Geomodeling: Georeferencing Real World Objects *

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Abstract

Geomodeling is the research theme of a pre-competitive research project undertaken by CRIM. It focuses on the role of image and data understanding in the general area of geographic information systems (GIS). The objective is to produce a computing environment capable of constructing, managing, and operating on geo-referenced spatial databases. The global architecture consists of four main components: Image/Data Understanding; Databases for models of real-world objects, features, and images; Knowledge Bases for domain knowledge, computer vision knowledge, and GIS knowledge; and Environments for Developers and Users. Each component is briefly described and results of one targeted application, Road Sign Recognition, are presented.

1 Introduction

This paper presents a pre-competitive research project undergoing at Centre de recherche informatique de Montréal (CRIM). The research theme is Geomodeling, which focuses on the role of image and data understanding in the general area of geographical information systems (GIS). The objective is to produce a computing environment capable of constructing, managing, and operating on geo-referenced spatial databases with the assistance of image understanding and knowledge based system.

Geomodeling concerns itself with the following four aspects of GIS functions: Collection and Correction; Storage and Retrieval; Processing and Analysis; Output and Report. For data collection and correction, a structured and integrated set of image understanding algorithms is provided to process geo-referenced data and images such as scanned maps or images captured by stereo cameras mounted on a moving vehicle equipped with global positioning systems (GPS). Successive applications of algorithms recognize instances of task-dependent models of the real-world objects (RWOs) and determine their precise spatial references. Figure illustrates the environment that allows a user to activate such a process, where a RWO is represented by a symbol in a utility map. Dedicated algorithms manage to find instances of the symbol model supplied by the user in the map and the map's longitude-latitude coordinates allow the computation of the RWO's exact position in the global geo-referenced system. The instances are then incorporated as part of the target application in the geo-referenced object databases.

For storage and retrieval, an important challenge is to develop technology for organizing and searching large spatial databases for efficient retrieval of images and spatial information regarding RWOs of interest to the users. To address user queries, image semantic characteristics may be associated with the actual images and stored together as complex image objects in the image database. These semantic characteristics play a major role in facilitating the actual object modeling phase of application development. The unifying attribute is the global positioning of the objects contained in the images. For processing and analysis, Geomodeling concentrates on the analysis of the data for the purpose of answering user's query on the RWOs, their features, and images. The output aspect of Geomodeling concerns mainly the interface of the RWO databases with various application packages of the users' choice.

The rest of this paper is organized as follows. Section 2 briefly reviews other existing projects of related research themes. Section 3 presents the global architecture of Geomodeling and briefly de-

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scribes its components. Section 4 describes one application of Geomodeling, Road Sign Recognition, that is targeted for building a road network information system. Other applications of Geomodeling are briefly mentioned. Finally, Section 5 reports the current status and future work for the project.

2 Related research projects

Research related to GIS conducted in the general area of computer science has been concentrated on spatial databases [7] and databases for GIS [11], map data processing [4, 9], visual information management systems [8], and GIS applications [10].

In terms of research theme, the project that is closest to Geomodeling among all on-going research projects is RADIUS. In particular, the objectives of the site model construction part of project RADIUS [2] is similar to what Geomodeling is aiming to achieve. RADIUS (Research and Development for Image Understanding Systems) is a five-year project funded by ARPA (Advanced Research Project Agency) to develop a prototype system to interpret aerial photographs for operational intelligence applications. The objective of RADIUS [6, 13] is to provide image understanding technology that can be deployed operationally. Site models are three-dimensional representations of facilities such as buildings, roads, parking areas, and other features in a location of intelligence interest. The input to the site model construction may be all possible source of data. Some image understanding systems are under development to automate the construction process, while fully automated systems have not achieved performance that would be considered operational. Researchers are investigating ways of organizing site model databases for the purpose of efficient site retrieval. While Geomodeling has very different targeted applications than RADIUS, it can benefit from the result of RADIUS in many aspects including decisions on the site model content and database design. Other than site model constructions, the role of image understanding in RADIUS is concentrated on change detection, which is not the concern of Geomodeling.

The objective of Geomodeling addresses the call of the NSF workshop on Visual Information Management Systems (VIMS) [8]. The management of visual information is one of the most important technologies needed across many traditional areas as well as new frontiers of computing. Amongst the major conclusions of the workshop were the requirement for innovation in all aspects of databases, computer vision, and knowledge management, and that such techniques are best developed in the context of concrete and practical applications. The workshop called on computer vision researchers to identify the characteristics required for interactive image understanding, rather than the discipline's current emphasis on automatic techniques. The workshop also called for knowledge representation research aimed at developing techniques for handling both symbolic and non-symbolic representations. To this end, Geomodeling is a research initiative addressing these issues, including a development methodology that undertakes the construction of real industrial applications.

3 Global Architecture

The global architecture of Geomodeling is shown in Figure 2. Two types of users are envisioned: the application developer, who is responsible for building the GIS application and associated databases; and the end-user, who interacts with the application for retrieval, analysis, and report generation. The architecture consists of four components:

1. Image/Data Understanding;
2. Databases for models of RWO, features, and images;
3. Knowledge bases for domain and image understanding knowledge;
4. Environments for Developers and Users.

Input data to Geomodeling is subject to the process of image and data understanding so that features and models of RWOs can be recognized and properly stored in the databases. The development strategy for Geomodeling is to construct a GIS-image-specific software layer on top of an image understanding (IU) library and knowledge-based environments.

Databases for RWOs, features, and images store recognized RWOs along with their features and images for use in the targeted applications. A well defined object class hierarchy benefits the efficient organization of object databases and eases the management of the complexity of real-life phenomena. Examples of RWO classes are city infrastructures (roads and road signs, bridges, buildings, etc.) and certain industrial infrastructures (electrical transformers, distribution lines, etc.).

The process of structuring RWO-related information into specific application databases employs domain-specific knowledge since similar arrangements of similar geometric primitives may identify different RWOs depending on the applications. Geomodeling provides facilities for building and maintaining knowledge bases for specific classes of RWOs according to application domains. Computer vision and GIS image understanding knowledge is also organized and maintained in knowledge bases. Creating an application requires that the application developer provide a *plan* of the task to be performed. The plan is composed of procedures which are either plans or specific image understanding algorithms. The application is executed when an inference engine interprets this plan by finding the appropriate IU algorithms according to the knowledge about 1) their functionality and characteristics, and 2) the problem to solve.

The development environment and the application environment provide all the necessary computational facilities for solving the problem of constructing software models of RWOs from georeferenced image and data. The user employs domain (problem-class) specific terms in communicating with the environment. As such there is no need for specialized knowledge of the underlying software and hardware. The components in the development and application environment are used in a concerted effort to develop, maintain, and execute a task-specific application.

4 Applications

One of our applications of Geomodeling is Road Sign Recognition. The objective of this application is to automate the process of collecting georeferenced data about various road signs for a road network information system. The input to the system are images captured by stereo cameras mounted on a GPS-equipped vehicle. The required entries to the database are: the location of the sign, the type of the sign, and the contents of the sign if it has any (e.g., the parking restrictions stated on a parking sign). The speed of processing is the most important issue for this application. With some overnight post-processing allowed, it is required that the system finish processing all the information acquired by the vehicle before it starts working on the next day. With the limited amount of time allowed for post-processing and limited amount of space for storing huge amount of digital pictures, the system will locate the signs in real time as the vehicle moves along streets at low speed. Once a sign is located, the stereo pair of images together with their GPS information will be stored for post-processing after which the sign and its contents will be recognized and its position computed. The combination of the GPS technique and image acquisition systems is widely used in the mobile mapping community ([5, 15], etc). An automatic insertion into the database can then be made.

Some work has already been achieved for real-time detection of road signs based on their color. Simple color labelling (performed according to federal regulations [1, 3]) reveals interesting regions in the scene where signs could be found, and a modified version of color indexing (popularized by Swain and Ballard [14]) is used as a validating tool in order to eliminate erroneous groupings resulting from the labelling pass and thus to cut down on the processing time required by an eventual shape analysis procedure (which is currently under development). Based on this approach, it is possible to detect signs such as turn restrictions and stop signs, even in cluttered road scene images. As an example, Figures 3 and 4 illustrate the type of processing being carried out by the system. These figures have been acquired by the right camera of the stereo pair.

Additional applications such as automatic map symbol recognition [12] and map warping [16] have already been created as part of Geomodeling. Moreover, work on contour line extraction from map images is currently under way.

5 Summary

We plan to complete our research and development on Geomodeling in the spring of 1997. Image understanding algorithms are being designed and implemented for the various applications of Geomodeling. Basic class hierarchies for images, features, and RWO models have been implemented using ObjectStore. Immediate work will be to complete the design and then implement the knowledge-based system components in Geomodeling. A knowledge base for image understanding is under construction at this moment.

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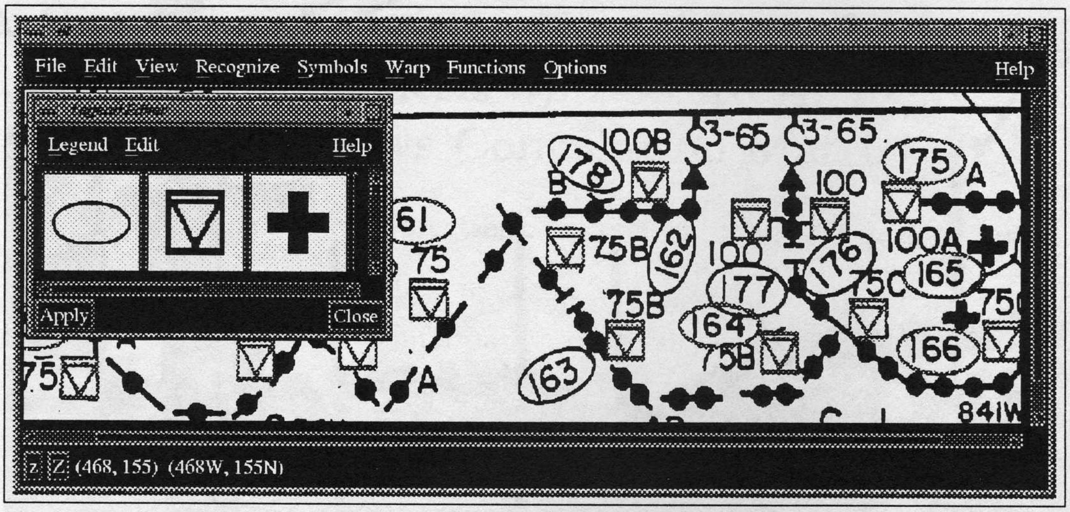

Figure 1: A snapshot of the environment of Geomodeling.

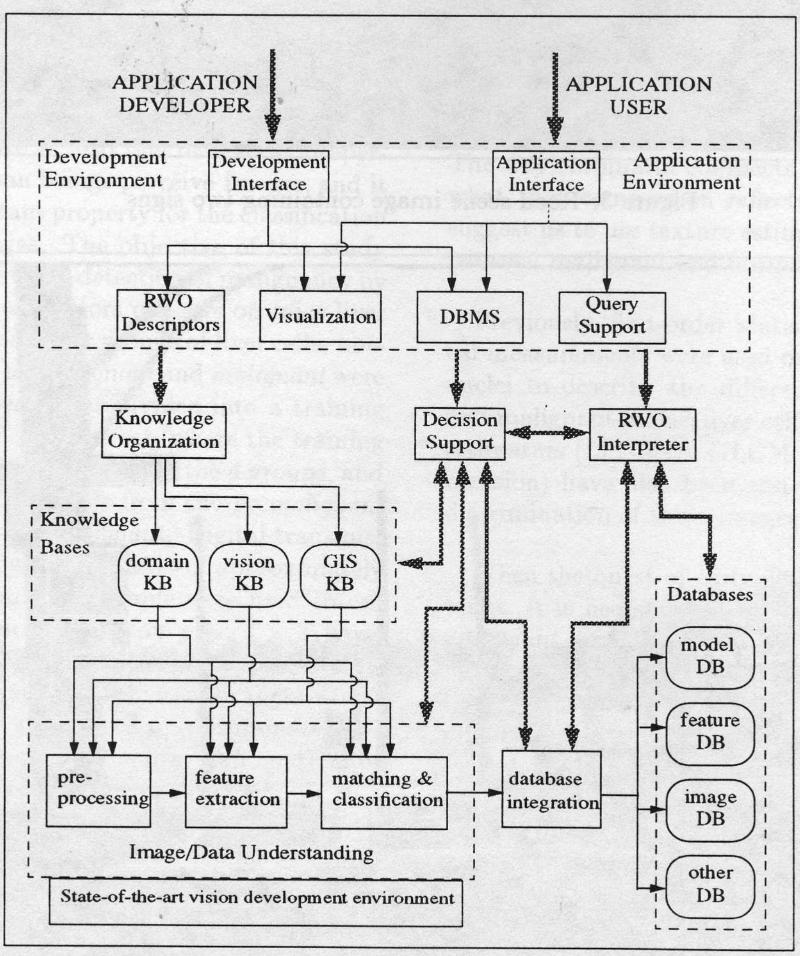

Figure 2: The global architecture of Geomodeling.

Figure 3: Road scene image containing two signs

Figure 4: Detection of the two signs (light boxes), with discarded hypotheses (dark boxes)