INTELLIGENT GIS AS AN AID IN URBAN PLANNING

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Abstract

Urban planning is a complex task depending on a great amount of data, knowledge and experiences of various experts, all of which make its automatization via conventional programs unsatisfactory. Problem space is too large to allow the optimal solution to be found in acceptable time, so artificial intelligence techniques must be used.

This paper presents the concept of PLEX, a knowledge-based system for urban planning. PLEX is based on GINIS, an object-oriented GIS architecture for inexpensive hardware platforms. PLEX uses GINIS's spatial data manipulation functions which access data from various sources, and user interface functions for data input and visualisation.

The intelligence of PLEX is obtained through a distributed intelligent agent architecture. Agents are separate programs which contain user interfaces and/or knowledge inference engines, and perform tasks typically performed by human experts. Some of the agents are completely implemented, while others are in the design stage. Completed agents showed great competence in their particular domains, and although the PLEX system is still in an early stage, we believe it could significantly improve urban planning process.

1 Introduction

Urban planning is an activity whose goal is the development of proposals for renewal and building new urban areas according to prespecified functional and aesthetical criteria. Urban planning is a complex task demanding numerous different resources. Classical methods of urban planning, which almost exclusively subsume work of a human expert, were inadequate, which was accepted as a fact in developed countries in early 1970s.

The basic characteristics of each urban plan are its functionality and aesthetics. Aesthetical qualities of a plan are very important, but cannot be described numerically and evaluated by objective criteria. Conventional programs cannot deal with such a task, and only knowledge can provide a higher level of services offered to users.

The first step toward automatization of this task was introduction of Geographic Information Systems (GIS). Early GISs provided means for retrieval, analyses and display of large amounts of data common in problems dealing with space [1]. Increased computing capabilities led to the "number crunching" or "sledge hammer" approach in modeling and planning urban phenomena [2]. The results of the approach are far from the expected ones, so artificial intelligence techniques, and especially expert systems, are being applied in particular areas of urban planning [3]. Lately some new GIS architectures appeared [4], which support human decision-making processes in urban planning.

In Computer Graphics & GIS Lab, the University of Nis, a set of GIS tools named GINIS have been developed. As the next step in automatization of urban planning, the development of PLEX system is underway as well as development of other similar systems (for example, MapSys — a spatial objects control system [5]). The following section introduces the concept of the PLEX system, while its particular components are discussed in sections 3 and 4. The evaluation of the system is presented with conclusions in the final section.

2 The architecture of the PLEX system

General urban planning is, as has already been emphasised, a complex task demanding knowledge and feeling for functionality and aesthetics. It is performed by teams consisting of urban planners, civil and electrical engineers, and other professionals from related areas. They all contribute to formulation of a harmonious and functional plan with their specific education and experience.

Conventional computer systems cannot solve this task in a satisfactory manner. Problem space is too large to allow the optimal solution to be found in acceptable time, spatial database is huge, and the knowledge is incomplete and unreliable. It is therefore obvious that the solution can be the application of knowledge—based systems. The best approach to solving such problems is cooperative work of multiple intelligent agents. Architectures based on multiple cooperative agents have been investigated broadly and are accepted as an appropriate solution for problems which involve multiple experts with different area of expertise [6; 7].

The main idea of the approach is to apply a "divide-and-conquer" strategy. The problem to be solved is decomposed into smaller subproblems which can be solved by one agent. Agents are programs which perform certain tasks or provide the user with assistance while performing the same. An PLEX agent contains up to two components: a processing module and/or a user interface depending on its role in the system. The Processing module can be a conventional program or a knowledge based expert system, depending of the task it deal with. Agents communicate by message passing. Messages are generated from input influences or certain events in the system. A message activates one or more agents interested in the event that generated the message.

In order to reduce the amount of knowledge needed by an agent, a special agent named Urban Planner Methodologist (UPM) is introduced. UPM contains methodological knowledge about urban planning, as well as knowledge about domains and functions of other expert systems. This agent is familiar with the goals of the system and all other agents and is to forward a message to all agents that could act upon it. The existence of such an agent has greatly increased the flexibility of the system and feasibility of other agents.

The architecture of PLEX system is illustrated on Figure 1. User defines goals to the UPM who then generates high level hypothesis which are sent to other agents. Some PLEX agents use GINIS functions in order to retrieve or analyse spatial database or for storage of intermediate or final solution of the urban planning process. GINIS architecture is discussed in more details in next section.

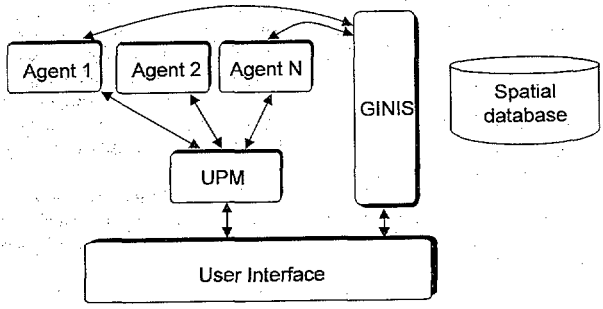

Figure 1. Architecture of the PLEX system.

The spatial database for urban planning contains several categories of data, topology of the land in form of a digital terrain model, containing a 3-D representation of terrain, statistical indicators of population density, development and usage of space, data about existing objects, which are very important because it is them which constrain a future urban plan, ecological data, also very important in urban planning

3 The GINIS system

The GINIS system is an open—architecture collection of GIS tools [8, 9]. It supplies user interface functions, input, storage, retrieval and display of data about objects. It provides a basis for an easy implementation of a problem—oriented system such as PLEX.

Two basic ideas underlying GINIS's design are: unified object-oriented data model is used for storing all data in the spatial database and a visual context is obtained by using scanned paper maps.

GINIS's object oriented data model is based on a hierarchy of spatial classes. The base class is a Feature which encapsulates temporal domain of all database objects. The subclasses on the first level encapsulate objects geometry, and they are: PointFeature, LineFeature, PolygonFeature and GridFeature. This classes encapsulate all data and methods necessary for manipulating geometric data about spatial objects. The next hierarchy level encapsulates the topological aspects of objects in subclasses NodeFeature, ChainFeature, TPolygon-Feature, ElevationModelFeature etc. The user develops a GIS application by deriving his/her own classes on the basis of predefined ones, adding relevant attribute data and corresponding methods.

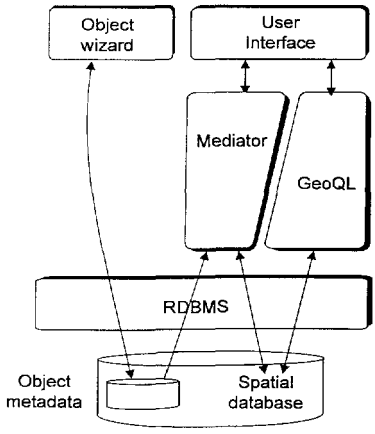

Figure 2. GINIS architecture

An important part of GINIS is also the collection of classes and methods for common attribute data types which are easily incorporated into user classes. ObjectWizard is an intelligent component of GINIS which supports the application development process using visual programming.

The implementation data model used in GINIS is the relational data model. All data necessary for mapping from Object oriented to relational data model and vice versa is generated by ObjectWizard and stored in the metadata repository. The mapping is performed by Mediator. GeoQL is an subsystem responsible for manipulating geometric data. It consists of compressor/decompressor functions for geometric abstract data types, spatial indexing facilities and an SQL extension. GINIS is implemented using ODBC application programmers interface so that spatial database can be located on inexpensive single-user systems or remote database servers.

Raster maps used in GINIS as visual contexts significantly improve the system's performances, because only objects retrieved from the database are the ones that are actually needed by the user. Besides this, raster maps enable fast head-up digitising and are close to the users, so training time could be reduced.

The architecture of GINIS expressed important advantages during design of PLEX. The user interface operates on cheap PCs, while the data management subsystem runs separately on file servers. In this way, a high level of data security is preserved, and cooperative work is supported. The spatial database can be distributed among several file servers, transparently to the user.

4 PLEX agents

As it was already mentioned above, urban planning is a complex task encompassing knowledge and activities from various domains. It is a typical task for knowledge—based systems. The problem of urban planning is decomposed in the PLEX system into a number of subproblems with very specific, restricted areas, with analogy with profiles and activities of human experts participating in the planning process. Each of these subproblems is solved by an agent.

While the development of GINIS is almost completed, the agents are currently in the design phase. The multi-agent architecture adopted in PLEX allowed for the high level of modularity in system's development — the agents can be developed simultaneously, since they are independent. No agent except UPM is aware of the other ones. Communication via the UPM agent enables an agent to utilise hypotheses (ie. partial solutions) developed by other agents. Since the knowledge contained in agents is incomplete and unreliable, and is an approximation of the real knowledge, there is a possibility of generation of incorrect hypotheses. Multi agent architecture expresses advantages over other architectures in such situations, because other agents could correct these errors, since they are completely independent.

PLEX solves problems through several phases. In the first one, a global frame of the plan is established, and is consecutively refined in the following phases. Input data consists of important factors, like the anticipated increase of population, priorities in directions for settlement expansion, proportion of family houses and buildings, growth of industry and business, anticipated population density in existing and new areas and alike.

UPM possesses knowledge about other agents in the system and general urban planning knowledge. This feature of UPM demands a longer implementation phase compared to other agents, but this knowledge provides the general control of the system. UPM generates global hypotheses for developing an urban plan, which consists of hypothesis aimed at specific agents which could contribute at the current problem state. UPM activates these agents by sending them appropriate messages, evaluate their results and decides upon the next step. GPE (Global Plan Expert) is the agent which contains knowledge of legal regulations in the area of urban planning. It determines required residence areas, number of schools, hospitals, day-care centers and similar institutions from the input data. GPE also anticipates average number of population movements per day, which is needed for planning traffic lines. Similar parameters are set in the areas of industry, business and infrastructure.

Other agents specialise in particular aspects of the plan. AAE (Areas Allocation Expert) is the agent whose goal is to distinguish areas which satisfy user's demands and hypotheses generated up to that moment from the available ones. Potential areas are obtained by retrieving the spatial database, with the query formulated on the basis of priorities in directions for settlement expansion, priorities in using free areas over populated, but non-functional ones and so forth. The results (areas to be potentially included in the plan) are ranked and the most promising ones are chosen. These areas are inputs for other agents, like LAE (Location Allocation Expert), an agent which determines positions for specialised institutions like schools, hospitals and others. Figure 3 illustrates rules that agents use in generating the plan.

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IF the object to be located is a hospital,
THEN air pollution of the chosen area must be very low,
     AND subterranean waters is medium to low,
     AND noise level is low,
     AND terrain slope is flat.
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Figure 3. An englishified example of PLEX rules

WRE (Water Resources Expert) and EE (Energy Expert) check whether partially-formed plan can fulfil population needs for water and electric power. WRE, for example, estimates if the existing pipes can supply enough water for new areas. If this is not the case, it determines the changes that are to be made, their price and feasibility. If any of these agents reaches the conclusion that the plan cannot fulfil the demands, it generates appropriate messages for the UPM agent. In that case, UPM rejects the plan and requests a new version by activating AAE.

5 Conclusions

Urban planning is a complex task depending on a great amount of data, knowledge and experiences of various experts. Basic characteristics of an urban plan are its functionality and aesthetics. Aesthetical qualities of a plan are very important, but cannot be described numerically and evaluated by objective criteria. Therefore, conventional, data—based programs like geographic information systems, cannot automate such a task completely, and only knowledge can provide a higher level of services offered to users.

This paper presents the concept of PLEX, a knowledge-based system for general urban planning. PLEX uses GIS tools for interfacing the user and for communication with the spatial database. The other modules of the system, based on the multiagent architecture, provide for realisation of such a complex function. System components are currently in different stages of development: while GINIS is finished, agents are in the design and knowledge acquisition stages. Some changes in the number or the structure of agents could be expected, but the adopted architecture supports such experimentation in the development of the system.

Evaluation of a knowledge—based system is far from being an established procedure. In most cases, the number of existing similar KB systems is too small to allow comparisons. We are not aware of any KB system for urban planning. On the other hand, even in situations when there exist several systems, they usually work in different environments, under diverse constraints, in disjunctive or even toy domains, and most of them has not reached the stage of maturity.

The reasons mentioned above prevent us from evaluating the PLEX system. We feel, however, that the open architecture of PLEX (specifically, the usage of RDBMS, window—based interaction and its multiagent architecture) gives the firm foundation for obtaining desired effectiveness of the system. Although the system is still in an early stage, we believe it will be a great improvement over existing systems.

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