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Automated Synthesis of Image Processing Procedures Using AI Planning Techniques *

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Introduction

This paper describes the Multimission VICAR (Video Image Communication and Retrieval[1]) Planner (MVP) (Chien 1994) system, which uses artificial intelligence planning techniques (Iwasaki & Friedland, 1985, Pemberthy & Weld, 1992, Stefik, 1981) to automatically construct executable complex image processing procedures (using models of the smaller constituent image processing subprograms) in response to image processing requests made to the JPL Multimission Image Processing Laboratory (MIPL). The MVP system allows the user to specify the image processing requirements in terms of the various types of correction required. Given this information, MVP derives unspecified required processing steps and determines appropriate image processing programs and parameters to achieve the specified image processing goals. This information is output as an executable image processing program which can then be executed to fill the processing request.

Currently, a group of human experts, called analysts, receive written requests from scientists for image data processed and formatted in a certain manner. These analysts then determine the relevant data and appropriate image processing steps required to produce the requested data and write an image processing program in a programming language called VICAR (LaVoie et al.1989).

Unfortunately, this current mode of operations is extremely labor- and knowledge-intensive. This task is labor intensive in that constructing the image processing procedures is a complex, tedious process which can take up to several months of effort. There are currently tens of analysts at MIPL alone whose primary task is to construct these VICAR programs. Many other users at JPL and other sites also write VICAR scripts, with the total user group numbering in the hundreds.

The VICAR procedure generation problem is also a knowledge-intensive task. In order to construct VICAR procedures, an analyst must possess knowledge of:

1. image processing and image processing programs (as of 1/93 there were approximately 50 frequently used programs, some having as many as 100 options)
2. database organization and database label information to understand the state of relevant data
3. the VICAR programming language to produce and store relevant information.

Because of the significant amount of knowledge required to perform this task, it takes several years for an analyst to become expert in a VICAR image processing area.

The MVP task targets automated generation of image processing procedures from user requests and a knowledge-based model of an image processing area using artificial intelligence (AI) automated planning techniques. In AI planning, a system uses: 1) a model of actions in a domain; and 2) a model

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[1] This name is somewhat misleading as VICAR is used to process considerable non-video image data such as MAGELLAN synthetic aperture radar data.

of the current state to reason about what actions to take to achieve some specified goals. By partially automating the filling of basic science requests, request turnaround time will be reduced, analysts' time will be freed for more complex and challenging science requests, and analysts' workload will be reduced.

VICAR is a general-purpose image processing programming language designed to promote the development and re-use of general-purpose image processing algorithms for MIPL needs. The primary function of VICAR is to allow individual image processing steps (called VICAR programs) to be combined into more complex image processing scripts called procedure definition files (PDFs). As one of their primary duties, MIPL analysts construct PDFs to perform image correction, image enhancement, construct mosaics, and to create movies and render objects. Individual processing programs perform functions such as:

photometric correction - correcting the image for lighting conditions due to the position of the sun relative to the imaging device and target,

radiometric correction - correcting for varying camera response depending on where in the field of view the image is read,

line fill-in - interpolating missing lines caused by data transmission errors.

By composing individual programs which perform these specialized functions, analysts can create complex image processing procedures (PDFs) to perform multiple types of correction and register the images to allow combination of multiple images into larger images.

The MVP Architecture

The overall architecture for the MVP system is shown in Figure 1. The user inputs a problem specification consisting of processing goals and certain image information using a menu-based graphical user interface. These goals and problem contexts are then passed to the decomposition-based planner which uses skeletal and hierarchical planning methods to classify the problem type and then uses this classification to decompose the problem into smaller subproblems. During this decomposition process, MVP determines which information on the database state is needed by the planner to solve the subproblems.

These subproblems are then solved by a conventional operator-based planner that uses the subproblem goals and initial states as indicated by the problem decomposition. The resulting plan segments are then assembled using constraints derived in the decomposition process. The resulting plan is then used to generate an actual executable VICAR PDF using conventional macro-expansion techniques.

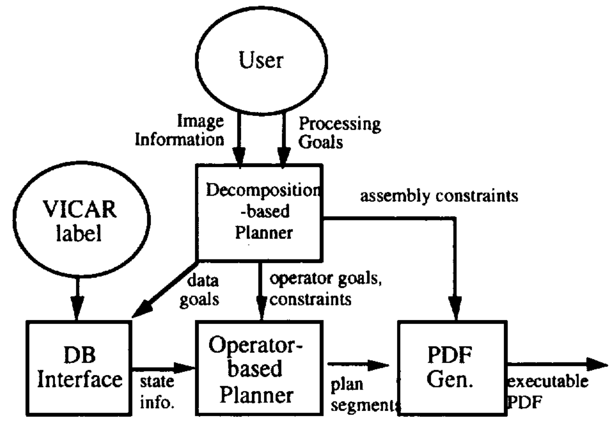

Figure 1: MVP Architecture

Plans in the MVP domain can be of considerable length (up to 100 steps) and each step (or VICAR program) can involve reasoning about numerous complex effects (many operators have tens of effects). Due to the large search space caused by this complexity, conventional operator-based planning approaches are not able to tractably construct plans in the VICAR domain without significant control knowledge.

Additionally, even if a purely operator-based planning approach were able to generate plans to solve the VICAR problems, these plans would be difficult for MIPL analysts to understand. Typically, analysts begin by classifying the general problem being addressed into one of a general class of problems, such as mosaicking, color triple processing, etc. They then use this classification and the problem context to decompose the plan into several abstract steps, such as local correction, navigation, registration, touch-ups, etc. A planning system which mimicked this approach to producing VICAR PDFs would be desirable.

Skeletal and Hierarchical Planning Using Decompositions in MVP

Skeletal planning (Iwasaki & Friedland 1985) is an approach to planning which casts planning as a structured classification problem. In skeletal planning, a planner identifies a new problem as one of a general class of problems, based upon the goals and initial state. This technique was originally developed as a model of experiment design in molecular biology; however, skeletal planning is also an accurate model of how expert analysts attack VICAR procedure generation problems. Typically, in a VICAR problem, there is a central goal for processing, such as mosaicking, which then dictates a decomposition of the overall problem into subproblems such as local correction, navigation, and registration. MVP attacks a VICAR problem by first determining the general problem class, and then using this problem class to perform an initial decomposition of the top-level image processing goals.

Hierarchical planning (Stefik 1981) is an approach to planning where abstract goals or procedures are incrementally refined into more and more specific goals or procedures as dictated by goal or procedure decompositions. MVP uses this approach of hierarchical decomposition to refine the initial skeletal plan into a more specific plan which has been specialized, based on the specific current goals and situation. This allows the overall problem decomposition to be influenced by factors such as the presence or absence of certain image calibration files or the type of instrument and spacecraft used to record the image. For example, geometric correction uses a model of the target object to correct for variable distance from the instrument to the target. For Voyager (VGR) images, geometric correction is performed as part of the local correction process, as geometric distortion is significant enough to require immediate correction before other image processing steps can be performed. However, for Galileo (GLL) images, geometric correction is postponed until the registration step, where it can be performed more efficiently.

MVP uses a decomposition-based approach (Lansky 1993) to perform Skeletal and Hierarchical planning. In a decomposition-based approach, decomposition rules dictate how in plan-space planning, one plan can be legally transformed into another plan. The planner then searches the space plans defined by these decompositions. Decomposition-based approaches are extremely powerful in that many other paradigms, such as modal truth criterion planning (Lansky 1993), can be implemented in a decomposition-based approach.

This decomposition-based approach to skeletal and hierarchical planning in MVP has several strengths. First, the decomposition rules very naturally represent the manner in which the analysts attack the procedure generation problem. Thus, it was a relatively straightforward process to get the analysts to articulate and accept classification and decomposition rules for the subareas which we have implemented thus far. Second, the notes from the decomposition rules used to decompose the problem can be used to annotate the resulting PDF to make the VICAR programs more understandable to the analysts. Third, relatively few problem decomposition rules are easily able to cover a wide range of problems and decompose them into much smaller subproblems.

Operator-based Planning in MVP

MVP uses classical operator-based planning techniques to solve subproblems produced by the decomposition-based planner. An operator-based planner uses: 1. a model of actions, A (in this case the model represents the requirements and effects of individual VICAR steps); 2. a specification of a current state, C (this corresponds to the current database state); and 3. a specification of a goal criterion, G (this corresponds to user request specification), to derive a sequence of actions, A', that when executed in the current state C, results in a state which satisfies the goal criterion G.

To illustrate this process, consider the following 5 simplified image processing operators shown in Figure 2. Preconditions are attributes which must be true of the image file before the step can be run, and effects are attributes which are made true by executing the step. This information can be summarized by the information shown below indicating the relevant programs for achieving the goals of missing line fill-in, spike removal, and radiometric correction for Voyager and Galileo images. When constructing a plan to achieve these goals, depending on the project of the image file (e.g., either Voyager or Galileo), MVP will know the correct program to use because the preconditions enforce the correct program selection.

Operator	VGRFILLIN	GLLFILLIN	ADESPIKE	FICOR77	GALSOS
Preconditions	VGR image EDR (binary header) present	GLL image	(GLL image) or ((VGR image) and (raw values))	VGR image	GLL image raw pixel values
Effects	missing lines filled in.....		spike removal	radiometric corr. blemish removal not raw values	radiometric corr. Reed-Solomon overflow corr. saturated pixel corr. not missing line fill-in

Figure 2: Simplified Planning Operators

However, determining the correct ordering of actions can sometimes be complex. In this case, the correct order to achieve the goals of line fill-in, spike removal, and radiometric correction is dependent upon the project of the file. In the case of Voyager files, ADESPIKE (spike removal) requires raw pixel values, and FICOR77 (radiometric) changes pixel values to correct for camera response function, so FICOR77 removes a necessary condition for ADESPIKE. This interaction can be avoided by requiring that ADESPIKE occur before FICOR77. VGRFILLIN requires a binary EDR header on the image file which is not maintained by ADESPIKE, this interaction can be avoided by requiring VGRFILLIN to be executed before ADESPIKE.

The Galileo case is slightly different. GALSOS undoes missing line fill-in so that it interferes with GLLFILLIN. This interaction can be avoided by enforcing GLLFILLIN after GALSOS. Additionally, GALSOS requires raw pixel values, and ADESPIKE alters the pixel values, so ADESPIKE interferes with this condition. This interaction can be avoided by requiring that GALSOS occur before ADESPIKE.

	Voyager	Galileo
fill-in missing lines	VGRFILLIN	GLLFILLIN
remove spikes	ADESPIKE	ADESPIKE
radiometric corr.	FICOR77	GALSOS
Execution Order:	VGRFILLIN	GALSOS
	ADESPIKE	GLLFILLIN
	FICOR77	ADESPIKE

This simple example illustrates the types of interactions and context-sensitivity that the VICAR image processing application entails. All of these interactions and context sensitive requirements are derived and accounted for automatically by MVP using the operator specification, thus allowing construction of plans despite complex interactions and conditions.

Current Status and Conclusions

MVP is currently operational and in use by analysts at JPL's Multimission Image Processing Laboratory (MIPL). Over a test suite of 5 typical mosaicking and color reconstruction tasks, an expert analyst estimated that MVP reduces effort to generate an initial PDF for an expert analyst from 1/2 a day to 15 minutes, and that it would reduce the effort for a novice analyst from several days to 1 hour.

MVP uses a combination of decomposition-based and operator-based planning paradigms to substantially automate the process of generating image processing procedures for radiometric correction and color triplet reconstruction. Current efforts involve expanding MVP to cover areas in filtering, stretching, and more complex relative navigation tasks.

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