

PROCEEDINGS OF THE 3rd ASIS SIG/CR CLASSIFICATION RESEARCH WORKSHOP

## Skeletal Plans Reuse: A Feature Structure Classification Approach

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In order to reuse the existing skeletal plans in the manufacturing process planning system PIM, in this paper, we propose a plan reuse framework, in which a feature structure is used as the address of a skeletal plan and reusing these skeletal plans is approached by retrieving the most specific general candidate and effectively modifying it. A taxonomic hierarchy of these feature structures and its discipline of classification are introduced for guarding the effective retrieval. Two applications of this proposed framework are described in this paper.

### 1 INTRODUCTION

Generating plans from scratch is a computationally expensive process. Often, a large percentage of planning problems, such as 80 percent of all mechanical engineering tasks, are solved by reusing old plans to fit the new situation [1]. A major obstacle to successful deployment of plan reuse mechanism schemes is how to map/fix/retrieve the appropriate plan that can be efficiently reused in the new situation through minimum cost modifications. Recent research [2] [3] [4] shows that efficiency can be greatly improved if the reuse mechanism has the ability to locate and retrieve an appropriate candidate and to refit the new situation by minimum modification.

In the manufacturing process planning system PIM [5] [6] [7], we utilize a skeletal plan to represent an expert's knowledge about the necessary manufacturing process for his workpieces or special parts of workpieces, described as feature structures. The complete production plan is then generated by performing a sequence of abstracting, selecting, refining and merging of these skeletal plans. The skeletal plan reuse becomes more important as the library collection of existing skeletal plans increases greatly and the workpiece becomes more complex.

In order to achieve the reuse of skeletal plans effectively, in this paper, we propose to provide a conservative retrieval strategy to carefully select an appropriate existing plan and to fit it to the current situation by modifying it. This requires us to generalize feature structures associated with the skeletal plans and to classify them into a partial taxonomic space. From the taxonomic hierarchy of feature structures, we can easily find the best candidate and modify the retrieved skeletal plan to fit the new workpiece.

### 2 OVERVIEW OF PIM

The PIM system (Planning in Manufacturing) is a knowledge-based Computer Aided Process Planning (CAPP), which provides a set of representation formalisms to bridge the representation

gap from CAD to CAM and to reduce the complexity of the problem (CAPP). The application feature representation language FEAT\_REP (FEATure REPresentation)[7], and an expert's process planning knowledge representation language SKEP\_REP (SKEPeletal plans REPresentation)[6], are two of these formalisms. The skeletal plan is proposed to represent the expert's knowledge about the necessary manufacturing process for his workpieces or special parts of workpieces. These special parts of workpieces can be described as feature structures in PIM, one kind of feature graphs. Feature structures denote the internal structures of these associated skeletal plans. A skeletal plan for a "shaft-crest" is illustrated in the left side of Figure 1, in which the feature about the "shaft-crest" workpiece is specified in the operational feature structure of this skeletal plan. Skeletal plans are associated with and dependent on features. The features associated with these skeletal plans describe the manufacturable parts of the workpiece. A complete production plan is generated by performing a sequence of operations of skeletal planning such as selection, refinement and merging.

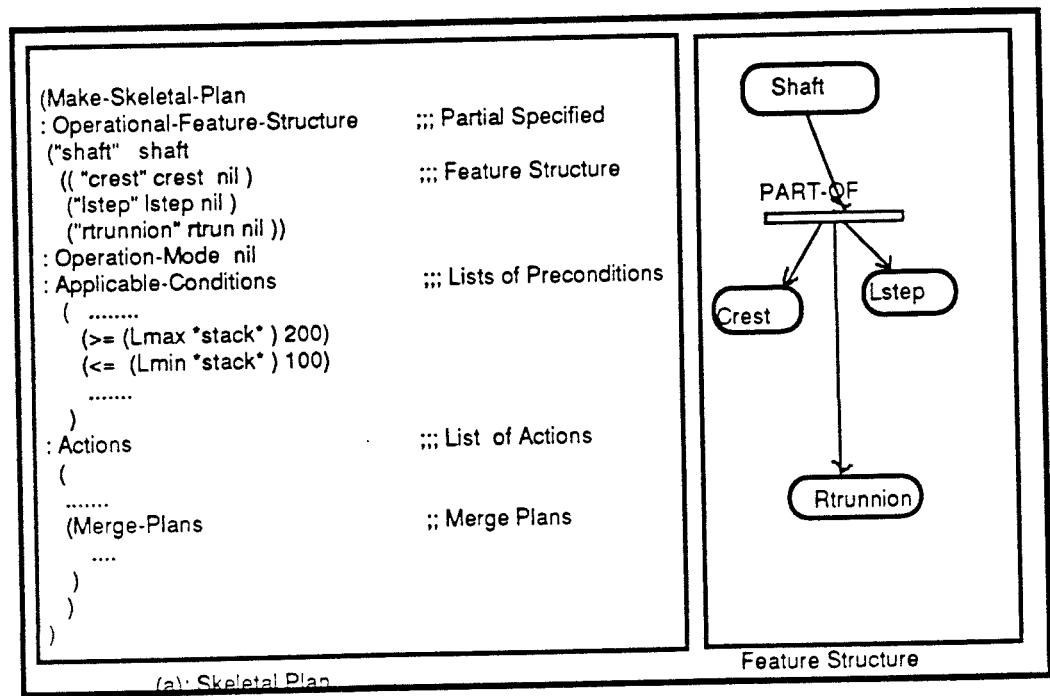


Figure 1: A skeletal plan and its corresponding feature structure

The strategy behind PIM is to reuse previous skeletal plans for a different workpiece or in new working environments. In many cases in PIM, the reused skeletal plan can be used to adapt to new situations or to improve the performance, e.g. acquiring new skeletal plans through reusing existing skeletal plans, and speeding up the procedure of skeletal planning by reusing some previously planned skeletal plans. Therefore, introducing an effective skeletal plans reuse framework becomes more important.

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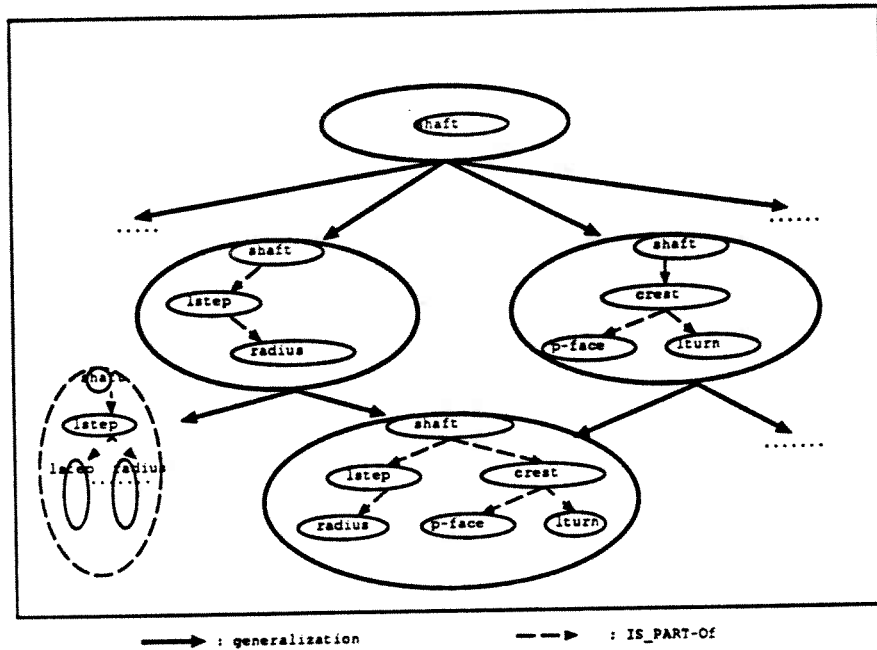


Figure 2: A taxonomic hierarchy of *feature structures*

### 3. CLASSIFICATION OF FEATURE STRUCTURE

In our framework, we introduce the generalization relation between these feature structures and classify these into a generalization hierarchy of feature structures.

#### 3.1 Taxonomy of Feature Structure

Generalization defines a partial ordering of feature structures called the generalization hierarchy. For any feature structure  $U$ ,  $V$  and  $W$ , the following properties are true:

- Reflexive:  $U \subseteq U$
- Transitive: If  $U \subseteq V$  and  $V \subseteq W$ , then  $U \subseteq W$ .
- Antisymmetric: If  $U \subseteq V$  and  $V \subseteq U$ , then  $V = U$ .
- Top:  $T \supseteq U$
- Bottom:  $U \supseteq \perp$

An illustrated taxonomic hierarchy of feature structures is shown in Figure 2, where the "shaft" feature is a generalization of the "shaft-lstep" feature. The generalization hierarchy of feature structures is built by classification.

### 3.2 Classification Algorithm

To classify a feature structure in the hierarchy, we need to compute the set of immediate generalizations and the set of immediate specializations of it in the hierarchy. This information gives us the virtual address for inserting it into the hierarchy.

The algorithm illustrated as follows for classifying a feature structure in the graph form in the hierarchy.

---

```
(defun classify (gname) ;; gname is the given name of feature graph
  (let ((gr (get-cgraph gname))) ;; Getting feature graph from hash
    (setq *immed-predors* nil)
    (setq *immed-succors* nil)
    (setq *wustack* nil) ;; Initializing these global variables
    (if gr (cond ((cgraph-marker gr) gname) ;; If classified,
      (t (progn (Search-Hierarchy gr *top-cgraph*))) ;; Finding the predors
        ;; and succors of
        ;; gr
      (insert gr *immed-predors* *immed-succors* ) ;; insert it
    )))
```

---

**Table 1: A classification algorithm for feature graphs**

Considering the algorithm for classification in Table 4, the first phase is to initialize the global variables and to check whether it is already classified or not. The second phase is to find the immediate predecessors and the immediate successors using the function “*Search-Hierarchy*”. The third phase is to insert the given feature graph named “gname” into the hierarchy by operating on the set of “\*immed-predors\*” and “\*immed-succors\*”, which is illustrated in the following figure:

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```
(defun Insert (gr pred succ)
  (dolist (pvar pred)
    (dolist (svar succ)
      (when (Is-present (car svar) (car pvar))
        (remove-link-graph (car pvar) (car svar )))))
  (dolist (pvar pred)
    (add-link-graph (car pvar) (cgraph-name gr)))
  (dolist (svar succ)
    (add-link-graph (cgraph-name gr) (car svar))))
```

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**Table 2: Insert “gr” in the partial order, given its neighbourhood**

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### 4. REUSE FRAMEWORK IN PIM

#### 4.1 Problem Statement

The skeletal plans reuse problem in PIM is addressed as follows: Given a new workpiece in a situation (recognized as feature) and a group of existing pairs consisting of a skeletal plan and its feature structure described as  $\{[F_0, P_0], \dots, [F_{n-1}, P_{n-1}]\}$ . Produce: A skeletal plan called  $P(n)$ , which will be generated by effectively modifying the retrieved set  $\{P(i), \dots, P(j)\}$ .

#### 4.2 Retrieval Process

Within our reuse procedure which includes the steps of recognition, retrieval and modification, the retrieval process is an important step. It proceeds with the following steps:

- The classification process - to classify the target feature  $x$  in the taxonomy of feature structures and to find the partial relations  $u \subseteq x \subseteq v$ . This process is similar to the taxonomic reasoning in KL-ONE[9].
- The selection process - to choose the best candidate from the partial taxonomic space. The selective strategy is listed as follows: If  $x = u$  or  $v$ , this process selects feature structure  $u$  or  $v$  as the best candidate and ends this retrieval process. If  $v = T$  and  $u \neq \perp$ , then this process has to select the feature structure  $u$  and then exit from the retrieval process. If  $v = T$  and  $u = \perp$ , then this process selects nothing and goes to the interviewing process. Otherwise (this is usually case), the conservative strategy for retrieval is to take  $v$  as the candidate and then goes on the projecting process.
- The projecting process - to find the difference part of  $v$  in  $x$  and to form the new target feature structure  $x'$ . This process is finished by splitting the unmatched part of feature graph  $x'$  with  $v$  from  $x$ . This process makes sure that the projected graph is a feature structure and can be used as the new retrieval target.

The interviewing process - to ask domain expert to help acquiring the feature structure.

As illustrated in Figure 2, for example, the reuse procedure for a given workpiece which is recognized as a "shaft-1step-1step-radius", is follows: At first, this feature was classified into the existing taxonomic hierarchy and the classified feature is marked in Figure 2 as virtual circle; secondly, according to the principle of selection strategies, we select its generalization feature structure "shaft-1step-radius" as a reused candidate, then we get the new target feature "1step" after the projection of the selected candidate graph into the previous target; thirdly, we would run the interview process if there existed no "1step" feature in this hierarchy.

## 5. APPLICATIONS

### 5.1 Application(I): Designing Skeletal Plans

One application in our *PIM*, which is based on the proposed skeletal plan reuse framework, is to design new skeletal plans by reusing previous ones[8]. This skeletal plan designer is proposed to reduce the acquisition task for skeletal plans which represent expert knowledge about process planning. This visual designer for skeletal plans has been implemented as one module of *PIM* and follows this reuse framework mentioned above.

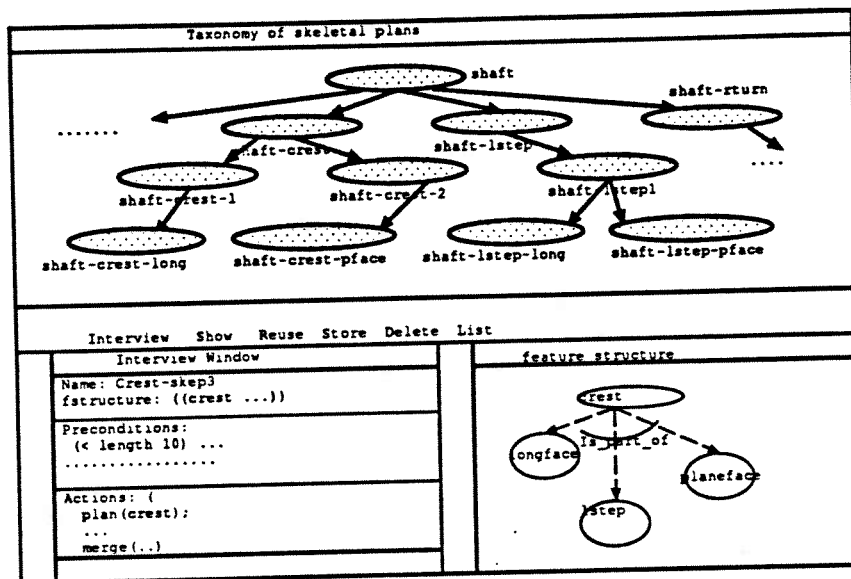


Figure 3: Designing Skeletal Plans by Reuse in *PIM*

Figure 3 illustrates the procedure for reusing skeletal plans within the visual designer. The middle button window provides a group of commands such as "Reuse"; the upper window shows the taxonomic hierarchy of existing skeletal plans; the bottom-left window is an interviewing window which supports the interviewing process illustrated above; both input and display of the feature structure of a certain skeletal plan are finished in the bottom-right window. Thus, after the *feature structure* of a certain skeletal plan has been inputted, we need to run the "Reuse" command and get a reused path of skeletal plans in the taxonomic hierarchy illustrated in the upper window, which can be listed by the "List" command, and then fire the "interview" to use the interviewing process to edit the retrieved skeletal plans.

### 5.2 Application(II): Speeding Skeletal Planning

In the *PIM* system, a complete product plan about a given workpiece is created by so-called skeletal planning, which selects the skeletal plan according to its internal feature structure, refines them by activating their actions and merges these refined skeletal plans into a complete one. During the process of skeletal planning, some immediately stored skeletal plans are generated and these skeletal plans also can be reused to adapt a new situation to reduce the cost of recreation; on the other side, the selection of these skeletal plans obeys the conditions of the satisfaction of interna

feature structures and a taxonomic hierarchy which stores these skeletal plans in the proper sites can speed up the selection process in skeletal planning. Figure 4 shows how to reuse the planned path to speed up skeletal planning.

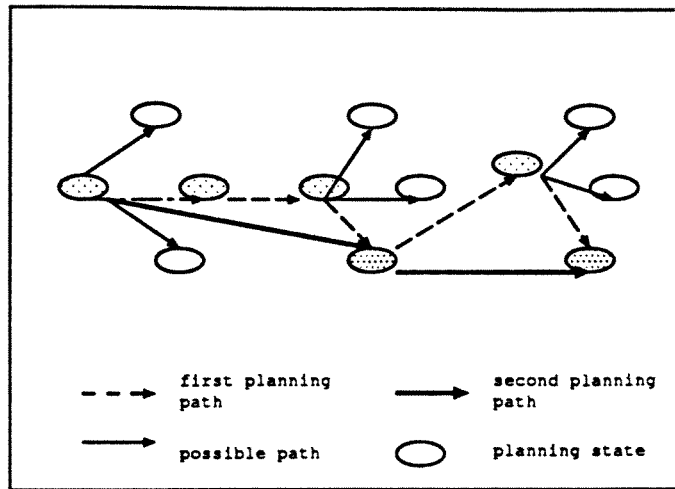


Figure 4: Reuse existing paths to speed up skeletal planning

The skeletal plan reuse scheme mentioned above can speed up skeletal planning from both the selection of skeletal plan and the retrieval of immediate skeletal plans.

## 6. CONCLUSION

This reuse framework is implemented as one module of *PIM*. The current version greatly reduces the design task for new skeletal plans by using existing skeletal plans. It also supports the effective retrieval during the skeletal planning process and speeds up skeletal planning. These successful applications show that classification of feature structures not only provides an effective taxonomy for skeletal plans, which are adequate for applying for the *PIM* system, but also greatly improve the efficiency of processing.

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