THE SYNERGY OF GIS WITH OTHER SYSTEMS

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ABSTRACT

The synergy of commercial GIS packages with other specialist systems and methodologies is usually imposed in order to meet the requirements of advanced geographic applications. The paper examines the alternative scenarios regarding the synergy of GIS with other systems towards the development of Intelligent GIS. Several prototype systems developed for different application domains are also presented.

1. INTRODUCTION

Current GIS packages though powerful toolboxes, most with hundreds of functions, they suffer from several limitations, which 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 and lead into new and richer approaches to problem-solving with high level of intelligence, namely *Intelligent GIS* (Stefanakis 1997)

In general, there are two ways to go for establishing the synergy of current GIS and other systems towards the generation of IGIS:

a) *systems interoperability*, i.e., coupling of pre-existing systems using linkage components; and,
b) *systems integration*, i.e., 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, establishing workflows, database assembly, and so on.

On the other hand, the use of pre-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 (Abel et al. 1994). Hence, the second alternative should be carefully considered as well.

The purpose of this paper is to examine some issues regarding the synergy of GIS with other systems towards the development of Intelligent GIS. Several prototype systems developed for different application domains are also presented.

The discussion is organized as follows. Section 2 briefly presents some candidate specialist systems for the synergy with current commercially available GIS packages. Sections 3 and 4 examine the systems interoperability and integration issues, respectively. Sections 5, 6 and 7 present 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. Finally, Section 8 concludes the discussion by summarizing the contributions of the study and giving hints for future research towards the development of IGIS.

2. 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:

a) *Database Management Systems*: A DBMS consists of a set of programs that manipulate and maintain the data in a database (Elmasri and Navathe 1989). They were developed to manage the sharing of data in an orderly manner and to ensure that the integrity of the database is maintained.

b) *Model Base Management Systems*: A MBMS performs a task which is analogous to that of a DBMS. Instead of storing data, an MBMS stores elements of models. Its purpose, like that of a DBMS, is to use a structure, which 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 (Densham 1991).

c) *Expert Systems*: 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 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 (Rich and Knight 1991).

d) *Decision Support Systems*: 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 (Densham 1991). 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.

3. 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 been presented.

A reference model for interoperable systems proposed by Abel et al. (1994) draws on experience in the closely related field of federated database systems (Sheth and Larson 1990), which deals with the interoperability of multiple heterogeneous database systems, that have been independently designed and retain some degree of autonomy in their operation. By extending the database three schema model to system (such as a GIS or an environmental model), it is argued that many aspects of the task of coupling systems (the components of the integrated system) can be attributed to accommodating differences between external, conceptual, and physical schemata. Applying the federated database reference model four specialist linkage operation types are suggested to provide the means to accommodate those differences:

- *Transformation operations*: They map data under one components schema to equivalents under another schema (e.g., degrees Fahrenheit to degrees Celsius or a vector 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 by two or more components (e.g., the command "show burned areas" in a forest fire management 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 components. An accessor operation might also assemble data fetched from two or more components (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 operations provide basic capabilities for coupling systems. Combinations and configurations of linkage components can then be used to identify the major types of configurations of coupled systems, their capability for fusing capabilities and, to a lesser extent, their usability. For instance, the *loosely-coupled* architecture corresponds to the presence of transformation and accessor components, while the *tightly-coupled* architecture to all of transformation, accessor and constructor components.

For systems consisting of *two components* two basic types of configurations are possible, although many variants differing in implementation detail exist (Abel et al. 1994):

1. *Peer-to-peer architecture*: Only transformation (T) operations are present as linkage operations. While there is a capability for data transfer between the components, the end user must initiate actions by the components separately. In general, this architecture offers poor fusion of capabilities and low usability, however, it has typically low cost of implementation.
2. *Embedded system*: Transformation (T), accessor (A) and constructor (C) operations are present as linkage components. Here, one component (the master) has the capability to invoke actions by another (the agent) within a command stream expressed in terms of the constructs of the master's external schema. To the end-user, the capability is apparent as an ability to stay within the environment of the master component. In general, the embedded-system configuration can provide a higher degree of fusion of capabilities and higher usability.

For systems consisting of *more than two components* direct analogies of the peer-to-peer and embedded-system configurations exist as trivial extensions of the two-component architectures and their broad characteristics remain. The use of a common agent by the two or more masters for a specific function, however, can provide particular benefits in fusion and usability. Two important functions are data management and the end-user interface (Abel et al. 1994).

1. *Common database manager*: The shared use of database management system has the particular implementation benefits of replacing data transfer through export/import by in-situ data access and reducing redundancy (i.e., multiple copies of data).
2. *Common user interface*: A common interface module has potential advantages in both usability and the fusion of capabilities. Strategically, the usability benefits largely flow from providing a single external schema for the system rather than confronting the user with several schemata, which inevitably differ in some respects.

4. SYSTEMS INTEGRATION ISSUES

The use of pre-existing systems to the generation of more powerful tools is accompanied by several 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 the components (Abel et al. 1994).

Hence, the alternative of designing a new system from scratch, which fuses all desired capabilities and properties of individual components (systems) should be considered carefully. Obviously, building such a system is a costly and time-consuming process. However, building of 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 (Cambell and Cromp 1990, Abel et al. 1992, Leung and Leung 1993).

5. THE MEFISTO PROTOTYPE

The purpose of this Section is to present the *Mediterranean Forest Fire Fighting Integrated Strategic Tool* (MEFISTO) prototype (E.U. Environment Research Program developed under contract EV5V-CT94-0477 and funded by E.U.) (Lymberopoulos et al. 1996). MEFISTO is an Environmental Information System, which has been implemented by coupling a commercial GIS package with a forest fire simulator (an analytic model), in order to meet the requirement of end-users by providing them a system with high level of intelligence.

The aim of MEFISTO project was to develop a state-of-the-art, operational tool capable of forecasting the fire spread in relation to weather conditions, vegetation, topography, roads and other infrastructure information. This has been obtained by embedding the real-time forest fire simulator AIOLOS-F (developed under contract EPOC-CT90-0020, funded by the E.U.) into a customized GIS software package. The latter provides the simulator with all necessary geographic and meteorological data to predict the speed, direction and intensity of the fire front. The product of the project is a forest fire forecasting system. Appropriate graphics and panels are provided for easy data modification and immediate utilization of the results.

The MEFISTO prototype has been developed on an HP-Unix platform using the commercial GIS package GDS (Graphic Data System). The GDS (EDS product, Version 5.3.6) GIS consists of the following modules: a) *GDS Core*, being the integrated environment for GIS application building; b) *GDS Attribute*, to support the internal GIS development of a DBMS without the need of the employment of an external one; c) *GDS Site Modeler*, to develop digital terrain models from vector data; and d) *GDS EPI* (External Program Interface), used for the integrated development of programs in PASCAL, FORTRAN or C within the environment of GDS.

The MEFISTO prototype consists of five major components (MEFISTO 1996). These components linked together form the system architecture as illustrated in Figure 1

- *Input Data:* The input data required by the forest fire forecasting system fall into four categories: a) geographic data, b) fire data, c) meteorological data, and d) other data/parameters. Geographic data should be available before the fire, so that the geographic database is built; whereas the rest of the data are made available during the fire and hence they are real-time data.
- *GDS Software Package:* The GDS is the GIS platform on which the application has been developed. It consists of five components from the application point of view: a) input interfaces, b) data processing, c) geographic database, d) AIOLOS-F interface, and e) display and monitoring (i.e., output interfaces).
- *AIOLOS-F:* It is the forest fire simulator (analytic model) of the system. It is a program written in FORTRAN programming language which communicates with the GDS software package through the external program interface (EPI module).
- *Output Data:* The system output products take several forms, such as maps, tables and text. All these can be obtained and stored (i.e., maintain history) either in digital form (i.e., graphical displays or files) or in hard-copies (i.e., print-outs). System output products fall into three categories: a) predicted fire-front and temperatures at different points in time, b) predicted wind parameters, and c) other output data (e.g., pressure and density field, etc.).
- *User Environment:* The user interface assists the communication between the user and the system. Three subsystems (modules) have been developed to meet the requirements of the end-users. All three modules provide a user-friendly menu-driven environment.

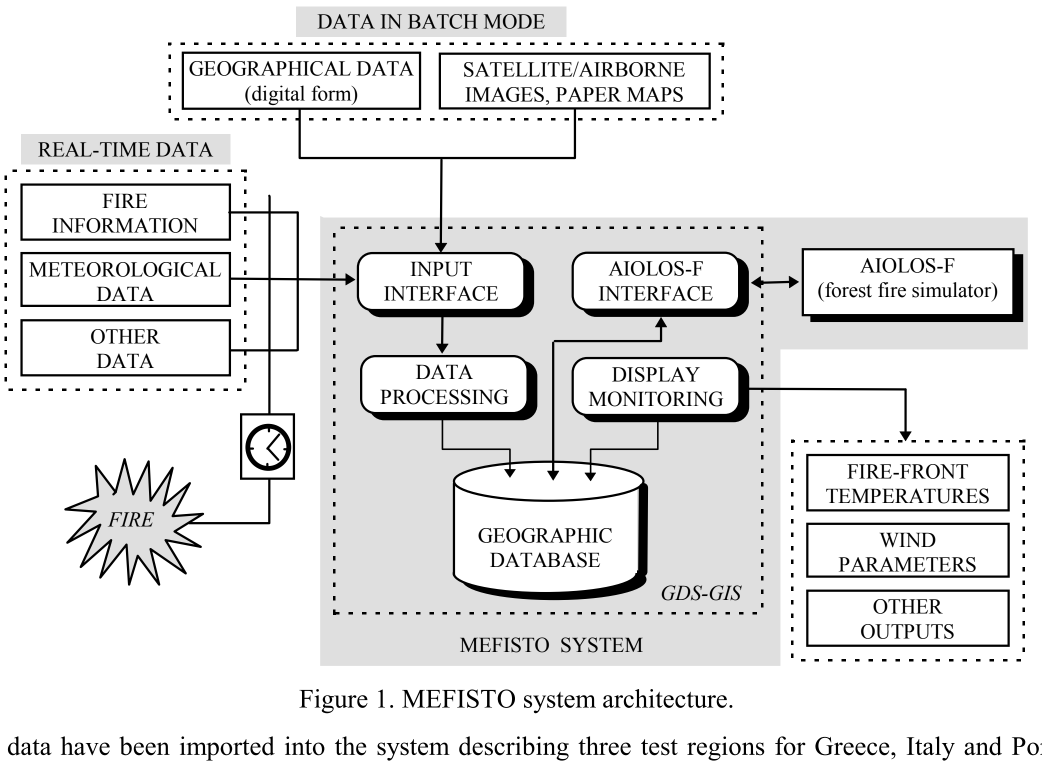

Figure 1. MEFISTO system architecture.

Geographic data have been imported into the system describing three test regions for Greece, Italy and Portugal. The resolution and accuracy of these data vary depending on the data sources. Figure 2 presents a typical working screen of the MEFISTO system. Figure 3 depicts the ignition points (light gray area), the area burned 20 (gray area) and 35 (black area) minutes after ignition, as predicted by the forest-fire simulator, for a test area of Attiki, Greece and a northern wind.

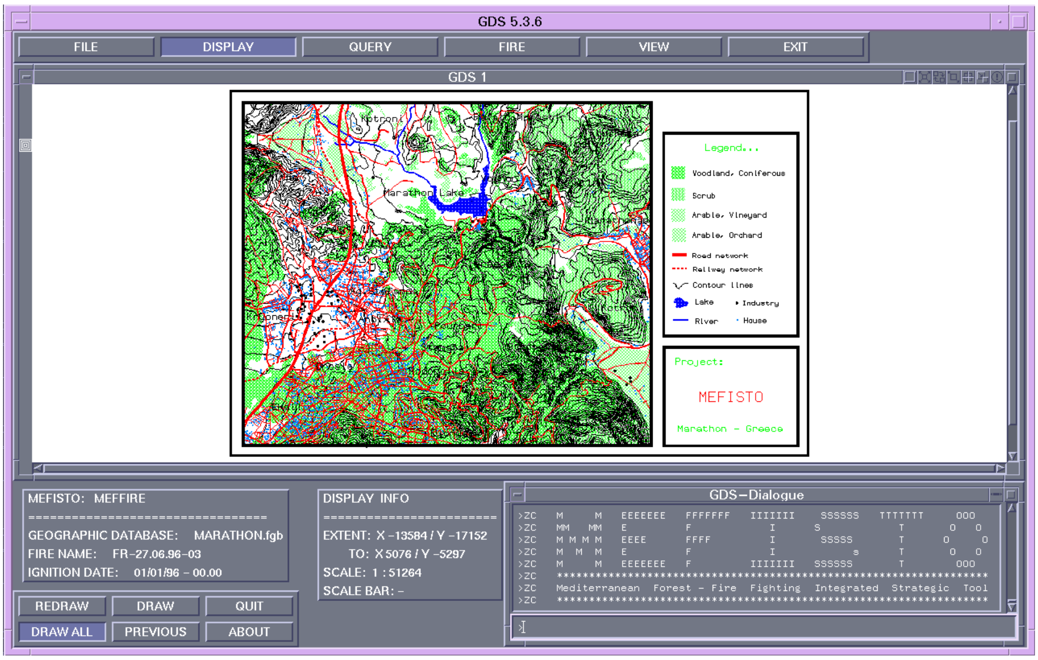

Figure 2: A typical screen of MEFISTO system.

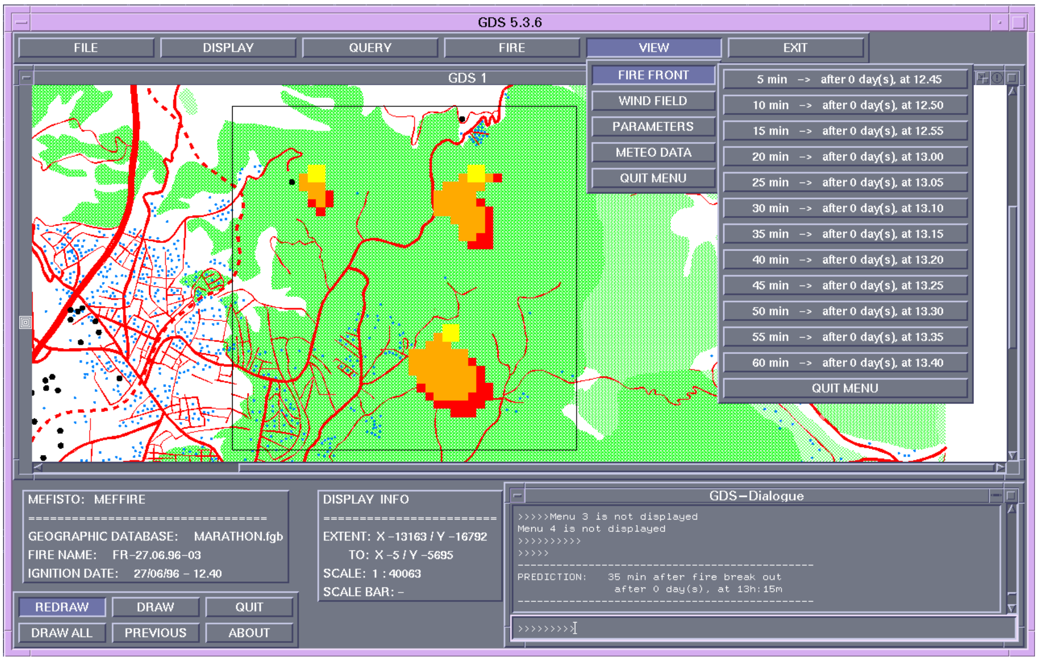

Figure 3. Three fire fronts at different time stamps.

6. THE ARCHAEOTOOL PROTOTYPE

The purpose of this Section is to present the *ARCHAEOTOOL* prototype (EPET-II Project, funded by the General Secretariat of Research and Technology of Greece). ARCHAEOTOOL is a computer-based tool to assist archaeological excavations and recordings, which has been implemented by coupling a commercial PC-GIS package with a commercial PC-DBMS, in order to meet the requirements of end-users by providing them a system with high usability.

Archaeological excavations constitute the way to approach societies and civilizations of the past, especially when written evidences are poor or non-existent. However, the destructive nature of the excavation procedure makes necessary the adoption of documentation methods for all accumulated information, so that a systematic and objective recording of archaeological findings and stratigraphic relations is achieved. The contemporary needs regarding both the excavation methodology and systematic documentation of information lead to the accumulation of a large set of data of various types, such as texts, catalogues, pictures, drawings, measurements, etc. The recording, management, and scientific exploitation of information derived from excavations constitute a hard task, which can be significantly assisted by the use of computer technology.

The research project ARCHEOTOOL (1997) resulted in the implementation of a prototype system, which adopts the capabilities offered by the computer technology, and is able to assist the recording and exploitation of the accumulated information from the excavation procedure. This prototype system has been adopted to assist the prehistoric excavation of Akrotiri in Thira island and the classical excavation of Dion in Olympus mountain.

The prototype consists of a set of tools which offer the following: a) simplification of the work performed by the archaeologists in a daily basis and improvement of the results quality; b) an integrated and accurate recording of both thematic and geometric information characterizing the excavation findings; c) generation of thematic maps of excavation area based on the information attached to them; and d) support of both geometric and thematic queries posed by archaeologists as part of their research activities.

The commercial systems used for the implementation of the prototype for the Akrotiri excavation are the MS-Access and the PC-MapInfo in the roles of the DBMS and GIS respectively. A set of tools have been implemented in both systems to meet the users' requirements. Specifically, those tools assist: a) the generation of appropriate paper forms and diary pages to record information accumulated by the excavation procedure; b) the updating of the thematic database by inserting data of the filled paper forms into the system; c) the querying of the thematic database; d) the generation of findings catalogs and diary pages, so that publications may be supported; e) the statistical analysis and evaluation of excavation data; f) the generation of the excavation area plans; g) the updating of the geometric database; h) the searching of both the thematic and geometric databases; i) the generation of thematic maps based on results derived from the statistical analysis.

The prototype architecture, shown in Figure 4, has been implemented (Cheras 1997) for the needs of ARCHAEOTOOL project. This architecture provides a common interface to both subsystems, which has been developed using a graphic and object-oriented programming tool for MS-Windows 95 (i.e., Visual Basic). Figure 5 illustrates a typical screen of the ARCHAEOTOOL prototype.

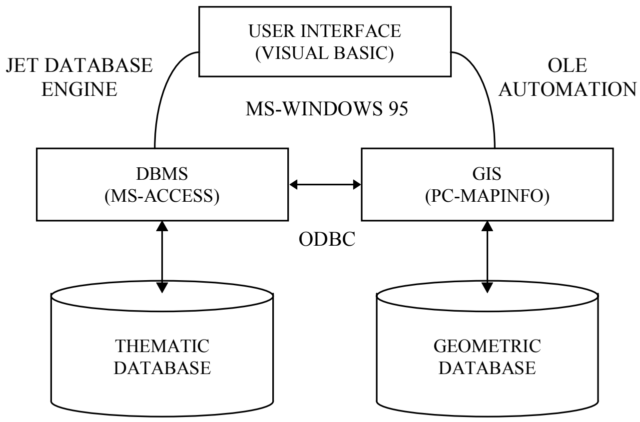

Figure 4. An advanced architecture for ARCHAEOTOOL system.

7. THE PATHFINDER PROTOTYPE

The purpose of this Section is to present the *PATHFINDER* prototype (Tsiakaliaris 1996). PATHFINDER is a GIS-based tool to assist different kinds of navigation, and has been implemente by integrating a path finding model into a commercial GIS package, in order to meet the requirements of end-users by providing them a system with high usability.

The prototype system integrates in PC-MapInfo software package the methodology for the optimum path(s) finding in a two dimensional space consisting of areas with variable travel cost measures assigned to them as introduced by Stefanakis and Kavouras (1995). The algorithm describing the methodology has been written in a MapBasic program, which works in conjunction with MapInfo. Appropriate user-friendly interfaces have been built to meet the requirement for navigation.

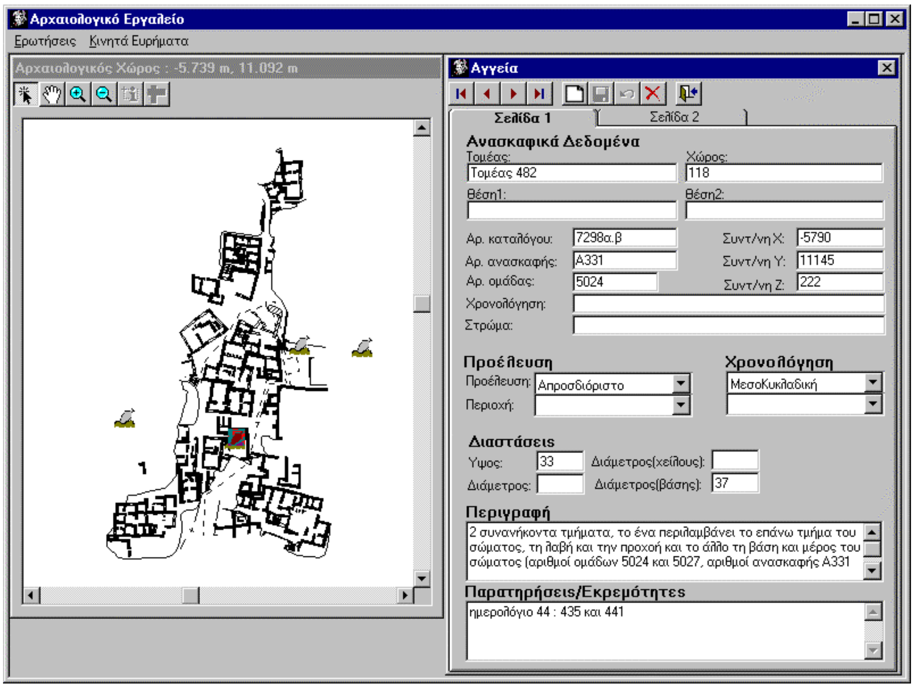

Figure 5. A typical screen of ARCHAEOTOOL system.

Figure 6 illustrates two examples of the graphic outputs generated by the system (statistical results are also provided). Specifically, Figure 6a indicates the shortest sea course between two harbors in the Aegean sea (pixel size is equal to 6 km; total cost: 70,2 km; direct and indirect neighbors considered; time required to compute the path using A^* algorithm: 1 sec in a P120 PC with 32MB RAM); while Figure 6b shows the fastest path from a given location to a parking lot on an orienteering map of Scotland (pixel size is equal to 5 m; total cost: 16 min and 9 sec; direct and indirect neighbors considered; time required to compute the path using A^* algorithm: 30 sec in a P120 PC with 32MB RAM).

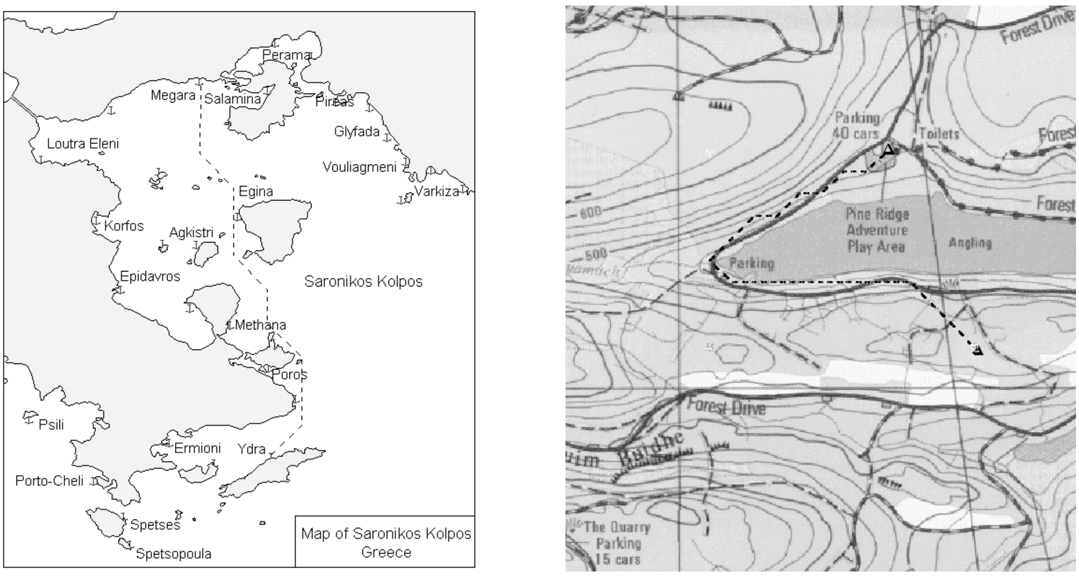

Figure 6. The PATHFINDER system: Real world examples of optimum path finding.

8. CONTRIBUTION AND FUTURE RESEARCH

The synergy of commercial GIS packages with other specialist systems and methodologies is usually imposed in order to meet the requirements of advanced applications. In general, there are two ways to go for establishing that synergy and end up with an intelligent GIS: a) through systems interoperability, and b) through systems integration. Both alternatives should be considered by application developers in order to build efficient systems and meet users' requirements.

The contribution of the study can be summarized as follows:

- A short description of the candidate specialist systems for the synergy with commercial GIS packages towards the development of intelligent GIS is given.
- Several issues regarding the synergy of GIS with other systems are examined, while the advantages and disadvantages of the two alternative ways are highlighted.
- Three prototype systems developed by coupling commercial GIS packages with other systems at variable architectures are described.

Future research in the area includes:

- A more extensive research on the issues of systems synergy and users' requirements. This study will assist the extraction of a basic set of functions that are commonly required by different application domains and should be integrated into the existing GIS packages.
- Design and implementation of effective techniques for the integration of analytic models into GIS software packages.

REFERENCES

Abel, D.J., Kilby, P.J., Davis, J.R., 1994, The systems integration problem. IJGIS, 8, pp. 1-12.

Abel, D.J., Yap, S.K., Ackland, R., Cameron, M.A., Smith, D.F., Walker, G., 1992, Environmental decision support system project: an exploration of alternative architectures for GIS. IJGIS, 6, pp. 193-204.

ARCHAEOTOOL, 1997, User's Guide. General Secretariat of Research and Technology of Greece.

Cambell, W.J., Cromp, R.F., 1990, Evolution of an intelligent information fusion system. PE&RS, 56, pp.867-70.

Cheras, A., 1997, A prototype system for archaeological excavations. Diploma Thesis, KDBS Lab, NTUA, Greece.

Densham, P.J., 1991, Spatial decision support systems. In Maguire et al. 1991, pp. 403-412.

Elmasri, R., Navathe, S.B., 1989, Fundamentals of Database Systems (Benjamin-Cummings).

Leung, Y., Leung, K.S., 1993, An intelligent expert system shell for knowledge-based GIS: 1. The tools, 2. Some applications. IJGIS, 7, pp. 189-213.

Lymberopoulos, N., Papadopoulos, C., Stefanakis, E., Pantalos, N., Lockwood, F., 1996, A GIS-based forest fire management information system. EARSeL Journal, 4(4), pp. 68-75.

Maguire, D.J., Goodchild, M.F., Rhind, D.W., 1991, (eds) Geographic Information Systems: Principles and Applications (Longman).

MEFISTO, 1996, User's Guide. Intracom SA, Greece.

Rich, E., Knight, K., 1991, Artificial Intelligence (McGraw-Hill).

Sheth, A.P. Larson, J.A., 1990, Federated database systems for managing distributed, heterogenious and autonomous databases. ACM Computing Surveys, 22, pp. 183-236.

Stefanakis, E., 1997. Development of Intelligent GIS. PhD Dissertation, National Technical University of Athens, Greece.

Stefanakis, E., Kavouras, M., 1995, On the determination of the optimum path in space. In Proceedings of the 2nd International Conference on Spatial Information Theory, Semmering, Austria, pp. 241-257.

Tsiakaliaris, C., 1996, A prototype system for the determination of the optimum path(s) on plane surface, Diploma Thesis, KDBS Lab, NTUA, Greece.