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SESSION 5
EXPERT SYSTEMS

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CECoS: A case experience combination system for knowledge acquisition for expert systems

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This paper presents a new knowledge-acquisition system—the Case Experience Combination System (CECoS). With CECoS, two information or knowledge sources are jointly analyzed. Previously recorded problem solutions (individual cases) are combined with an expert's high-level understanding of the global structure of a task domain. By combining the detailed case information with an expert's general insights, CECoS provides the domain knowledge with which skeletal plans can be automatically constructed.

Within the last decade, knowledge acquisition has emerged as an important area in the field of expert-system development. Although some researchers investigated the elicitation of knowledge independent of a sophisticated model of expertise (Boose & Bradshaw, 1987; Diederich, Linster, Ruhmann, & Uthmann, 1987), others have emphasized the importance of developing appropriate models of expertise (Breuker & Wielinga, 1989; Chandrasekaran, 1986; Clancey, 1985). Obviously, a complete knowledge-acquisition technique must include both the formation of a model of expertise that can be implemented on some computer system and the elicitation of corresponding knowledge.

As a result of knowledge-elicitation research, various methods for interviewing humans and probing their expertise have been transported from the behavioral sciences into artificial-intelligence research (Hoffman, 1989), and the usefulness of these methods for the development of expert systems has been investigated. The development and application of the appropriate tools have shown how repertory grids, think-aloud methods, scaling techniques, or having the expert perform special tasks (and other data collection and analysis procedures) can be utilized for knowledge acquisition.

Research on model-based knowledge engineering has produced a number of principles on how models of expertise can be formed or selected from a library of models. Problem classes (Clancey, 1985), generic tasks (Chandrasekaran, 1986), and interpretation models (Breuker & Wielinga, 1989) are somewhat different but, at the same time, similar incarnations of models of expertise.

To develop a successful expert system for a complex real-world application such as computer-aided planning, model-based knowledge engineering must be coordinated with appropriate knowledge-elicitation procedures. Without a model of expertise, a knowledge engineer would be overwhelmed by the mass of unorganized entities that must be dealt with during knowledge acquisition. Without appropriate knowledge-elicitation tools, establishing a complete knowledge base would be too time consuming. For the desired coordination, which should be performed during the domain definition (Woodward, 1990), the knowledge engineer must consequently deal with the following three problems:

1. A good model of expertise must be found or developed. For the purpose of the present paper, it is not critical which single specific-model-approach is selected (Karbach, Linster, & Voss, 1990) but only that the knowledge acquisition is model-based—that is, that a model is used and that the model is basically adequate for the desired application. Such a model may be obtained by selecting it from a library of models (Breuker & Wielinga, 1989)

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or by constructing it, for instance, through an ontological analysis (Alexander, Freiling, Shulman, Rehfuss, & Messick, 1987).

2. Traces of expertise, which serve as information sources, must be found and adequate knowledge-elicitation procedures must be developed so that knowledge can be efficiently elicited. Such tools may also attempt to elicit implicit knowledge (Lewandowsky, Dunn, & Kirsner, 1989), which experts cannot directly verbalize.

3. Finally, knowledge elicitation must be coordinated with the specifically selected model of expertise so that the elicited knowledge appropriately supplements the model. In complex real-world domains, a number of different traces of expertise will exist. Some traces of expertise may be generally accessible but incomplete; others may be confidential within some community and possibly contradictory between different competing communities. Therefore, it is quite critical to develop or select a model so that the knowledge details required for some model can indeed be supplied.

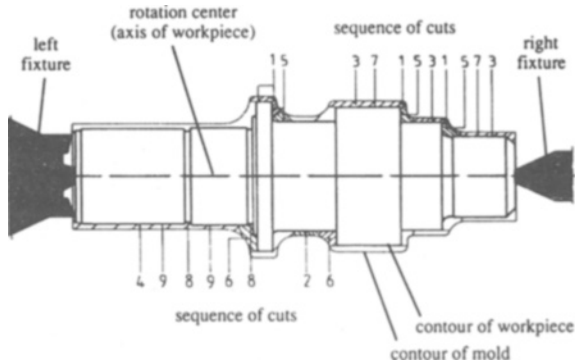

Figure 1. Graphical representation of a simplified workplan for a rotational part. (From "Examples for Application" (p. 22), Plochingen Neckar, Germany: Feldmühle AG. Copyright 1984 by Feldmühle AG. Reprinted by permission.)

Mechanical Engineering as the Application Domain

The application domain of the described knowledge-acquisition tool is mechanical engineering and computer-integrated manufacturing (CIM), in which knowledge-based product models (Legleitner, 1990) are to be shared among different tasks (Bullinger & Salzer, 1989). However, for the purposes of the current paper, only computer-aided planning (CAP) for the manufacturing of workpieces (Chang & Wysk, 1985) and, more specifically, the manufacturing of rotational parts will be considered.

Rotational parts or workpieces are manufactured by putting some more or less cylindric piece of metal (mold) into the fixture (i.e., chucking) of a manufacturing machine. The chucking fixture, together with the attached mold, is then rotated at a relatively high speed, with the longitudinal axis of the cylinder as the rotation center. The rotational axis and all movements of a specific cutting tool (movements which perform a cut, as well as movements which only position the tool) lie in a plane. While the chucking fixture and the attached mold are rotated, a cutting tool moves along some contour. The desired geometric shape of the workpiece is thereby obtained. As a result of this processing, axle shafts, drive shafts, or bevel wheels may be produced.

The technique of manufacturing a rotational part may be better understood by a comparison to pottery. The manufacturing processes are similar to those used to make a pot in the following way: One puts, or attaches, a piece of clay to a potter's wheel and shapes the clay to a specific form only by removing some parts of the clay while the potter's wheel is turned. Contrary to the way a pot is made with soft clay, which also allows a potter to push some material to a neighboring position, a rotational part or workpiece (metals) is shaped solely by removing materials with a hard cutting tool.

Figure 1 shows a graphical representation of a (partial) workplan for a rotational part. The geometric forms of the mold and the target workpiece are overlayed. The specific chucking fixture is shown, and the sequence of cuts is specified. For a complete workplan, additional specifications are needed, such as which cutting tools to use.

Although the principles of manufacturing a rotational part may be simple, the actual manufacturing process and, consequently, the respective planning task are complex. The complexity arises from the large number of different possibilities for an operation and the various dependencies among different operations. An additional com-

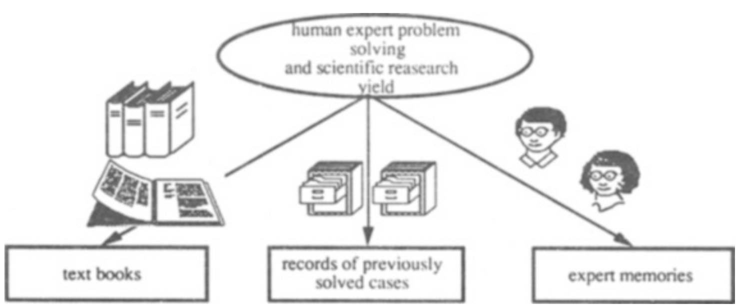

Figure 2. Traces of expertise.

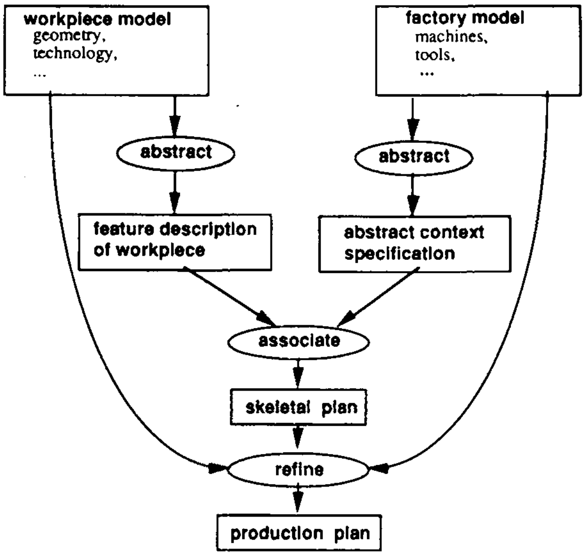

Figure 3. Model of expertise for production planning.

plexity in the planning process originates from the large body of modern technologies, accumulated scientific knowledge, and various practical experiences, all of which can be applied for improving or even optimizing the manufacturing process. Therefore, production planning is knowledge-intensive. Especially for this domain, the development of expert systems is, as a result, a promising endeavor (Pfeiffer, Siepmann, & Teichmann, 1988; Richter, 1990).

By means of the analysis of mechanical engineering knowledge, three traces of expertise that can be utilized for knowledge acquisition were identified:

1. Theoreticians are usually concerned with general rules. The general knowledge that renowned theoreticians have accumulated in their research can be found in various publications or textbooks.

2. The specific solutions that practitioners have found over a number of years are stored in the filing cabinets or databases of companies. Sometimes, records of previously solved cases have also been published (e.g., Feldmühle AG, 1984, p. 22).

3. By means of their possibly implicit expert memories, which they have acquired over a number of years (de Groot, 1966), practitioners may possess an expert classification for the various types of workpieces. These expert memories may be tapped with appropriate knowledge-elicitation techniques.

Figure 2 shows an illustration of the three identified traces of expertise. These traces of expertise may partially complement one another. Consequently, from the different traces of expertise, a more complete and qualitatively better knowledge base may be constructed with an integrated knowledge-acquisition method than with isolated knowledge-acquisition procedures.

Model of Expertise for Production Planning

By analyzing expert performance, a high-level model of expertise was constructed for the desired application, which is shown in Figure 3. By building such a model on a cognitive foundation, a cognitively adequate expert system may be developed that meets a higher level of ac-

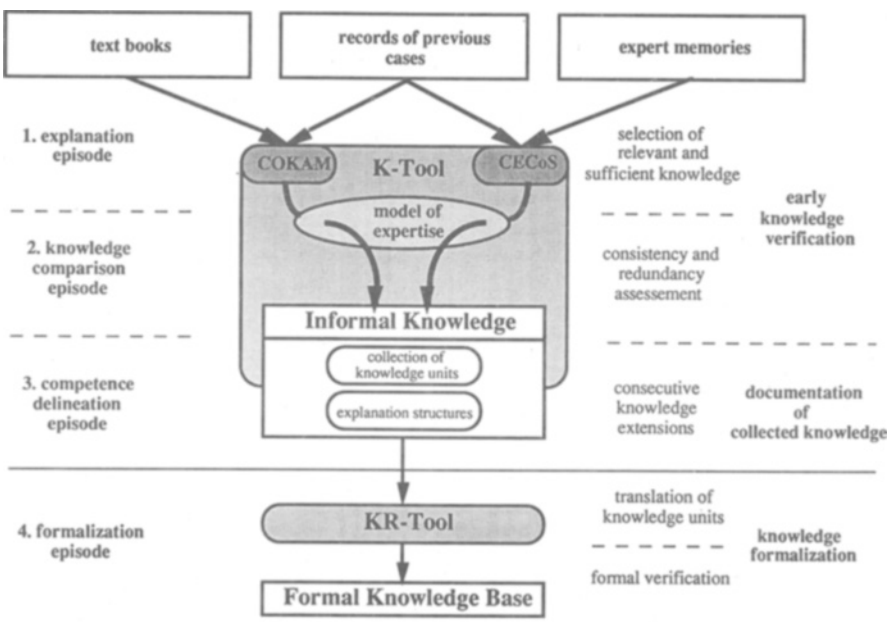

Figure 4. Integrated knowledge-acquisition method (after Schmalhofer, Kühn, & Schmidt, in press).

ceptability of the application domain by the professional community (Schmalhofer, 1987). In addition, a cognitively adequate model also facilitates the verification of knowledge in the elicitation phase: when the elicited knowledge is classified according to the way of thinking in the specific-application domain, the expert will, for instance, feel much more comfortable in verifying the acquired knowledge as authentic expert knowledge.

The abstract types of processing of the resulting model of expertise that are shown in Figure 3 can be described in the following way: The problem of production planning consists of finding an adequate production plan for a given workpiece that is to be manufactured in a given factory. The description of the workpiece is presented by the workpiece model and the description of the factory (i.e., the available machines and tools in the factory model). From these concrete data, an abstract feature description of the workpiece and an abstract context specification are obtained through the application of abstraction or classification rules. To these abstract workpiece and context descriptions, a skeletal plan (Friedland & Iwasaki, 1985) that may be seen as an abstraction of a concrete production plan can be added (Bergmann, 1990). The skeletal plan is then refined with the help of the workpiece and the factory models so that an executable production plan is obtained.

Integrated knowledge acquisition from text, previously solved cases, and expert memories have been described by Schmalhofer, Kühn, and Schmidt (in press). Therefore, this integrated knowledge-acquisition method will be only briefly outlined. It consists of four episodes, which are shown in Figure 4. During the elicitation of knowledge (explanation episode) the relevance and sufficiency of a trace of expertise of general information (e.g., expert memories) is determined by relating it to specific cases. More specifically, the general information is used to explain the specific cases. In the second, or knowledge comparison, episode, the consistency and redundancy of the elicited knowledge is assessed for each category of the model of expertise. In the third episode, the realm and competence of the elicited knowledge is delineated. The formalization of the knowledge is then performed in the fourth episode.

The main sections of the paper describe CECoS, which performs a combined knowledge elicitation from expert memories and records of previously solved cases. Although CECoS can be used in combination with knowledge acquisition from text, the current paper will be restricted to the description of the the case experience combination system.

General Description of CECoS

CECoS, which is a tool for eliciting and extending production plans, analyzes two of the three delineated knowledge sources: the solution records, which are stored in filing cabinets (databases), and expert memories, which may include a high-level understanding of the global struc-

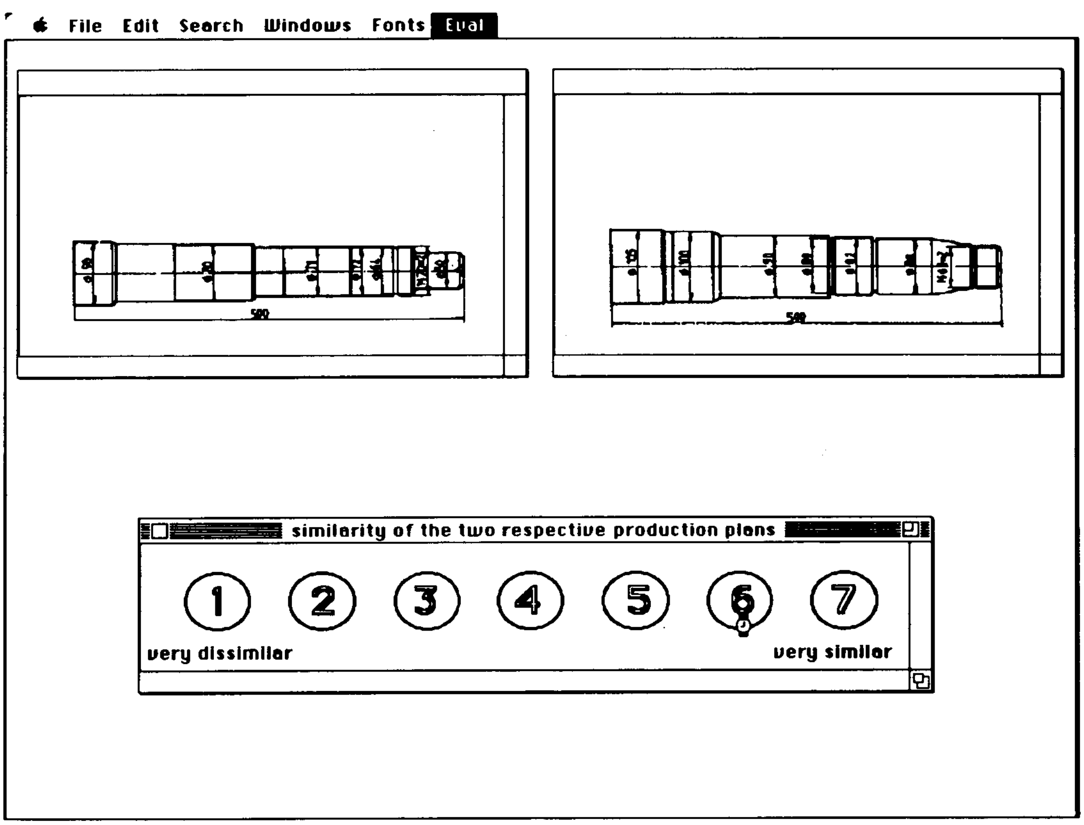

Figure 5. Elicitation of implicit expert memories about production classes.

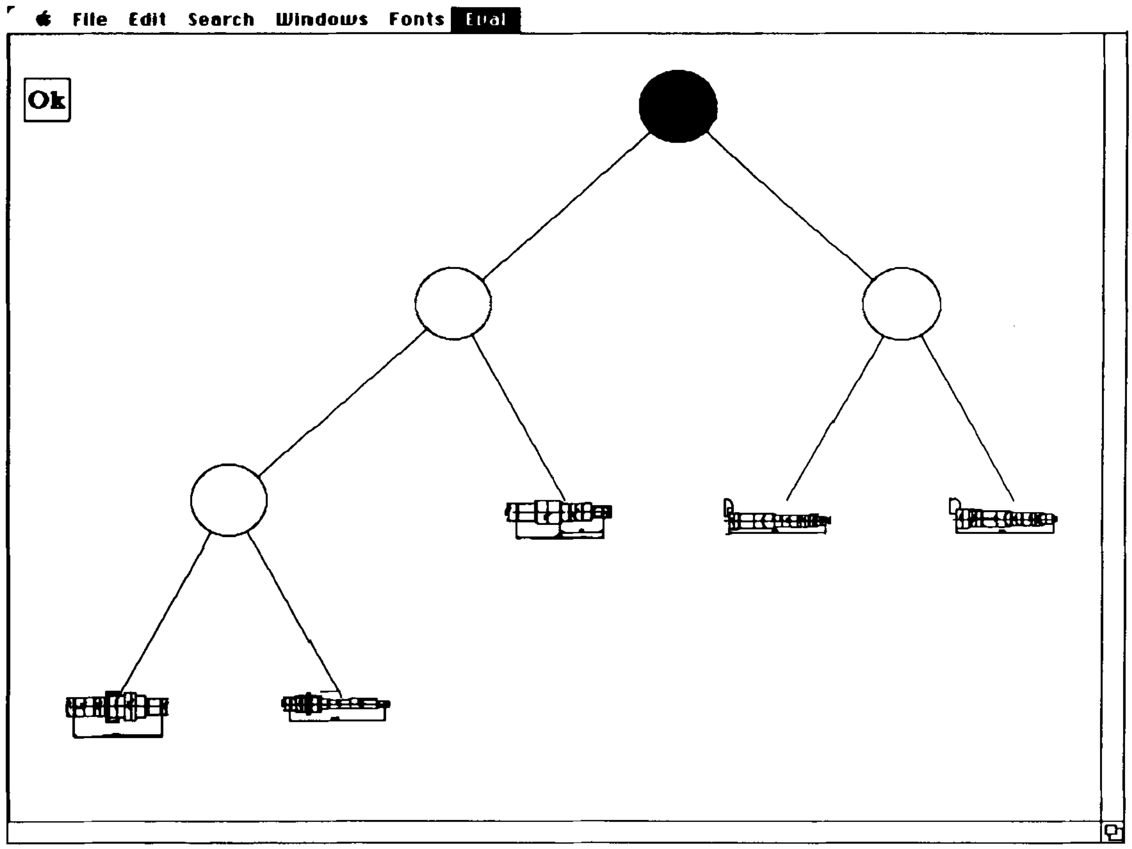

Figure 6. Hierarchy of production classes.

ture of the task domain. In the first step, CECoS retrieves the solution records. A formal representation is used to describe the problems and the solutions. This formalism will be needed later to construct an operational definition for the various production classes.

In the second step, CECoS performs a hierarchical classification of problem classes by eliciting global judgments from a human expert. The expert is advised to perform a paired comparison of the problem descriptions that CECoS acquired in the first step. A hierarchical cluster analysis based on the resulting data yields a hierarchical order of problem classes. CECoS provides a graphical user interface with which the expert can further modify and edit the established hierarchy of problem types. CECoS supports the expert in producing appropriate feature descriptions for each class of the obtained hierarchy by a simple domain-adjusted data management and presentation facility.

In the third step, the results of the first and second knowledge-acquisition steps are combined. The expert is thereby requested to define the previously generated features by means of a formal notation of the problem description. The acquired knowledge is then used to construct skeletal plans from the concrete cases used in the previous CECoS steps. A detailed description of this procedure, which utilizes explanation-based techniques, is given in Bergmann (1990).

A first application of CECoS for production planning in mechanical engineering indicates that CECoS can be successfully used to integrate previously recorded problem solutions with an expert's high-level understanding of the tasks in a particular domain.

First Results of a Pilot Application of CECoS

The described knowledge-acquisition tool has already been partially applied to elicit the expert's episodic knowledge with respect to the production planning of drive and axle shafts. The tool application and example results are described below.

Five shafts were selected from a catalogue (Feldmühle AG, 1984). Technical drawings of two of the selected shafts are shown in Figure 5. A scanner was used to fetch the technical drawings of the five shafts into the knowledge-acquisition tool. The technical drawings serve as a graphical representation of the respective product models.

According to Step 2 of the procedure, all of the possible pairs of product models were randomly presented on the screen. In the first elicitation task of this step, the mechanical engineer (expert) had to assess, for each pair,

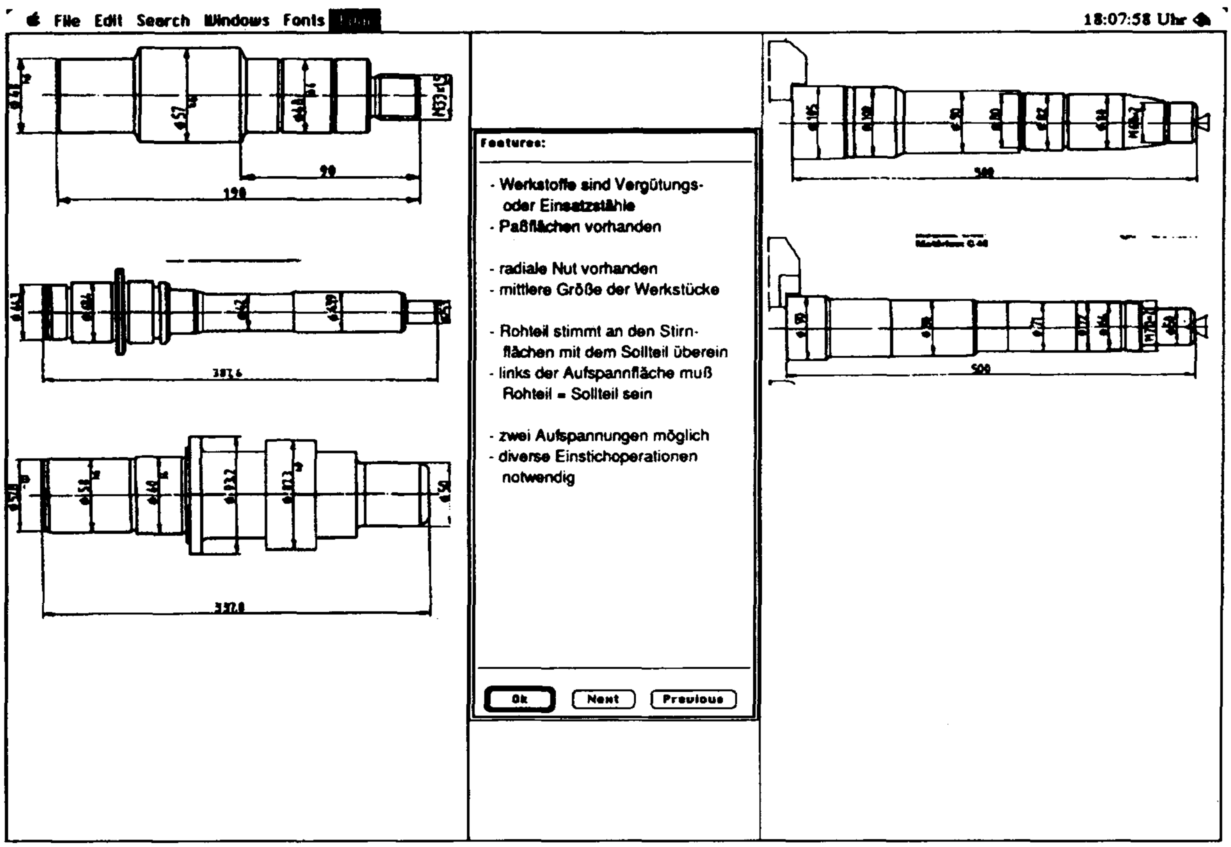

Figure 7. Explaining a hierarchically organized set of production classes.

how similar the respective productions plans should be. The expert indicated the similarity by assigning a rating between 1 and 7. A snapshot of the screen for such a paired comparison is shown in Figure 5.

With the $n*(n-1)/2 = 10$ collected similarity ratings, the tool performed a cluster analysis that resulted in a tree-shaped configuration, which is shown in Figure 6. By means of this tree, an initial hierarchy of production classes for product models is established in which each nonterminal node indicates a class. The terminal nodes stand for corresponding instances. In this particular case, the expert was satisfied with the hierarchy obtained from the cluster analysis. Therefore, he did not use the editing facilities to modify the obtained tree structure.

The second elicitation task of Step 2 required the expert to give an explicit delineation for each class by generating characteristic features that differentiate among the classes. In this phase, all nonterminal nodes of the class hierarchy are mouse-sensitive. After clicking on a node, a text window is opened and the characteristic features are entered. In the initial attempt, the expert generated between 3 and 8 features, with more features generated for the subordinate classes. Figure 7 shows a snapshot of the screen as it enters the features of the root class of the given hierarchy.

In Step 3, the expert and a knowledge engineer cooperated in defining the characteristic features of each class in terms of some primitives for geometrical and technological elements of the product models in the context of the uniform-representation formalism.

The obtained features can be classified into the abstract and associate categories of the model of expertise (see Figure 3). The following three features are examples of abstraction and association features:

1. Such features as "Kontur_monoton_fallend" (profile monotonically decreasing) were defined rather readily, because they can be easily related to geometrical or technological primitives.

2. Features that referred to the mechanical properties of the workpiece during the production process were more difficult to define. For example, the feature "stabiles_Verhalten" (workpiece_behaves_stable_during_production) had to be defined by a relatively complicated combination of terms, such as length_of_workpiece, minimal_diameter_of_workpiece, and material_of_workpiece.

3. Some features that directly referred to a possible manufacturing plan of the workpiece could not yet be successfully defined in terms of the properties of the product model. Examples of such features are: "zwei_Aufspannungen_nötig" (two chucking fixations necessary)

and "nur bei geringer Schnittgeschwindigkeit herstellbar" (requires low cutting speed).

Conclusion

Previously solved cases are usually not stored in human memory in a detailed fashion. Instead, human memory forgets the details and remembers the essential characteristics of a case. Contrary to novices, who judge the similarities of two or more cases according to superficial features of the case, experts evaluate the similarities of cases by their respective solution methods (Chi, Feltovich, & Glaser, 1981). CECoS utilizes such expert judgments of paired comparisons to identify the various production classes that experts use in production planning. For each identified production class, the expert then generates a feature description. By the use of explanation-based learning, the definitions of the production classes can then be used to automatically generate skeletal plans from the previously developed concrete workplans.

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