peer-to-peer architecture.

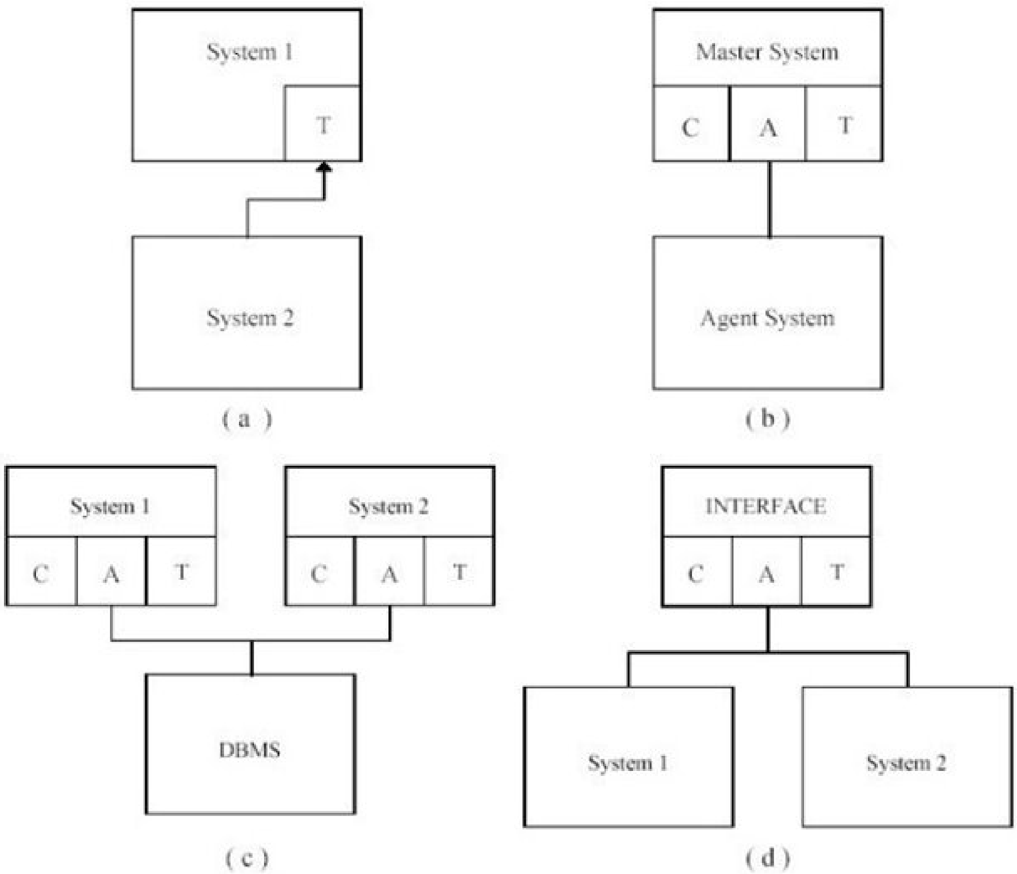

Figure 1. Configurations for interoperable systems

For a synergy involving *more than two systems* trivial extensions of the peer-to-peer and embedded-system configurations can be applied. However, the use of a common agent by the two or more masters for a specific function can provide particular benefits in fusion and usability. Two important functions are data management and end-user interface facilities:

1. *Common database manager*. The shared use of a common database management system has the particular implementation benefits of replacing

data transfer through export/import operations and of reducing data redundancy (Figure 1c).

2. *Common user interface*. A common interface module has potential advantages in both usability and the fusion of capabilities (Figure 1d). The usability benefits largely originate from providing a single external system schema to the user.

2.3. Systems Integration Issues

The use of existing systems for the generation of more powerful tools is accompanied by several problems in achieving high performance and establishing a consistent user interface. This is simply because of the inevitable differences in data models, data transfer formats, and end-user interfaces between the systems.

Hence, the alternative of designing a new system from scratch, which fuses all desired capabilities and properties of individual systems, should be considered carefully. Obviously, building such a system is a costly and time-consuming process. However, building integrated systems is likely to have a significant impact on the evolution of GIS. It forces a reconsideration of the strengths and weaknesses of the existing technology and provides fresh challenges to adapt and enrich that technology. To date, a few prototypes can be found in literature.

3. Connecting GIS with Human Users

Recent experience shows that successful computer support for human activity can only be achieved effectively if people are viewed as an integral part of any computer-based system. There are many cases where the lack of considering human factors in systems design has caused these systems to be unusable at critical times.

The term *human–computer interaction* (HCI) was introduced during the 1980s to define the study of computer systems with the emphasis on human users. HCI studies the interface issues between computer machines and humans by examining the psychology of humans when interacting with machines, as well as training, organization, and health issues. The user interface is no longer considered an optional extra, to be attached to the system after the rest of the design and implementation is complete. Quite the contrary, humans are placed at the center stage of design process. (For more details, see *Interacting with GIS: From Paper Cartography to Virtual Environments.*)

Three key aspects for successful system design have been proposed, taking into account the HCI issues. They must be

(a) *user-centered*,
(b) *integrated*, and
(c) *iterative*

The first aspect eliminates the temptation of letting technologists alone design the system. Users should be involved at all stages of the design process, especially those who will use the end product (i.e., the end-users). The second component integrates in the design process expertise from several disciplines, such as computer science, linguistics, philosophy, psychology, sociology, anthropology, ergonomics, engineering, design, and graphics. Finally, the third aspect suggests an iterative design process, so that users and the integrated disciplines are involved when appropriate.

The design of a GIS should be characterized by all three components above in order to meet the scope of its development: that is, to be usable by people and to produce information of value in a decision process.

3.1. Types of Human–Computer Interface

The interaction between a human user and a GIS or any other computer system is supported though different types of interface, which range from their earliest ancestor, the command line entry, to the most recent developments of graphical user interface (GUI) technology.

In *command line entry* type the user is provided with a command prompt where predefined and well-structured commands are typed. Those commands are recognized by the system and the corresponding operations are performed. The major disadvantage of this type of interaction is that the user must be aware of the valid commands and the appropriate syntax that the system expects. On the other hand, by adopting this type, experienced users may provide the system with precise instructions.

Menus provide another alternative type of interaction. A menu provides the user with a list of alternative options, which can be selected and affect the next state of the system. The major advantage over the previous type is that the user does not need to remember commands or their complex syntax. On the other hand, the amount of functionality provided by menus is limited. Different types of menus have been developed by software vendors to make systems user-friendlier, such as pull-down, pop-up, and roll-up menus.

Forms further facilitate human computer interaction. A form accommodates several heterogeneous pieces of information and the user is enabled to interact with all of them. For instance, in a GIS form-based interface, it is possible to select an object using the mouse and perform various types of editing, through the options of a pull-down menu, which depend upon the nature of the object. A more general type of form is the *dialogue box*, which enhances the communication between the system and the end-user. Appropriate graphic tools, such as buttons, check boxes and scroll arrows, facilitate the communication.

Natural-language dialogue is often proposed as the ultimate objective for human computer interaction. If computer systems were able to understand user commands, typed or spoken in everyday language (e.g., English, Spanish, or Greek), then everyone would be able to use them. However, this is not the case, because natural language does not bound the command set that an application program must handle and also can be ambiguous. In addition, current voice recognizers with large vocabularies must be individually trained to recognize a particular user’s voice. Natural-language dialogue can be applied in limited-domain and limited-vocabulary systems, in which users are familiar with the system capabilities, and hence it is unlikely to have unreasonable requests. Drawing programs and operating systems with natural-language dialogue interfaces have been developed in the past.

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Biographical Sketches

Emmanuel Stefanakis received his Dip.Eng. degree in rural and surveying engineering in 1992 from the National Technical University of Athens, Greece. In 1994 he received the M.Sc.E. degree in geodesy and geomatics engineering from the University of New Brunswick, Canada, and in 1997 the Ph.D. degree in electrical and computer engineering from the National Technical University of Athens, Greece. Since 1992, he has been involved in several research projects funded by the EU, the Canadian Government and the Greek Secretariat of Research and Technology. In 2000, he joined the Department of Geography at Harokopio University of Athens, as a lecturer. His research interests include geographic information systems, knowledge and database systems, cartography, and web technology. He has over 25 articles in refereed journals and international conferences in the above areas.

Timos Sellis received his B.Sc. degree in electrical engineering in 1982 from the National Technical University of Athens, Greece. In 1983 he received the M.Sc. degree from Harvard University and in 1986 the Ph.D. degree from the University of California at Berkeley, where he was a member of the INGRES group, both in computer science. In 1986, he joined the Department of Computer Science of the University of Maryland, College Park as an Assistant Professor, and became an Associate Professor in 1992. Between 1992 and 1996 he was an Associate Professor at the Computer Science Division of the National Technical University of Athens (NTUA), in Athens, Greece, where he is currently a Full Professor. Timos Sellis is also the head of the Knowledge and Database Systems Laboratory at NTUA. His research interests include extended relational database systems, data warehouses, and spatial, image and multimedia database systems. He has published over 100 articles in refereed journals and international conferences in the above areas. Timos Sellis is a recipient of a Presidential Young Investigator (PYI) award for 19901995, and of the VLDB 1997 10 Year Paper Award together with N. Roussopoulos and C. Faloutsos. He is a member of the Editorial Boards of the *International Journal on Intelligent Information Systems: Integrating Artificial Intelligence and Database Technologies*, and *Geoinformatica*.