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Skeletal Plans Reuse: A Restricted Conceptual Graph Classification Approach

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Skeletal Plans Reuse: A Restricted Conceptual Graph Classification Approach

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Abstract

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 Restricted Conceptual Graphs are used as the internal representations of these skeletal plans and reusing these skeletal plans is approached by retrieving the most specific general candidate and effectively modifying. A similarity metrics about Restricted Conceptual Graphs is given for guarding the effective retrieval. Two applications of this proposed framework are described in this paper.

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1 Introduction

Generating plans from scratch is a computationally expensive process and computation complexity will be greatly reduced through reusing existing plans. The most percent of planning problems such as 80 percent of all mechanical engineering tasks, are solved by adapting old plans to new situations[1]. A Major obstacle to successful deployment of plan reuse mechanism schemes is how to map/fix/retrieve the appropriate plans that can be efficiently reused in the new situation through almost minimum cost modification. Recent researches[2][3] [4][5] show that efficiency can be greatly improved if the reuse mechanism for plans has the ability to retrieve and locate the applicable part of existing plans, and also to effectively modify the inapplicable part plan to refit the new situations.

In our proposed *PIM* system[6][7], a manufacturing process planning system, we utilize skeletal plans to describe expert knowledge about process planning on the part or whole of a workpiece. Reusing these existing skeletal plans for new workpieces or in new working environments becomes more important, especially when the complexity of workpieces and the amount of existing skeletal plans increase, or when the working environment changes. This requires us to introduce an appropriate internal representation of skeletal plans which can address certain relations between them such as the generalization relation.

Conceptual graph[8] which provides powerful knowledge representation mechanisms, is one adoptable candidate for our applications. However, a general conceptual graph is expensive and inefficient in our application domain, e.g. the classification of the general conceptual graph is intractable and expensive[10]. On the other hand, a given domain only needs a domain-specific representation framework instead of a general and intractable one. Restricting the general representation leads to better efficiency of processing and better fitness of domain. Therefore, for our domain applications, Restricted Conceptual Graph (*RCG*), which inherits and restricts some mechanisms of conceptual graph, is proposed; and a *RCG* based reuse framework is presented, in which a restricted conceptual graph is used to represent the internal structure of a skeletal plan and is classified into a hierarchy. Reusing these existing skeletal plans is performed through selecting the most specific general conceptual graphs and modifying their skeletal plans.

After giving the overview of the *PIM* system in the second section, we propose the Restricted Conceptual Graph in the third section. The plan reuse framework including the conservative controlling strategy about retrieval and its application in PIM are described in section 4 and conclusion is drawn in section 5.

2 Overview of *PIM*

The PIM system (Planning in Manufacturing) is a knowledge-based Computer Aided Process Planning (CAPP), which provides a group of representation languages and formalisms to bridge the gap between CAD and CAM. In these formalisms, SKEP_REP (SKEPeletal plans REPresentation) is a skeletal plan representation language to describe expert knowledge about manufacturing process planning. A skeletal plan about *"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 features associated and dependent. The features associated with these skeletal plans are to 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.

The plan reuse in *PIM* is to reuse previous skeletal plans for a different workpiece or in new working environment. 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.

3 Restricted Conceptual Graph

The proposed Restricted Conceptual Graph (*RCG*) is a special kind of conceptual graph, which is to restrict the representation mechanism of Sowa's conceptual graph [8] such as the number of relations, referent mapping, type function and formation rules. The definition of *RCG* is given in section 3.1.

The formation rules about *RCG* are introduced in section 3.2 and the taxonomy of *RCGs* is described in section 3.3.

3.1 Definition

The definition about *RCG* is given as follows:

- Definition: Restricted Conceptual Graph (*RCG*) is a finite, connected, graph (N,R) with labeled nodes and labeled relations. Every labeled relation has one or more arcs, each of which must be linked to one labeled node. A single labeled node can form a *RCG*. The labels of node are any arbitrary strings included in named N set. The labels of relation are a limited set R which depends on the applicable domain. Each of these relations has its own formations rules.

In our application domain, the domain-specific relation set R only includes three relations, R = { *IS_PART_OF, IS_CONTEXT_OF , IS_INSTANCE_OF* }. The *IS_PART_OF* relation represents the "part of" relation among these linked labeled nodes. The *IS_CONTEXT_OF* relation represents that the labeled node has meaning only under the context of the linked labeled node. The *IS_INSTANCE_OF* relation means that the labeled node is a instance of the linked labeled node.

A Restricted Conceptual Graph of a skeletal plan of *PIM* is illustrated in figure 1.

We define the labeled node, which *always* is linked from others, as the IN labeled node such as the *"Lstep"* labeled node in figure 1; and call the node as OUT labeled node, which *always* links to other nodes and is not linked from any other labeled nodes, e.g. the *"Shaft"* labeled node in the figure 1.

3.2 Relation-Based Formation Rules

The formation rules in Restricted Conceptual Graph (*RCG*) are special forms of those of Sowa's, which are relation based.

For the relation *IS_PART_OF* , there are three formation rules for deriving a restricted conceptual graph X from others U and V:

- Copy: X is an exact copy of U.

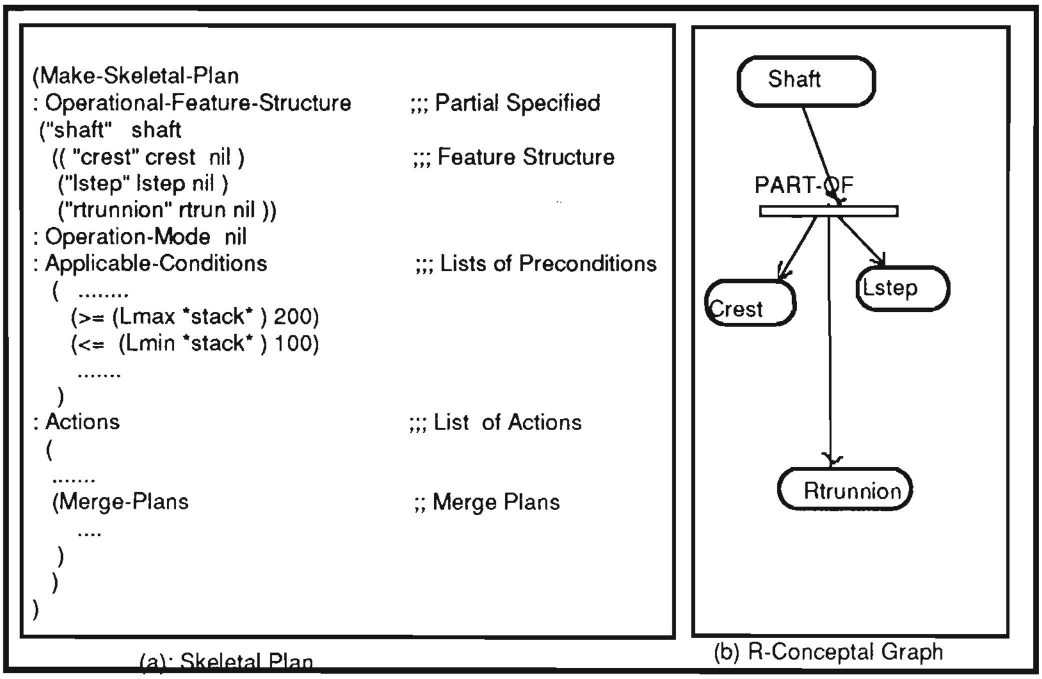

Figure 1: A *RCG* and its Corresponding *PIM*'s Skeletal Plan

- Top-Down Join: If a OUT labeled node n in U is identical to a IN labeled node m in V, then let X be the graph obtained by joining U and V and deleting m node.

- Bottom-up split: If we want to split the subgraph X from the graph U, copys the interface labeled nodes and split them. It is reverse operation of join.

The formation rules make guarantee that the formed *RCG* is right. There exists similar formation rules such as Copy, Restrict and Extend rules for IN relation in the *RCGs*.

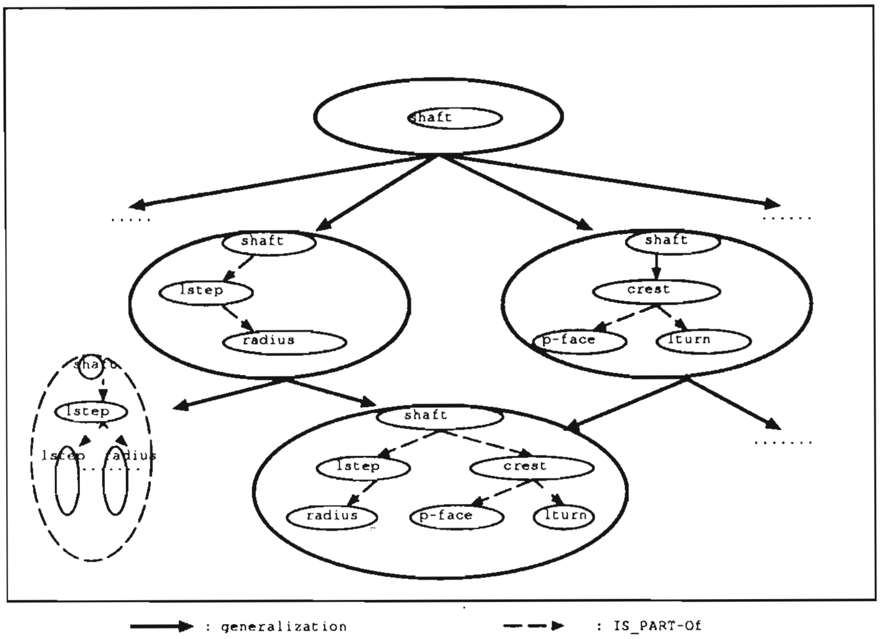

Figure 2: A Taxonomic Hierarchy of *RCGs*

3.3 A Taxonomic Hierarchy of *RCGs*

If a *RCG* U is derived from a *RCG* V by using the join, copy or restrict formation rules, then U is called a specialization of V, written as $U \preceq V$, and V is called a generalization of U.

Generalization defines a partial ordering of *RCG* called the generalization hierarchy. For any Restricted Conceptual Graphs U, V and W, the following properties are true, being similar to that of Sowa's:

- Reflexive: $U \preceq U$
- Transitive: If $U \preceq V$ and $V \preceq W$, then $U \preceq W$.
- Antisymmetric: If $U \preceq V$ and $V \preceq U$, then $V = U$.
- Top: $\top \succeq U$
- Bottom: $U \succeq \bot$

An illustrated taxonomic hierarchy of *RCGs* is shown in figure 2, where the *"shaft" RCG* is a generalization of the *"shaft-lstep" RCG*. The generalization hierarchy of *RCGs* is built by effective classification. The classification of RCGs is more efficient than that of general one.

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 Restricted Conceptual Graph S(n)) and a group of existing pairs of skeletal plan and its *RCG* described as {[S0,P0],...,[S(n-1),P(n-1)]}. Produce: A skeletal plan called P(n) will be generated by effectively modifying the retrieved *RCG* set {P(i),...,P(j)}.

4.2 Basic Cycle of Reuse

The reuse procedure in *PIM* proceeds in the following steps:

- Recognition: to recognize the *RCG* out of a given workpiece.
- Retrieval: A group of *RCGs* named {S(i),...,S(j)}, is retrieved from the partial *RCG* space {S(0),....,S(n-1)}.
- Modification: The modification of the retrieved skeletal plans P(i),..,P(j) taken from these pairs is to be completed by merging or splitting these skeletal plans.

4.3 Controlling the reuse

Controlling the reuse procedure is to get the minimal cost modification of these existing plans. In our framework, the retrieval process is an important step in the basic reuse cycle. The retrieval process proceeds the following steps:

1. the classification process - to classify the target *RCG* x in the hierarchy of *RCGs* and to find the partial relations $u \preceq x \preceq v$. This process

is similar to the taxonomic reasoning in KL-ONE[9]. Classification is done in two phases. The first phase is a constrainted topological search of the generalization space to get the immediate generalizations of the conceptual graph. The Phase two searches topologically the intersection of the subhierarchies found in Phase one. A breadth-first search of the taxonomic generalization space is implemented, similar to that of [10].

2. the selecting process – to choose the best candidate from the partial *RCG* space. The selective strategy is listed as follows: If $x = u$ or v, this process selects u or v as the best candidate and ends this retrieval process. If $v = \top$ and $u \neq \bot$, then this process has to select the u and to exit from the retrieval process. If $v = \top$ and $u = \bot$, then this process selects nothing and goes to the interviewing process. Otherwise, if not exists another v' which satisfies the $x \preceq v'$, this is most cases, the conservative strategy for retrieval is to take v as the candidate and goes to the projecting process; if exists another v' satisfying $x \preceq v'$, then it is to select more similar one to x whose similarity metric is illustrated in the following section 4.4.

3. the projecting process – to find the difference part of v in x and to form the new target *RCG* x'. This process is finished by splitting the unmatched part of graph x' with v from x. The splitting operation is executed by the bottom-up split formation rule, which makes sure that the projected graph is a *RCG*. The x' can be used as the new retrieval target.

4. The interviewing process – to ask a domain expert to help.

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

4.4 Similarity Metrics about *RCS*

Semantic distance was introduced in the paper [8]; however, Sowa did not specify exactly how semantic distance should be defined but suggested that semantic distance might be defined as the number of acrs in the short path through the type lattices from concept type to another one that did not pass through the top type $\top$.

In order to introduce the semantic distance into our framework, we follow Sowa's minimal common generalization graph[8] and define the semantic distance between two conceptual graph as the arithmetic average of the semantic distance between each of them and the minimal common generalization (MCG) graph of them, as illustrated as follows:

$$Sim(g1, g2) = \frac{Sim(g1, MCG(g1, g2)) + Sim(g2, MCG(g1, g2))}{2} \tag{1}$$

The similarity metrics *Sim* satisfies the following properties:

- Zero Property: Sim(g1,g2) = 0 if MCG(g1,g2) = $\emptyset$
- Symmetric Property: Sim(g1, g2) = Sim(g2,g1)
- Positive Property: Sim(g1, g2) $\geq$ 0
- Triangular Property: Sim(g1, g2) + Sim(g2,g3) > Sim(g1,g3)
- Normalization Property: Sim(g1,g2) $\leq$ 1 ; Sim(g1,g2) = 1 if g1 = g2

Thus the similarity metrics satisfying above axioms can be given by the similarity degree between the conceptual graph and its subgraph, as the minimal common graph of any graphs is a subgraph of each of these graphs. In our framework, the similarity metrics is relation dependent and for the *IS_PART_OF* relation, we give the following similarity metrics: given any two *RCG* g1 and g2 where g1 $\leq$ g2, the similarity degree of these two g1 and g2 is computed by the similarity degree of the IN labeled node in these graphs, that is illustrated as follows if the two node n and m consists of nodes $\{n_1,...,n_N\}$ and $\{m_1, ..., m_M\}$ correspondingly through the IS_PART_OF relation where M $\geq$ N.

$$sim(n,m) = \frac{\sum_{i=1}^{N} sim(n_i, m_i)}{|M|} \quad (2)$$

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[11]. This skeletal plan designer is proposed to reduce the acquisition task about 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 the RCG based reuse framework mentioned above.

The figure 3 is illustrating the procedure of reusing skeletal plans within the 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 a interviewing window which supports the interview process illustrated above; both input and display of Restricted Conceptual Graph of a certain skeletal plan are finished in the bottom-right window. Thus, after the *RCG* structure of a certain skeletal plan had been inputed, we need run the *"Reuse"* command and get a reuse 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 interview process to edit the retrieved skeletal plans.

5.2 Application(II): Speeding Skeletal Planning

In the *PIM* system, complete product plan about a given workpiece is created by so-called skeletal planning, which selects the skeletal plan according to their internal feature structures, 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 internal feature structures and a

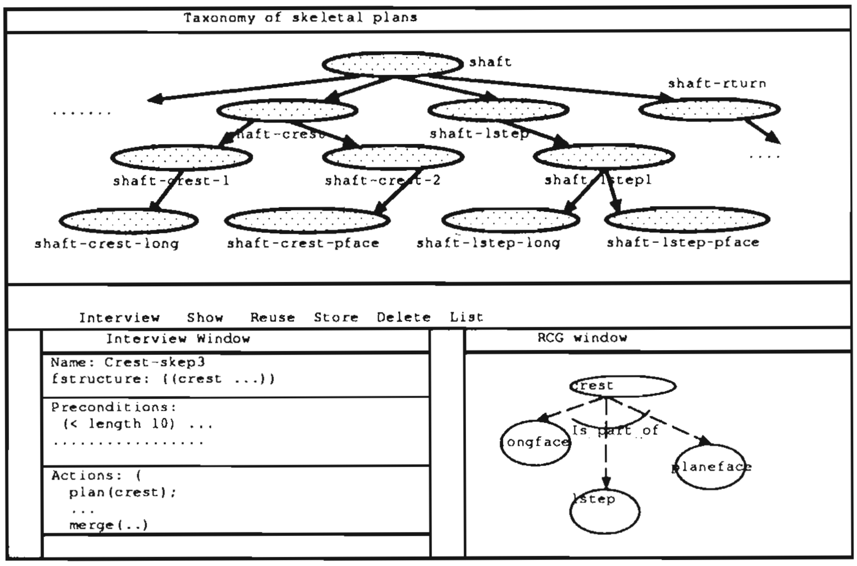

Figure 3: Designing Skeletal Plans by Reuse in *PIM*

taxonomic hierarchy which stores these skeletal plans in the proper sites can speed up the selecting 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

The Restricted Conceptual Graph (*RCG*) based 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 an effective retrieval during the skeletal planning process and speeds up skeletal planning. These successful applications show that restricted conceptual graphs not only retain the effective representation mechanisms of conceptual graph, which are adequate for applying for the *PIM* system; but also greatly improve the efficiency of processing.

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Zusammenfassung

In letzter Zeit werden verstärkt Anstrengungen zur Automatisierung der Arbeitsplanung unternommen. Insbesondere sollen wissensbasierte Methoden helfen, bisher offene Probleme zu lösen. So entstanden eine Reihe von Prototypen zur Arbeitsplanerstellung, über die in zahlreichen Veröffentlichungen berichtet wurde.

Nach einer Einführung in die Begriffswelt und Problematik der Arbeitsplanerstellung werden im ersten Teil dieser Arbeit eine Anzahl dieser Systeme untersucht und verglichen. Daraus werden Anforderungen abgeleitet, die ein System zur Arbeitsplanerstellung erfüllen sollte, aber teilweise noch nicht vorhanden sind.

In zweiten Teil wird das Konzept eines Systemes entwickelt, das versucht diesen Anforderungen gerecht zu werden. Eine Anforderung ist die Möglichkeit des Anschlusses externer Programme (wie z. B. CAD-Systemen und Datenbanken) an das Arbeitsplanungssystem.

Die Entwicklung und Implementierung einer Client Server Architektur zur Verwirklichung dieser Schnittstelle

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