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Knowledge Acquisition from Text in a Complex Domain

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Prof. Dr. Gerhard Barth
Director

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Contents

Knowledge Acquisition from Text in a Complex Domain [1]

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Abstract. Complex real world domains can be characterized by a large amount of data, their interactions and that the knowledge must often be related to concrete problems. Therefore, the available descriptions of real world domains do not easily lend themselves to an adequate representation. The knowledge which is relevant for solving a given problem must be extracted from such descriptions with the help of the knowledge acquisition process. Such a process must adequately relate the acquired knowledge to the given problem.
An integrated knowledge acquisition framework is developed to relate the acquired knowledge to real world problems. The interactive knowledge acquisition tool COKAM+ is one of three acquisition tools within this integrated framework. It extracts the knowledge from text, provides a documentation of the knowledge and structures it with respect to problems. All these preparations can serve to represent the obtained knowledge adequately.

1 Introduction

Although numerous descriptions may be available about some complex real world domain in textbooks, in written documents (e.g. documentations of companies) and through the explanations of various domain experts, these descriptions do not easily lend themselves to an adequate representation. Such descriptions are usually uncommittal, unprecisely stated, at different levels of generality, overall incomplete and at times even contradictory.
This is even true for domains where precise physical laws apply, such as in the real world domain of mechanical engineering. Since the physical laws are

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idealizations of the real world, unreflected predictions derived from these laws will often crucially deviate from the respective event in the real world. Very often it becomes too complex, or not all data are known to compute a solution from such laws. Therefore, the problem is to find out which data are available, which relations are important, and how to solve the specific problem with the available knowledge. In other words, the complexity of a domain not only consists of the large amount of data, interactions and complex laws. It additionally consists of the difficulties in relating the available knowledge to a specific problem that is to be solved.
In the application domain of mechanical engineering, the tool COKAM+ (**C**ase-**O**riented **K**nowledge **A**cquisition **M**ethod from Text) [16, 9] collects the basic taxonomies of materials, and tools, together with the relevant physics knowledge from task-independent descriptions in textbooks. COKAM+ relates the acquired knowledge to concrete problems and their solutions, i.e. cases the solutions of which were already applied to solve real world problems.

First, our application domain, the manufacturing of rotational parts is described. In the next section, an integrated knowledge acquisition framework is briefly presented with respect to one of its tools COKAM+ . Then, it is shown how COKAM+ acquires knowledge from texts and relates it to problems, which are already structured by another tool of the framework. The acquired knowledge is to be formalized so that a domain theory is built. The final discussion describes the applicability of COKAM+ in other domains and compares it to some other knowledge acquisition methods from text.

2 A Complex Application Domain

In this section, the application problems which are in the domain of manufacturing of rotational parts and the problem solutions are introduced. The available knowledge and the necessary knowledge are described.

2.1 Description of the Problem and its Solution

The problem of production planning in mechanical engineering [17, 19] consists of finding an adequate production plan for a given workpiece, which is to be manufactured in some factory. For the manufacturing of a rotational part, the production plan consists of a sequence of chucking and cutting operations by which the workpiece can be manufactured. Drawings (CAD) define the geometric form of the mold, from which the workpiece is to be manufactured and the target workpiece. The chucking fixture, which is rotated with the attached mold with the longitudinal axis of the cylinder as the rotation center, the cuts and their specific order must be planned. For each cut, the cutting tool, the cutting parameters and the cutting path have to be determined. A complete description of the real world problems also includes further technological data of the workpiece (surface roughness, material, etc.) and precise workshop data (CNC machines with their rotation power and number of tools and revolvers, etc.).

2.2 What Knowledge is Documented in Texts?

There is an extremely large spectrum of cutting tools available, which leads to ISO-norms one for toolholders (ISO 5608) and one for tool inserts (ISO 1832) described in catalogues of companies which produce cutting tools. Within these norms about $1,8*10^7$ toolholders and $1,5*10^8$ inserts exist and can be combined, with respect to some restrictions, to more than $3,5*10^{12}$ meaningful cutting tools. From that large spectrum of available tools one medium size company typically uses about 5000 tools for their production. Additionally, some highly specialized cutting tools are constructed and produced on demand. All the tools can be applied differently and can create different effects depending on the cutting parameters. The catalogues give some examples for the application of the tools which graphically show the problem and its solution and provide cases for the knowledge acquisition process.
Textbooks of mechanical engineering often contain very general and theoretical knowledge. For instance, the workpiece materials and the materials of cutting tools are often described as hierarchies. These hierarchies represent the chemical and physical structures of the specific materials. Other relevant properties are the hardness, the persistence of the hardness with increasing temperatures, their sensitivity to shocks, etc. These properties are only partially correlated with the chemical composition and are thus only to some extent reflected in the taxonomic hierarchy. Although it is hardly possible to derive from this information which cutting material to use in a specific context, this only weakly structured and incomplete information seems nevertheless to play an important role in mechanical engineering. More specific and thereby more useful knowledge has been assembled from systematic experiments and theoretical and approximative calculations. Such results are often presented in table format.
Because of the large amounts of such knowledge and the relatively small usefulness for concrete problems, it does not make sense to bring this knowledge into a knowledge base in an unfiltered way.

2.3 What Knowledge is Necessary?

Think-aloud protocols [15] and the literature in mechanical engineering [6] show that the experts who develop production plans very often overcome the complexity of their task by doing skeletal plan refinement. A general inference structure [3] which we call model of expertise describes this problem solving method for the manufacturing of rotational parts as follows: From the concrete description of the workpiece and the available manufacturing environment more abstract feature descriptions are first constructed. These abstractions are then associated with an appropriate skeletal plan that has been stored in the knowledge base. The skeletal plan is finally refined with the help of the workpiece and the factory description into the concrete production plan.

The model of expertise implies the planning method of reuse of plan schemata [8, 13], which becomes the general structure of the to be developed expert system. Therefore, model of expertise specifies what kind of knowledge has to be acquired for the expert system, namely abstraction rules, refinement rules and skeletal plans which are associated with features of the problem description.

3 Integrated Knowledge Acquisition Method

Within an integrated knowledge acquisition method [14] the knowledge which is described as relevant in the model of expertise is acquired from three different sources of information (texts, cases and the expert's respective memories) with the help of three tools.

First the tool CECoS (**C**ase-**E**xperience **Co**mbination **S**ystem) [2] is applied. CECoS supports the delineation of a hierarchy of problem classes and their description by features. The problem classes are formalized stepwise whereby the formalization is guided by the model of expertise. With the help of CECoS experts also delineate a hierarchy of operator classes – operators are steps of the production plan. The hierarchy of operator classes is utilized for structuring the knowledge acquisition process with the tool COKAM+ .

COKAM+ acquires preconditions and consequences from texts for the operators and the operator classes. Furthermore, abstraction and refinement rules are obtained from texts. The acquired knowledge is also formalized step by step.

The formalized production classes and their feature descriptions obtained through CECoS and the formalized task-related engineering and common sense knowledge, preconditions and consequences supplied by COKAM+ can then be used to automatically construct skeletal plans and associated application conditions through the tool SPGEN (**S**keletal **P**lan **Gen**eration Procedure) [13]. SPGEN is based on explanation-based generalization as described by [10].

The interaction among the three tools is determined by this integrated knowledge acquisition method. From COKAM+'s point of view, CECoS provides one of its inputs, i.e. an operator class hierarchy and informal feature definitions, and for SPGEN its domain theory consisting of formal preconditions, consequences and abstraction and refinement rules is acquired.

4 Acquisition from Text with COKAM+

In our complex real world domain, the interactive tool COKAM+ is applied to acquire formal descriptions of the operators in the production plan and the appropriate task-related and common sense knowledge, i.e. abstraction and refinement rules. Such descriptions can be found in mechanical engineering textbooks, catalogues and documentations of a company. COKAM+ does not aim to comprehend the text completely, but to extract that knowledge from the text that is needed to obtain a sufficient domain theory and that can be stepwise transformed into a formal representation. In order to support the user as much as possible, information retrieval methods, natural language processing, browsing systems and Hypertext methods can be applied in different ways at different phases of the procedure. In the following, the acquisition process of COKAM+ is described in detail by using examples.

4.1 Input from CECoS

COKAM+ obtains a hierarchy of operator classes from CECoS and defines the concrete operators and their classes within this hierarchy. COKAM+ does not check whether the hierarchy is correct, but uses it as a guidance for the definitions.

Figure 1 shows an example of a part of an operator hierarchy. The hierarchy tree can be read in the following way: The vertical distance is an indication for the similarity. Thus the two operators on the lower left side of figure 1 are more similar than the two on the right side. The expert explains that the two on the left only differ in the tolerances and the type of the insert whereas the two on the right also differ in the cutting path. In order to describe an operator the expert names features (see gray boxes in figure 1), e.g. "cutting material SN80". On the next higher levels the classes are defined by more general features like "bezeling" or "rough turning" which are terms for cutting types. If other single operators are generalized further types of cutting can be identified, e.g. "finishing", "fine finishing", "thread turning" etc..

To acquire a domain theory with COKAM+ which SPGEN needs to generalize plans into skeletal plans, not only concrete operators and their classes, but also specific sequences of operators (often called macros in mechanical

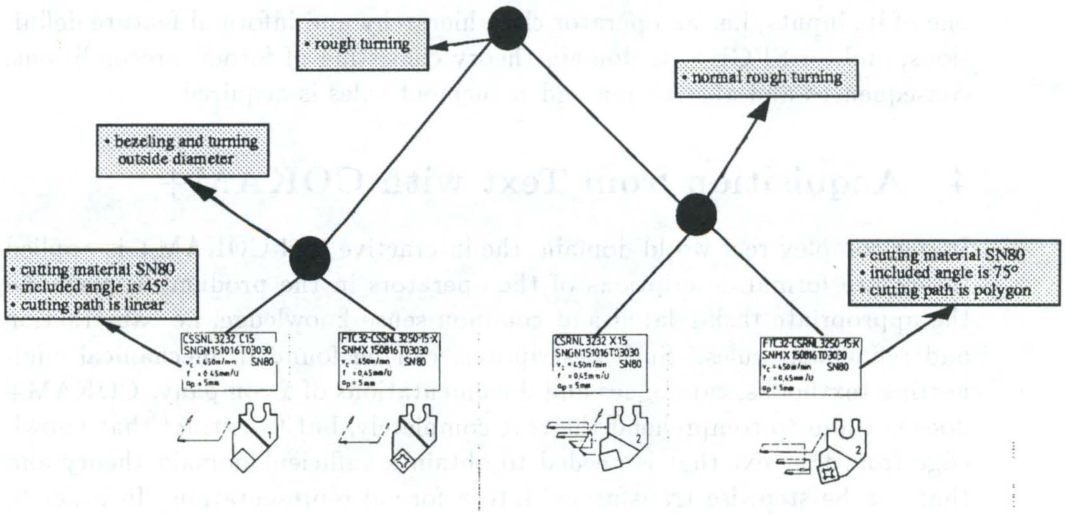

Figure 1: Example a Hierarchy of Concrete and General Operators

engineering) should be considered. In production plans, some specific types of operators often appear in the same order. Most of such sequences are well-known and the experts describe them by features, e.g. "processing of monotonic contour".
All features which are collected for the operator and macro classes provide cues for the definitions of the latter which are then acquired with COKAM+.

4.2 Constructing an Informal Knowledge Base

4.2.1 Extracting Relevant Knowledge from Text

At first, texts which contain relevant information for the to-be-developed expert system need to be found. Mechanical engineering textbooks, catalogues and documentations of a company can be used for the collection of presumably relevant knowledge which is subsequently enhanced by the expert's elaborations. In order to find texts segments which can be used to explain the selected operators, the features which were acquired with CECoS can be used as keywords to search a large bibliography of mechanical engineering literature. The information retrieval technique of latent semantic indexing [4] is applied to find relevant texts in bibliographies or text segments which do not directly match any particular keyword. This is very helpful, since a search based on these very specific keywords obtained from CECoS can be too restrictive at that phase. There are various levels of information search for which some examples are given in the following:

Surface Matches In the simplest case, a relevant text segment may be found through a search at the surface level of the text. Such a search is performed by looking for keywords. By searching for the keyword "cutting material" given as the feature description of the concrete operator in figure 1, the following text segment was found:

Text segment 1 *"An important requirement of cutting materials is that the cutting material must be harder than the workpiece material under the temperature resulting from the cutting process."*

Matches between Paraphrases Since the same objects or actions are often referred to by different terms even within one text, not all text segments which describe a certain object or action can be found with surface matches. With a table of aliases, additional relevant text segments can be found [5]. Generalizations of terms can be used such as "silicon-nitrite-ceramic" for "SN80" or "ceramic" for "silicon-nitrite-ceramic". Thus the following text segment was found by looking for the term "SN80":

Text segment 2 *"Silicon-nitrite-ceramic is less shock sensitive than aluminium-oxid-ceramic. It can thus be used not only with higher cutting speeds, but also with the same feeds as coated hardened metal. Its domain of application is the lathing and milling of cast iron workpieces with cutting speeds up to* 800m/min *or feeds up to* 0.8$mm/rotation$*."*

Matches at the conceptual level Even when a paragraph does not contain any of the relevant keywords and aliases, it may contain important information. This occurs when related concepts are discussed in a text. Since the key terms which are used in some text indirectly specify the gist of the text, different clusters of words can be used as indirect indices for the gist of a text segment. By using such latent semantic indices [4], the text can be searched for segments with certain gists. With latent semantic indexing the following text segment which is relevant for the cutting material "ceramic" can be found:

Text segment 3 *"When a shock-sensitive cutting material is used on a mold with a rough surface, bezeling is required."*

"Shock-sensitive" and "cutting material" belong to a word cluster which also contains the word "ceramic". Although the term "ceramic" is not mentioned in the text segment, it can be correctly related to "bezeling" because of the word cluster.

4.2.2 Decontextualization of Text Segments

The text segments which are extracted from texts first must be decontextualized so that they can be understood without the context of the text. However, a link to the original text is stored when they are added as knowledge units to the informal knowledge base. For the support of decontextualization, there are a lot of approaches in natural language analyzing, e.g. anaphora resolution. The following example shows how a decontextualization based on anaphora resolution can be performed. From original text section (from E. Paucksch, Zerspantechnik, p. 14, translated, see text segment 2) the expert selects the last sentences beginning with *"Its domain ..."* as relevant. This sentence must be decontextualized so that the first knowledge unit runs as follows:

Knowledge unit 1 *Application of Silicon-Nitrite-Ceramic:*
"The domain of application for silicon-nitrite-ceramic is the lathing and milling of cast iron workpieces with cutting speeds up to $800m/min$ *or feeds up to* $0.8mm/rotation$*."*

4.3 Structuring the Informal Knowledge Base

Now the knowledge unit 1 can be interpreted, but the range of its various interpretations is too large. In a following step, the possible interpretations of the knowledge unit are therefore restricted to the desired interpretation with respect to the task of the future knowledge-based system. For the application of cutting tools in lathing processes, it is of no interest that knowledge unit 1 also is valid in milling processes. The unit is modified according to the concrete application which is termed recontextualization:

Knowledge unit 1: child 1 *Application of Silicon-Nitrite-Ceramic:*
"For lathing cast iron workpieces with silicon-nitrite-ceramic the cutting speeds are up to $800m/min$ *or feeds are up to* $0.8mm/rotation$*."*

In COKAM+ there also are two further types of recontextualization. The knowledge units are to be related to one or more categories of the model of expertise. The operators which are given by CECoS and which determine the range of the desired future knowledge-based system describe the specific situations to which the knowledge units are also related.

4.3.1 Structuring through the Model of Expertise

The knowledge units can be assigned to the views of the model of expertise to indicate how they will be used by the knowledge based system. Through the model of expertise the domain can be divided into six views, namely *detailed* and *general product views*, the *detailed* and *general plan views*, and the *detailed* and *general environment views*. The knowledge unit 1: child 1 is assigned to the views *product general and environment general* because the material of the workpiece (cast iron) relates to the product and the material of the cutting tool (silicon-nitrite-ceramic) relates to the environment. Additionally, because of the concrete parameters of the plan (cutting feed and cutting speed) it is related to the *plan view*, too. This is a default assumption because the unit specifies a precondition as will be shown in the following section.

4.3.2 Explanation of Concrete Operators

For the explanation of concrete operators each operator is presented to the expert. The expert then searches the informal knowledge base and selects all knowledge units which specify relevant preconditions and consequences of the particular operator. If relevant preconditions cannot be found in the informal knowledge, the expert is to add new knowledge units. This procedure is the best way to really find all the relevant preconditions and consequences. By combining theoretical knowledge from text with the expert experiences, both gaps in the theoretical knowledge as well as gaps in the experts' memories are likely to be discovered.

Figure 2 shows part of the explanation of a cutting operator. The arrows pointing from the knowledge units to the operator represent preconditions, e.g., the knowledge unit 1: child 1 at the top of figure 2, and the arrows from the operator to the knowledge units represent consequences. Whether the preconditions hold or not, must be checked for the current world state. Since the current world state is described by a number of concrete facts ("SN80") and since the precondition is stated in general terms ("silicon-nitrite-ceramic"), several inference steps which refer to domain knowledge such as the hierarchies of workpiece and cutting materials must be performed. The explanation trees on the left side of the different preconditions represent the knowledge units which are abstraction or refinement rules for testing the preconditions. These knowledge units are also acquired from text and experts.

Explanation structures are acquired for the concrete operators as well as for the generalization of operators which are described by different operator classes. The preconditions and the consequences for generalized operators

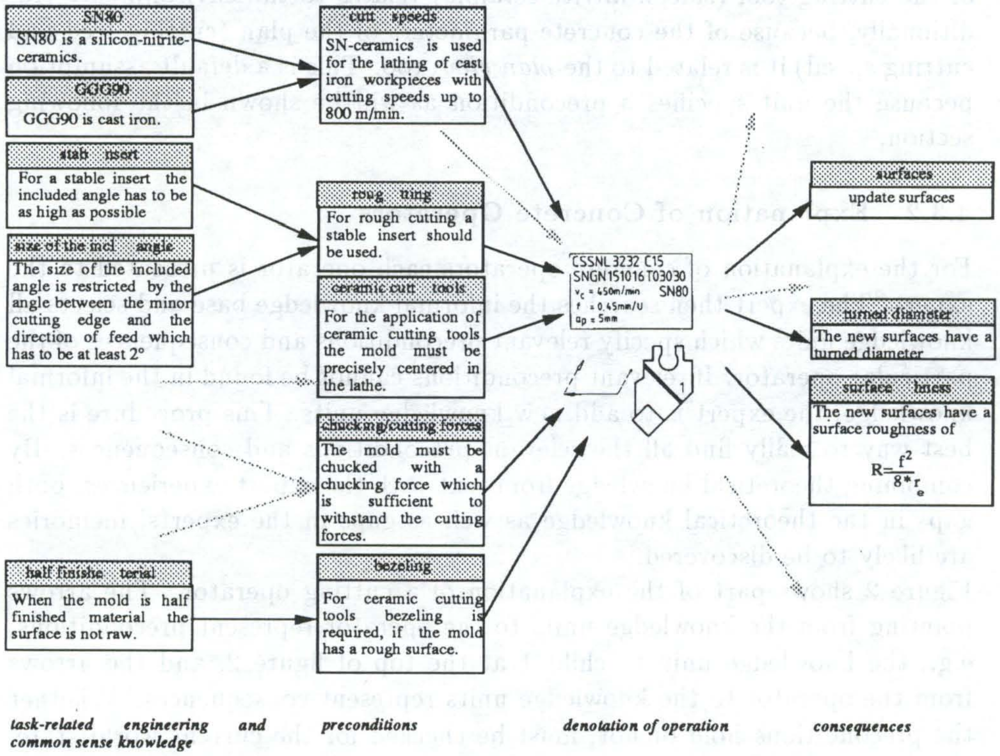

Figure 2: Explanation for the First Cutting Operator of a Case

are essential for the construction of somewhat general skeletal plans, which can be applied to different problem types in the hierarchy of problem classes.

4.4 Step-wise Knowledge Formalization

The knowledge units are now well prepared to be incrementally transformed into a formal representation. The knowledge units are attached to the views of the model of expertise and templates corresponding to a specific view or a specific combination of views are provided for the semi-formalization. Additionally, the templates in COKAM+ depend on whether the knowledge units are preconditions, consequences or task-related and common sense knowledge. Several helpful restrictions can be defined because of this information. Examples are the preconditions or consequences which are always related to the views *detailed* or *general plan*.
A very general template for a precondition can be defined:

$precondition(operator, expression).$

A more specific template for the precondition (knowledge unit 1: child 1) is shown in knowledge unit 1: child 2, where the corresponding knowledge unit is related to the views *general product* and *general environment*.
Furthermore, COKAM+ that allows the construction of a child knowledge unit from any existing knowledge unit and records its source knowledge unit supports the preparation and the formalization of knowledge units. The following two knowledge units show, how the extracted, decontextualized knowledge unit 1 which is specified as a precondition is transformed into a formal representation. Thereby a second generation and a third generation of knowledge units are constructed with the help of COKAM+ . The second generation or child 2 shows the semi-formalization with the help of templates.

Knowledge unit 1: child 2 *Application of Silicon-Nitrite-Ceramic:*
"$precondition(operator,$
$expression(product, environment))$"

The last generation consists of the formalization into target language.

Knowledge unit 1: child 3 *Application of Silicon-Nitrite-Ceramic:*
"$precondition(cut(speed(Speed), feed(Feed), path(Path), tool(Tool)),$
$(workpiece\_material(Path, cast\_iron), cutting\_material(Tool, ceramic)) \rightarrow$
$(Feed < 0.8, Speed < 800))$"

The established child – source – links between the knowledge units help to track down errors or inconsistencies which are later detected in the formal knowledge base. Since the formalization is performed incrementally in small steps, such errors are also less likely to occur.

4.5 Interaction with SPGEN

In SPGEN, the plan execution is simulated on the basis of the available domain theory acquired by COKAM+ . By sequentially executing each operator the preconditions for its application are checked and its effects are determined. A set of Strips–like rules with add- and delete-actions represents the effects of the operators. Thus SPGEN provides the requirement that the domain theory acquired with COKAM+ must be a Strips–like description of the operators.

If the domain theory is sufficient, a complete explanation of the plan will be obtained. Otherwise the domain theory is not complete because of the prerequisite that only such cases are selected which have been successfully used in a real world application. In other words, the simulation of the plan in SPGEN is a formal verification of the domain theory and provides a feedback concerning its completeness with respect to a specific case.

5 Discussion

The prerequisites for an application of COKAM+ in a domain are: there must exist texts of the particular domain, there must exist recorded problem descriptions and solutions, and a model of the problem solving process must be developed. COKAM+ requires the human user to perform a number of operations in a particular sequence to obtain knowledge, which is then related to specific problem solutions within the domain. Furthermore, the application of COKAM+ assists in the structuring and the step-wise formalization of the knowledge and provides a documentation of this process, so that the knowledge acquisition process is also made obvious to other than the involved persons. Thus maintenance can be supported.

In comparison with systems like MEKAS [12] and COGNOSYS II [20] which also acquire knowledge from text COKAM+ can start where the other tools are finished. Whereas MEKAS and COGNOSYS II define the task or goal of the domain just by their application, in COKAM+ the desired competence of the knowledge base is already defined by the model of expertise and the operator classes. By using this additional information the selection of relevant knowledge can be supported. After a complete informal knowledge base is established, the various knowledge units are separately transformed into a formal representation. Such a formalization process can be executed stepwise and guided by templates, which depend on the model of expertise, the developed explanation structure and the desired representations, or some generic structures [20].

COKAM+ also shows a number of similarities to other knowledge acquisition methods from text [1, 11, 18, 7]. The system of Szpakowicz for example supports semi-automated acquisition of structures from technical texts. It presumes an initial general model according to the KADS-method and then acquires conceptual structures from texts. The operator supports the semi-automated system, if it cannot make decisions on its own. The SHELLEY of Anjewierden provides a hypertext-based protocol and concept editor, where the words of the stored text are mouse-sensitive, so that the definitions of the words can be inspected. Also, annotations are stored so that remarks from different people can be read on demand. SHELLY however aims at the development or selection of an interpretation model whereas in COKAM+ the model is a prerequisite for knowledge acquisition.

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