# Automated Forest Inventory Update with SEIDAM

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ABSTRACT – As part of the Applied Information Systems Research Program sponsored by NASA, a System of Experts for Intelligent Data Management, SEIDAM, has been created. As a component of SEIDAM, a case-based reasoning system called PALERMO was developed in order to reason about the process of digital forest inventory update. SEIDAM uses a set of software agents that carry out tasks such as translate point elevation data into a digital terrain model or import polygonal information from a geographical information file into an image format or ingest remote sensing data and update meta data databases. In this paper we discuss the new agents that were created for automatic classification and the ease with which they were added to the SEIDAM environment.

## INTRODUCTION

Due to the ever increasing exploitation of natural resources, it has become crucial that decision makers have a clear and concise picture of the actual state of the environment that falls within their jurisdiction. They can rely on modern database systems and geographical information systems (GIS) as a storage base for the information. In Canada, for instance, forest inventories stored in GIS are used by the provincial governments in order to issue tree farm licenses, logging permits, etc. In the province of British Columbia, forest products are one of the main economic resources. The province of British Columbia contains more than 40% of Canada's marketable timber. The main problem with electronic forest inventories is that they are seldom current to the present year and, therefore, may provide decision makers with inaccurate data.

In 1991, we began the creation of a System of Experts for Intelligent Data Management (SEIDAM) that could use remote sensing data to update existing digital forest inventories [2]. SEIDAM addresses several problems, two of which are intelligent data management and the processing of forest inventory and remote sensing information. As a component of SEIDAM, a case-based reasoning system called PALERMO (Planning And LEarning for ResOurce Management and Organization) was developed in order to reason about digital forest inventory update. SEIDAM uses a set of software agents that carry out tasks.

SEIDAM agents when activated in the proper sequence, can integrate automatically a topographic GIS file with a digital forest cover GIS file, and remote sensing imagery, such as from LANDSAT Thematic Mapper. Previously, once the integration was complete, the SEIDAM user was asked to manually digitize new clear cuts onto the digital map while using the image as a backdrop. After digitizing, SEIDAM activated another set of software agents in order to update the forest cover map given the newly digitized clear cut polygons. Since 1995, more software agents have been created. They now allow the user to use automatic classification algorithms and segmentation rather than carry out manual digitizing. The processing of these data requires expertise in several different fields: forestry engineering, database systems, GIS, remote sensing and digital image analysis. SEIDAM uses artificial intelligence technologies to perform both the management and processing of GIS and remote sensing data with a case-based reasoning system to assemble plans that can be executed to create integrated products [1,2].

## SEIDAM: THE SYSTEM

SEIDAM components are shown in Figure 1. In this diagram, data are stored in repositories shown outside the gray box. These data are the raw and processed forest inventory and remote sensing data as well as metadata describing the data sources. GIS metadata are stored in accordance with the FGDC standard and image metadata are stored following our standard. Inside the box, there are seven individual components: the SEIDAM expert system, the reasoning system, the smart access software agents, the image processing software agents, the GIS software agents, the SEIDAM knowledge base and the case base. A complete description of these components and the PALERMO reasoning system can be found in [1, 2].

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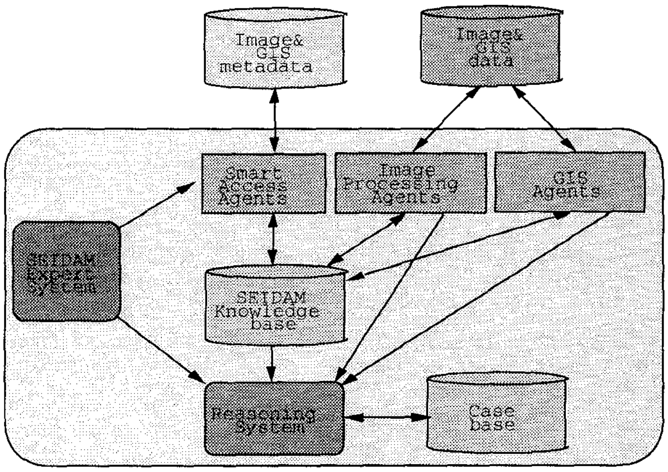


Figure 1. SEIDAM Architecture.

The Smart Access software agents utilize the user's goal statement to create SQL queries into the image and GIS metadata databases. The objective of these queries is to extract all of the information contained in the databases that is relevant to the user's goal. This information is placed in the SEIDAM knowledge base and is used by the reasoning system as its initial world. Software agents used by SEIDAM were specifically designed to work in conjunction with the problem solver. Each software agent is composed of: an expert system, a knowledge-base, a Prolog module containing a set of operators and a set of programs (software packages such as PCI image analysis or ESRI Arc/Info GIS). All of the agents were created with our training system called PAROT. This ensures that all agents are consistent with the requirements of PALERMO. The expert system component of the agent uses a set of procedural rules or sequences of steps that represent states and state transitions. A procedural rule normally fires an operator and then sets the next state according to the reaction of the program (a transition). This behaviour is a finite state machine (FSM) where each transition is deterministic.

## PLANNING

Table 1 describes how the SEIDAM environment maps into the requirements of a planning system. Let us recall the definition of planning:

*Given:*

- an initial world described by a set of facts (object-attribute-value triplets),
- a set of planning operators that have a pre-condition list, a delete list and an add list that describe: what facts must hold for the operator to be applicable, what facts will be deleted and what facts will be added,
- a goal statement containing the facts that must hold to satisfy the user's goal.

*Find:*

- a partially ordered set of operators that, if successfully applied, will ensure that the goal statement is satisfied.

Table 1. Problem solving in SEIDAM

| Planning | SEIDAM | Example |
|---|---|---|
| goal statement | product description | updated forest cover map |
| planning operators | SEIDAM agents | trim2dem: extracts a digital elevation model from a terrain resource information map<br>trim2dem::<br>if frame_get(current_map,name,A)<br>and frame_get(working_dir,path,B)<br>then delete [map(A,dem_file,C)]<br>add [ trim_to_dem,<br>map(A,dem_file,dem) ] |
| initial world | image and GIS metadata | digital elevation model filename /dwarf/robot/data/gis/092f013/dem |

In the context of SEIDAM, the initial world is described by the information contained in the metadata databases (e.g.: a digital elevation model exists in the file /dwarf/robot/data/gis/092f013/dem). Each operator in the set of planning operators describes how a software agent behaves (e.g.: the trim2dem software agent requires a terrain resource information map, TRIM, and produces a digital elevation model). The user's goal statement describes a product that would allow her to make a land use decision (e.g.: requires an updated forest cover map to determine whether or not to allow logging in a certain area; to create this product the goal would be that a forest cover file exists).

In a typical scenario for SEIDAM, a user selects a product used to make land use decisions via a graphical user interface. A product can be a digital forest cover map updated with TM imagery in order to determine change in the total area. The creation of this product becomes the goal that SEIDAM will submit to the reasoning system. SEIDAM's main expert system will then activate the smart access software agent that retrieves the relevant metadata from the remote sensing image and GIS metadata databases and stores the information in SEIDAM's knowledge-base. SEIDAM then submits the goal statement describing the product to the reasoning system. The reasoning system then creates a plan to satisfy the user's goal. If the reasoning system is successful, the plan is executed. The execution of the plan entails activating each agent in the order prescribed by the ordering constraints included in the plan. As the agents execute, they access, process and create new image and GIS data. After the successful activation of all of the agents, a product satisfying the user's goal has been created, and there is new information contained in the knowledge-base that must be stored in the metadata databases. SEIDAM will therefore activate the smart access agent to update the metadata databases.

## FOREST INVENTORY UPDATE

In [2], we showed how SEIDAM creates and executes a plan that integrates forest GIS files and LANDSAT TM imagery in order to allow users to manually digitize new clear cuts. This process is completely automatic and requires user input for digitizing only. The data integration and digitizing process is:

- `copy_files_to_working_dir`: this agent will copy the TM image and GIS files from the robotic mass storage device to a working directory on disk.
- `trim_to_dlg`: this agent translates TRIM GIS data into the digital line graph standard readable by Arc/Info.
- `import_hydrology`: this agent creates an Arc/Info hydrology coverage.
- `erdascp_lakes`: this agent translates the hydrology coverage into a PCI image file.
- `sieve_lakes`: since the hydrology data contains many small lakes, a smoothing filter is used to remove any lake smaller than nine pixels or 5500 $m^2$.
- `lakes_to_bitmap`: convert the smoothed hydrology image into a bit map.
- `trim_to_dem`: creates a point elevation file readable by Arc/Info from TRIM data.
- `create_tin`: create a DEM from a triangulated irregular network constructed with the point elevation file and place the result in an Erdas file format for input to PCI.
- `erdascp_dem`: create a PCI image file from the Erdas DEM file.
- `copy_bitmap`: copy the hydrology bit map into the DEM image file.
- `set_georeference_tm_large`: get geo-reference information from the TM image file and DEM image file and place it in SEIDAM's knowledge base.
- `create_tm_small`: create a small TM file that fits over the current map and copy a subset image from the original TM image file.
- `dem_to_pix_image_match`: copy DEM into small TM file.
- `set_georeference_tm_small`: add geo-reference information to small TM file.
- `tercom`: apply topographic relief to small TM file.
- `export_clear_cuts_to_pci`: export old clear cut vectors from Arc/Info to PCI.
- `digitize_clear_cuts`: allow user to digitize new clear cuts.
- `export_clear_cuts_to_arc`: export the new clear cut vectors from PCI to Arc/Info.
- `generate_products`: create any paper maps or tabular summaries of forest cover changes.

This process has been successfully applied. However, there are proven automatic classification methods, such as segmentation, that require even less user intervention. Indeed, once a segmented image has been created, the user need only select segments for clustering in order to produce a classified image. User intervention is reduced from manually digitizing cut block boundaries to pointing and clicking on clear cut segments.

The approach presented in [2, 3], shows that software agents can be trained to carry out the tasks listed in the process above. By using the same training interface, PAROT (PALERMO Agent ResOurce Trainer), it becomes a simple matter of training the system to perform cut block identification via segmentation classification. We have carried out this training and SEIDAM can now produce the a plan similar to the previous plan, but with the `digitize_clear_cuts` replaced with

```
create_gradient_image,
segment_gradient_image,
identify_cut_blocks,
cluster_image,
export_clear_cuts_to_arc,
```

Rather than performing manual digitizing, the user is now asked to assist during the classification process. The new steps are:

- `create_gradient_image`: the agent generates a gradient image using edge operators applied to six TM bands.
- `segment_gradient_image`: the gradient image is segmented and the segment boundaries overlaid on the image.
- `identify_cut_blocks`: the user identifies segments which are over new cut blocks.
- `cluster_image`: the segments are clustered and the new cut blocks are labeled.

We present an example of the automated capability within SEIDAM for forest inventory update using GIS and remotely sensed data from the primary SEIDAM test site, the Greater Victoria Watershed District (GVWD). Forest cover GIS files for the Greater Victoria Watershed District (GVWD) on Vancouver Island in southwestern British Columbia are used. The boundaries can be used as a mask to geographically constrain the remotely sensed data to the appropriate area. A LANDSAT TM image, shown in Figure 2 as bands 3 (R), 4(G), and 5(B), is fused with the GIS file.

The constrained image is segmented. Classification on this segmented image can help to ascertain certain structural units such as forest at various stages of growth, rock outcrops, and areas of forest cover change. Such a result from the segmentation process is shown in Figure 3. Structural units are clearly visible in the image as polygons. After classification, we obtain the result shown in Figure 4. In the final step of updating the polygon attribute database, the forest cover change polygons of Figure 4 are exported to the GIS data.

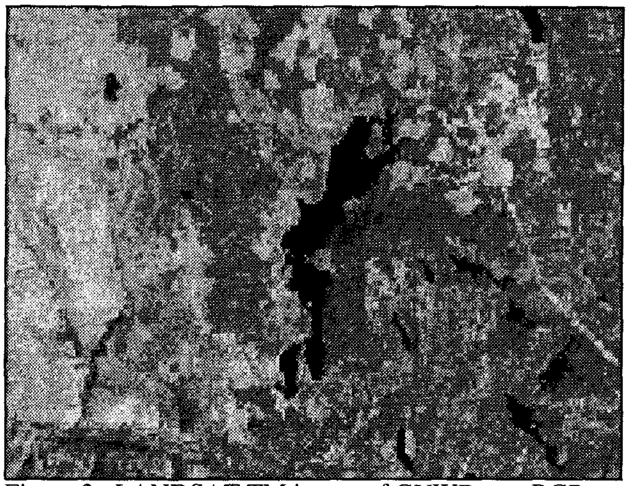

Figure 2 : LANDSAT TM image of GVWD as a RGB emulation with channels 3, 4 and 5 respectively.

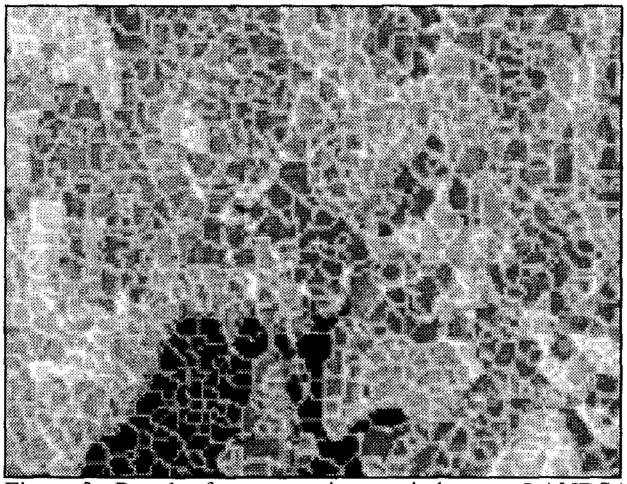

Figure 3 : Result of segmentation carried out on LANDSAT TM image of Figure 2 above. The segments are clearly visible in this result prior to classification.

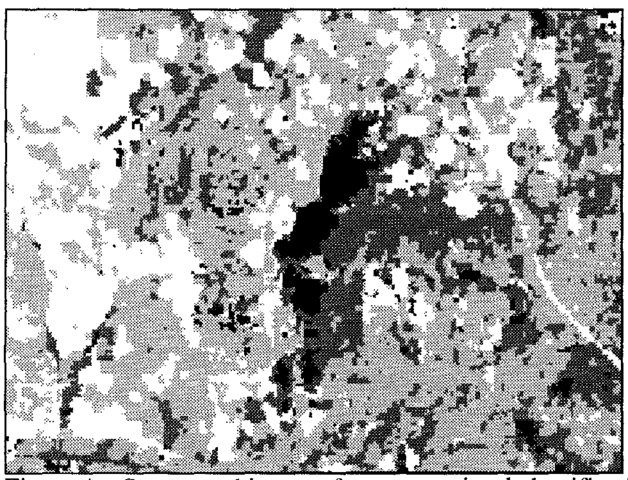

Figure 4 : Segmented image after user-assisted classification. Old growth appears as dark gray, younger vegetation areas appear as lighter shades of gray, and recent cut-blocks and rock outcrops appear as white. Water appears as black.

## CONCLUSIONS

SEIDAM can now execute forest inventory update using remote sensing imagery with automated image segmentation. The updated GIS files are stored in ARC/Oracle together with metadata conforming to FGDC standards. A CD-ROM has been created containing SEIDAM software and a test data set. The next version of SEIDAM will incorporate processing threads for AVIRIS and AIRSAR. Intelligent information systems make it much easier for users to use remote sensing data in their GIS environments.

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