An Improved Planner for Intelligent Monitoring of Sustainable Development of Forests

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Abstract - An intelligent system for data fusion of remotely sensed imagery and geographic information, System of Experts for Intelligent Data Management (SEIDAM), incorporates a reasoning system or planner. The planner organizes automatically a collection of image processing, GIS, communications, and data base agents or expert systems. The agents are organized to accomplish a user-specified goal, such as perform a forest inventory update. A new planner, PALERMO/TO, has been developed which is 65% faster than an earlier version. SEIDAM software is available on the web; www.aft.pfc.forestry.ca.

INTRODUCTION

Global concerns about greenhouse gas emission and absorption have led nations to examine the utilization of forests. Forests which are managed in a sustainable manner should not contribute to further global warming. Canada, as with other nations with strong interests in forests, has developed a set of criteria and indicators for ensuring sustainable development of forests [1]. We have proposed that Canada use remote sensing as a major tool for 16 of 83 indicators and partially for 9 additional indicators [2]. To be effective for this purpose remote sensing data must be used with existing topographic data and GIS data, such as historical forest cover, ecozones, geological maps, and tenure boundaries.

The fusion of remote sensing data with existing geographic data necessitates the adoption of a reference system. Topographic data is the common choice for this reference and is used to geometrically correct remote sensing imagery. For interpretation of the remote sensing imagery one also requires field data and other geographic information (GIS) data. Field measurements of forest type, diameter, tree height, and stem distribution are stored in a relational data base. Data sources are often distributed. Thus there is a requirement to be able to rapidly access data for integration and use in data fusion for sustainable development indicators.

A prototype system, SEIDAM (System of Experts for Intelligent Data Management) [3], has recently been constructed which can perform data fusion for the updating of a forest inventory. SEIDAM uses commercial image analysis tools (PCI), our RIASSA image processing functions [4], commercial GIS software (ESRI ARC/Info), a relational data base (Oracle or Ingres), and a high-speed ATM communication link operating at 155 Mb/s. The ATM fibre optic cable links SEIDAM to agencies of the BC provincial government, such as the BC Ministry of Environment, Lands and Parks (BCMELP), and to Canada's information super highway, CANARIE. Geographic Data BC of BCMELP holds the 7,000 topographic 1:20,000 digital elevation maps. For example, as part of a session or project, a user selects an area of interest by forest region, district, timber supply area, and / or map sheet number. SEIDAM automatically connects over the ATM network to BCMELP, downloads the corresponding irregularly-spaced elevations, translates the file to a file format compatible with ARC/Info, and executes the agents needed to produce a triangulated irregular network, followed by a rasterized digital elevation model. A meta data database of imagery and GIS files is searched for corresponding data which are corrected and integrated with the topographic data. User-specified products or goals are then met. The planner (PALERMO) is that part of SEIDAM which reasons about past cases, user goals, and available agents in order to create a new sequence of agents (a plan) which meets the desired goals.

THE PLANNER

Most case-based reasoning systems rely on sophisticated indexing schemes and adaptation rules to find solutions to new problems based on stored solutions to old problems. As a result, these systems expend considerable effort in retrieving and adapting cases to new problems. We have added generalization to case-based reasoning. Once a case has been retrieved and adapted to a new problem, the system will generalize the old case with the new case by using an algorithm similar to least general generalization. As the system gains experience, the case-base is generalized and, as is shown by the experimental results, the number of cases required to solve problems is significantly reduced [5]. Goal-directed generalization is a learning approach that uses a notion of relevance in order to focus its generalization effort. When a case is retrieved for adaptation, literals describing the applicable pre-conditions are assessed to determine their relevance to the goal statement.

The system, dubbed PALERMO, (Planning and LEarning for Resource Management and Organization), has been implemented and integrated into the SEIDAM environment. SEIDAM is a complex system that uses several AI approaches to manage large quantities of remote sensing and geographic data. It draws on expert system technology, software agents and case-based reasoning to gather and process remote sensing and digital geographic data. Agents perform tasks for users in a deterministic fashion; i.e. the agent's behaviour is dictated by a finite state machine. The agents process and modify information contained in a knowledge base by adding and deleting objects (frames). These characteristics allow us to construct planning operators for each agent that describes the tasks they perform. Planning operators are composed of a pre-condition list and add and delete lists. By giving agents the ability to describe the task they perform to PALERMO, it becomes possible for the reasoning system to assemble seemingly simple plans that satisfy complex goals. This results in allowing PALERMO to do higher level reasoning since the agents are themselves responsible for providing the lower level services that could be otherwise expensive to reason about.

The approach in PALERMO is to use a narrow search control mechanism as the basic problem solver and to expand its coverage of the search space by using analogy. Analogy was used in the PALERMO [5] system to help address two main issues: add the ability to a linear planner to create plans that could only be formed by a non-linear approach and to improve the performance of system during plan formation. Both of these objectives were reached. The results presented in this paper show how this approach can be extended to and applied to non-linear planning systems as well. As a first step, we implemented a non-linear system based on the total order planner TO [6]. We then added a learning component based on explanation-based generalization that stored generalized problem solutions created by the planner. Finally, solution retrieval and re-use were integrated which allowed the system to make search decisions based on past experience.

RESULTS

Since PALERMO was tested using the logistic transportation domain, the new planner, PALERMO/TO, was also tested in this domain. It is a standard domain used to test other planning/learning systems [7]. This domain is composed of different locations, airports and post-offices, spread out across different cities. To travel between two cities, planes must be used. The goals in this domain are to deliver packages from one location to another. The problem generator generates a random number of cities (four to 10), a random number of post-offices per city (two to four), a random number of trucks per city (one to four), one airport per city, a random number of airplanes (two to 10) and a random number of packages (10 to 15). The packages are distributed randomly across all possible locations, the airplanes are distributed randomly between the airports and the trucks are distributed randomly across the locations within their respective cities. Finally, a goal is generated that specifies a destination for one or more of the packages. As discussed in [5], the logistics transportation domain is similar to the remote sensing/GIS domain in the complexities related to multiple goal statement conjuncts and the sharing or resources to satisfy complex goals. Just as the delivery of several packages can require the use of the same plane(s) and/or trucks(s), the update of forest cover maps stored in a GIS can require the results of processing several remotely sensed images as well as digital terrain models created from point elevation data or surface attributes collected during field work.

For all of the experiments we started with an empty case-base. We then proceeded to generate 1000 problems for each experiment. The first 100 problems had one conjunct goal statements to solve, the next 100 problems had two conjunct goal statements to solve, and so on until the last 100 problems which each had ten conjunct goal statements to solve. All of the experiments were conducted on a SUN SPARC 20 dual processor running Quintus Prolog 3.2 in the Solaris 2.5 environment. In Figure 1, we compare the performance of PALERMO, our implementation of TO and PALERMO/TO (TO with analogy). Along the X-axis, we plotted the problem sets. Along the Y-axis, we plotted the average time to solve each conjunct in the goal statements.

Clearly, both PALERMO and PALERMO/TO outperform TO. As the system must deal with goal statements with an increasing number of conjuncts, the performance degrades significantly, particularly when the number of conjuncts exceeds four. On the other hand, PALERMO and PALERMO/TO seem to perform similarly throughout.

In Figure 2, we have removed the TO plot from the figure 1 in order to get a better view of the actual differences in performance. On average, PALERMO/TO solves each goal statement conjunct 0.1 seconds faster than PALERMO does.

The improved performance of PALERMO/TO over TO was due to a reduction in the number of search nodes required to solve each problem. In TO, as the number of conjuncts grew, the number of search nodes grew exponentially. In PALERMO/TO, the ratio of search nodes over the solution length is approximately one; i.e. the system always makes a choice of operator to solve a conjunct that leads to a solution. The improved performance of PALERMO/TO over PALERMO is mainly the result of eliminating the merge step that PALERMO needed to add a case for a conjunct to the current working solution.

CONCLUSIONS

SEIDAM (System of Experts for Intelligent Data Management) contained a planner, PALERMO [8]. We have modified PALERMO (PALERMO/TO) and improved its performance by 65%. The performance of PALERMO/TO was evaluated in the traditional domain of logistics problems. We generated 1000 problems with 5500 goals and computed their solutions. The results in this domain on a SUN SPARC 20 were as follows. Our implementation of Minton's Total Order (TO) planner [6], which is a non-linear search producing a totally ordered plan without use of analogy (i.e. no cases), required a CPU time of 2 hr 46.3 min. The original PALERMO with full analogy and generalization solved these 1000 problems in 28.3 min. The modified planner, PALERMO/TO solved these problems in 19.0 min. using full analogy with learning based upon an explanation-based generalization. The modified planner, PALERMO/TO, with full analogy is a major improvement. Our explanation for this improvement is in the reduction of the ratio of solution lengths to search nodes. In PALERMO/TO, the ratio of solution lengths to search nodes is approximately 1. However, in the TO planner this ratio rises as the number of sub-goals increases. A multi-sensor fusion system must be fast to be applicable to large-scale monitoring problems. It should also make use of past experience or cases. The SEIDAM system achieves these goals. The system documentation, and software can be seen at our web site, www.aft.pfc.forestry.ca. We acknowledge support from Natural Sciences and Engineering Research Council of Canada, NASA, and Natural Resources Canada.

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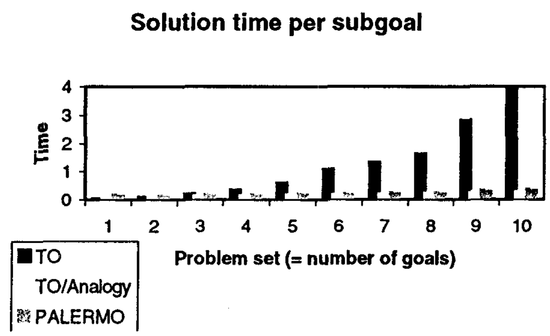

Figure 1. Time in seconds for three planners: Total Order (TO), Total Order with Analogy (PALERMO/TO), and PALERMO; versus the number of goals. The diagram shows that PALERMO/TO and PALERMO outperform TO demonstrating that the use of analogy can dramatically improve both non-linear and linear planners.

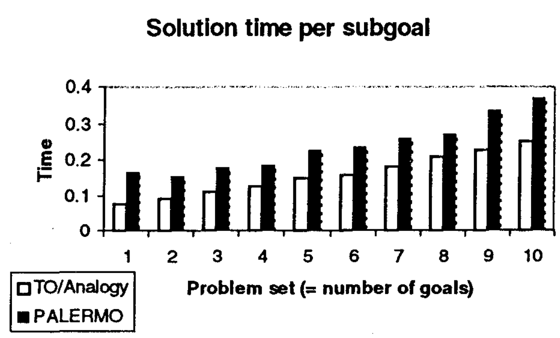

Figure 2. Time in seconds versus the number of goals. The non-linear planner, TO with analogy (PALERMO/TO), outperforms the linear planner because of the time required to generalize cases.