Improving optimization techniques with GIS

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Abstract

Spatial Decision Support Systems (SDSS) have evolved out the need to provide geographic information systems (GIS) users with the proper tools for which to resolve complex geanalytical problems. Given these tools, the user is able to make well informed decisions based on the problem at hand. The issue of telecom site and infrastructure planning, including analysis and selection, is a task that is well suited for such a system. A SDSS is currently under development in Croatian Telekom that will provide the casual, desktop GIS user with a user-friendly site evaluation and selection system combined with several standard optimizations techniques. The system was developed using VB programming for creating the user interface, and incorporates both the vector and raster data. ESRI Map Objects 2.0 component serves as the front end for accessing these site selection tools, model, and cartographic display.

The main purpose of this paper is not to discuss the detailed modeling issues such a system or description of optimization techniques, rather our emphasis is to show some thinking behind design and implementation of the system that may become a standard building block of the company decision support system.

Introduction

Geographic Information Systems (GIS) derive some of their problem solving power from engaging combinatorial optimization algorithms to find real-time solutions to large and complex spatial location problems. Most of these problems are NP-complete, and as such are intractable by using closed-form or exact solution techniques. The developments of computationally efficient heuristic solution techniques that can address the special needs of GIS (large scale, real-time problems) are lagging behind the general developments in the GIS functionality. This is evident by the few implementations of solution techniques to complex combinatorial problems that exist in current GIS, especially compared to the vast literature of solution techniques to these problems.

On the other hand, non-existing computerized tools for visualizing the problem data and its solutions have for long restricted the development of combinatorial optimization algorithms for spatial problems. Particularly, when developing iterative search techniques, such as the recently popularized tabu search (Rolland, Pirkul & Glover, 1996) and genetic algorithms, proper visualization of the problem data and solutions can help determine the various parameter settings required for these solution techniques to be successful. Without visualization tools, the proper parameter settings may be impossible, and the solution technique may not work for certain problem instances.

The dilemma here is that GIS itself holds the key to the visualization, and ultimately the successful solution of complex spatial optimization problems. Thus, the development of more powerful GIS relies on the use of GIS itself. We propose a solution to this dilemma, which can be implemented as a sub-system of a GIS. We present a general framework for an interactive, visual exploratory heuristic design system. The proposed system visualizes spatial optimization problems in several dimensions by giving a pictorial representation of the problem and its attributes, as well as of some problem parameters. By interacting with this GIS sub-system, the user can interactively communicate with the heuristic solution technique, modify the parameter setting, and study the effects on the problem in a visual manner.

The contributions of this research are as follows: We introduce the use of GIS in algorithm design. This should ultimately lead to wider availability of efficient problem solving methods in GIS. Moreover, we wish to promote a view of problem solving in GIS that differs from the current view of the mathematical or heuristic methods as a "black box." We hope to sensitize both GIS users and developers, and researchers in optimization to the unrealized benefits of interactive use of optimization techniques with GIS.

Linkages Between Optimization, DSS and GIS

Combinatorial optimization (CO) research deals with solving mathematically intractable problems. Many CO problems are grounded in data with a geographic dimension (i.e., location/allocation). The past research focus has not been on visualizing the underlying problem, but rather on finding efficient solution methods. GIS, on the other hand, focus on the visualization of geographically based data, but with little focus on complex problem solving. As such, GIS and CO are at two extremes. Bridging the gap between these extremes lies some of the research in decision support systems (DSS). Current research and practice in decision support systems show that most DSS also place a high emphasis on problem solving rather than problem structure and visualization. An inherent feature of most DSS is that they assume that the user has a fundamental knowledge of the problem and its dependencies. Thus, a user must first learn all the details of formulating and setting up a mathematical problem before utilizing such a system.

Research in the fields of human perception suggests the importance of using a graphical system (such as GIS), to represent complex problems. Applications in management have been sufficiently motivated by the limited mathematical skills of managers (Bell et al., 1984, 1985, & 1991; Hurrion, 1986), and this can likely be generalized to GIS users. The current state of research suggests that a graphical representation of a complex system of equations representing a transportation network is easy to understand and manipulate (Pirkul et al., 1995).
Past Research

The recent impact and importance of graphical interfaces in optimization are underscored by the number of papers that appeared in a text on new developments in the interfaces of computer science and optimization (Balci, Sharda & Zenios, 1992). Several graphical network editors and optimizers were suggested in this volume (EDINET, Ogryczak et al., 1992; NETPAD, Dean et al., 1992; GIN, Steiger et al., 1992). The importance of networks in modern day life has prompted extensive research in the fields of their representation and visualization. Becker et al. (1991) made an extensive examination of the utility of using computer graphics to represent large networks, such as the AT&T long distance network, and Anghern & Lüthi (1990) proposed network visualization in the context of DSS. Research in visual programming indicates that visualization can help enhancing users' understanding and remembering (Shu, 1989).

The common premise of the above research is that the ability of the human mind to process complex problems with many variables is limited (Miller, 1956; Newell & Simon, 1972). A visual display of the problem, as typically found in GIS systems, improves human understanding immensely. This premise is the very basis of our own research efforts: to build a bridge between the designer of combinatorial optimization algorithms and the GIS visualization engine. We go beyond past research, and present a system that aids the optimization experts in visualizing a class of complex optimization problems, and assisting in algorithm design. The system is based on an interactive cognitive human-computer interface, with intrinsic knowledge of an optimization problem.

SPATIAL DECISION SUPPORT SYSTEMS (SDSS)

The concept of spatial decision support systems (SDSS) represents an effort to address complex spatial problem solving and assist spatial decision making. Densham (1992) argues that by providing the user with a flexible problem solving environment, the user is able to increase their awareness and understanding of the problem task, as well as refine his or her knowledge of undesirable solutions. The components of a "true" SDSS as defined by Densham include the integration of a geographic database management system with analytical modeling capabilities, a visualization component or graphical user interface (GUI), and the decision making knowledge of domain experts (Densham, 1992). In addition the key aspect that separates SDSS from GIS are geographic information analysis (GIA) functions. These analysis components include:

1) support of analytical modeling;
2) appropriate spatial data to support the model;
3) flexible graphical (mapping) and tabular output; and
4) incorporation of flexible decision making processes.
5) incorporation of several optimization methods suitable for telecommunication purposes.

Lastly, Densham provides a framework for developing spatial decision support systems and provides theoretical design architecture. Armstrong and Densham (1990) discuss two groups of decision making approaches that may be incorporated into SDSS: programming techniques and heuristic methods. Programming techniques tend to be computationally intensive but always yield an optimal solution. Heuristic techniques yield sub-optimal solutions, however are able to provide recommendations more efficiently by means of suggesting a range of solution alternatives (Armstrong and Densham, 1990). The authors also discuss the most commonly used databases and their applicability toward SDSS. The rectangular data model, or geographic matrix, was found to be most appropriate when only one level of spatial aggregation is to be considered. Finally, the authors conclude that a newly developed hybrid data model is most suitable to spatial decision support systems, which is based on the entity-category-relationship (ECR) approach and an extended network model (Armstrong and Densham, 1990).

Project background

In past primary goal for most telecom operators in developing countries like Croatia was to reach all potential customers with telecom infrastructure, and do it fast. Shortage of adequate funding for replacing all older networks, leaded to weary heterogeneous situation (cables old up to 40 years in urban areas, cable insulations from paper to PVC, older networks with average lengths of 2,5 – 4 km, newer networks up to 1 km, etc.). Maintaining and restructuring such a network is quite complex problem; therefore an adequate documentation and planning system is absolutely necessary.

Today hottest question among telecom operators is QoS (Quality of Service) and how to satisfy customers and maximize profits. If you already have building blocks (applications, databases) such a described system, the logical next question is can you use this existing data to optimize, better plan and reconstruct existing telecommunication network (with acceptable margins of probability) and prevent or minimize network downtime.
When problem was initially defined the first assumption was that the simplified model of telecom network would be used. There are many reasons for that; real world telecom network consists of huge number of network elements, which are constructed from many smaller parts and so forth. Obviously, description of all that elements is big and difficult task. The relatively small Croatia has more than 1 800 000 subscribers connected with more than 2000 switches and that leads us to several millions connection points. Several projects are currently underway to establish company wide network inventory system and make connections to other IT systems in company.

Existing GIS database (not implemented in all TKC) currently holds site and schematic cable diagrams, duct and manhole drawings as well as OSP (DP, CCP) and switching equipment location and capacity. Georeferenced building and equipment locations with fault data attached are available for analysis. Up to now primary purpose of the GIS in HT was to support network operations and maintenance. Practically all departments use this database, primarily for real world visualization of telecom infrastructure, localization of demand for new lines, equipment and cable failure troubleshooting and future network planning.

When the GIS database was created, the primary goal was to establish connection between alphanumerical data in SQL DBMS and georeferenced information contained in numerous AutoCAD schematic and site drawings. In the future, special attention will be paid to adopt data acquisition and preparation procedures that will emphasize the importance of collecting new details in addition to O&M related data, and this is the direct consequence of the development and implementation of described system.

Along with telecom data GIS database contains data from local power company (high voltage installations, transformers), water installations, flood data etc. External meteorological database contains detailed data (daily acquisition) from many locations with temperature and precipitation.

Implementation of optimizing techniques directly into GIS system was done in Croatian Telecom few years ago when a customization of standard ESRI Arc View tool was done using avenue language and external dll written in C language (Šaric, 1996).

The project was successful in technology demonstration (integration GIS-optimization), but developed tools where never put in production because of lack of good GIS infrastructure in that time.

In last years HT Fixed Network and Mobile departments had gathered and checked significant amount of various types of GIS data, so decision was done to use existing knowledge and by means of modern development tools recreate old application. This includes rewriting optimization algorithms, better database integration and creating WEB based interface.

Result was that new standard tool was produced (fig 2.). Tool was created in VB and with ESRI Map Objects GIS engine and also has snap-in functionality; so new modules (as finished) can easily be incorporated. Until this moment two snap-in modules are in beta testing (implementation of basic access network optimization techniques and automatic generation of investment documentation).

Figure 2. New GIS framework for implementation of optimization techniques in access network

Generally all ideas from theoretical concept where confirmed on site testing, overall speedup of planning process is achieved, engineers working on new projects are satisfied by ease of use of new software and like integrated approach (everything needed for decision making process is few clicks away).

Summary and Conclusions

In this paper we presented a general framework for an integrated spatial decision support system. With the recent popularity of iterative search algorithms, there has been an emerging need for sound algorithm design and for finding decent parameter settings for these algorithms. Without proper visualization tools, such as a GIS system, the parameter settings and design might be difficult.

However, current GIS systems are not yet developed towards being interactive problem solving tools; neither for the mathematically untrained user, nor for the algorithm designer. By enabling our framework within a GIS system, we have a superior tool for checking new and old algorithms for solving many of the complex telecom optimization problems encountered within a GIS system itself.

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From Internet:

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