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EXTENDING PROBLEM SOLVER CAPABILITIES THROUGH CASE-BASED INFERENCE

Janet L. Kolodner  
Georgia Institute of Technology

for

Contracting Officer's Representative  
Judith Orasanu

BASIC RESEARCH LABORATORY  
Michael Kaplan, Director

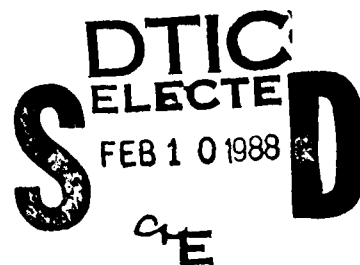


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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>This research note reviews work done on case-based reasoning. In this sort of reasoning, the problem solver makes inferences based directly on previous cases rather than using the more traditional method of reliance on general knowledge. Case-based reasoning results in several enhancements to problem-solving behavior over time. First, recall of previous failures warns the problem solver of the potential for failure, and allows it to avoid the repetition of past mistakes. Second, the previous decisions that have been made are (OVER) |                       |                                                                                |

ARI RESEARCH NOTE 87-8220. Abstract (continued)

→ suggested to the problem solver so that its decisions do not all have to be made starting from scratch. This lessens the search space, and also serves as a way of shortcutting the constraint satisfaction process. Third, if abstract schemata can be derived from cases that have been seen previously, generalized knowledge can be augmented. This allows real shortcuts in problem solving. Decisions that previously took several steps in reasoning to make may become easier through the application of a generalized schema. *Keywords:*

*cognitive**problem**↑*

## **Extending Problem Solver Capabilities Through Case-Based Inference\***

Janet L. Kolodner  
School of Information and Computer Science  
Georgia Institute of Technology  
Atlanta, GA 30332

### **1. Background**

Over the past several years, the research group at Georgia Tech has been engaged in a study of case-based reasoning. In case-based reasoning, the problem solver makes its inferences based directly on previous cases rather than by the more traditional approach of using general knowledge. Case-based reasoning results in several enhancements to problem solving behavior over time. First, recall of previous failures warns the problem solver of potential for failure and allows the problem solver to avoid making mistakes made previously. Second, previous decisions that have been made previously are suggested to the problem solver so that its decisions do not have to all be made from scratch. This lessens the search space and also is a way of shortcutting the constraint satisfaction process. Third, if abstract schemata can be derived from cases that have been seen previously, generalized knowledge can be augmented. This allows real shortcuts in problem solving. Decisions that previously took several reasoning steps to make may be possible through application of a generalized schema.

### **2. Making a Case-Based Inference**

Making a case-based inference, in the simplest case, includes the following set of steps:

1. Recall a previous case
2. Focus on appropriate parts of that case
3. Use those parts of the previous case to derive an appropriate decision for the new case

Recall of a previous case is done by probing the memory. According to Schank's (1982) MOPs theory, understanding of a new input (case) includes finding the best knowledge in memory that can be used to make predictions from it. Finding this knowledge is equivalent to integrating the new case with what is already in the memory. As reasoning is going on, according to this theory, memory is constantly being probed and updated, the case is getting better integrated, and better knowledge to use in making predictions about the case is being derived. According to the same theory, generalized knowledge and individual cases are organized together in the same memory (see Kolodner, 1984; Lebowitz, 1983 for means of implementing such a memory). As a result, as a case is being understood and integrated into memory, both generalized knowledge and individual cases become available to use in further processing it. It is the cases that are encountered during this understanding process that become available for case-based inference.

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Any particular case that is recalled could be quite large. The entire case is not necessary for making a case-based inference. In fact, the whole case with all of its details is too cumbersome to work with. Rather, the parts of the case that have relevance to the new case are the ones to focus on. How can these parts be determined? At any time during reasoning, the reasoner has a set of reasoning goals. It is these reasoning goals that determine which parts of the previous case to focus on. Reasoning goals are the set of things it is trying to make conclusions about. Thus, a reasoner that has to mediate a dispute will have goals associated with finding out the goals of disputants with respect to the disputed object, finding out about other related goals of either disputant, finding out how important each goal is to each disputant, figuring out what kinds of compromises will be acceptable, presenting a compromise solution to each side, and eventually, modifying the compromise according to the feedback provided by disputants and persuading each side of the utility of the solution. Given the current goal of the reasoner, focus is directed to those parts of the previous case that are relevant to fulfilling that goal. Thus, when a mediator is reminded of a case while trying to determine how important a particular goal is to a disputant, it will focus on how important the goal was to a previous disputant and what gave it that importance. When it is trying to persuade a disputant of the utility of a compromise, it will focus on the way that type of compromise was supported previously\*.

Where do these goals come from? One can think of a general purpose reasoner that is at least initially in charge of reasoning goals. As a problem is being reasoned about, the goals and subgoals that must be achieved to resolve it are derived by that reasoner. In Carbonell (1983, 1986), that reasoner is a means-ends analysis problem solver and therefore derives its subgoals by comparing the current and goals states, deriving their differences, and setting up goals of reducing those differences. In Hammond (1986) and Kolodner (1985; Kolodner, et al., 1985; Simpeon, 1985; Sycara, 1985), the set of goals are known a priori, and the reasoner goes through the set of goals sequentially. In Kolodner (1987), Cullingford & Kolodner (1986), the general purpose reasoner is a problem reduction problem solver. Initially, the goals of the case-based reasoner are derived from the goals of the general purpose reasoner. When memory returns a case, the case-based reasoner takes the case along with the current problem solving goals and attempts to achieve those goals by using the case.

\*See Kolodner, 1985; Kolodner, et al., 1985; Simpeon, 1985 for more about this. Carbonell, 1983, 1986 does not write about this directly, but his method in effect focuses in this way. The difference in the two methods has to do with where the goals come from rather than how they are used to focus.

Later goals of the case-based reasoner may be derived by the case-based reasoner when it needs additional knowledge to make its inferences or when it finds that focus must be changed (Kolodner, 1987), by the case that is recalled from memory (Carbonell, 1986, Hammond, 1986), by the general purpose reasoner (Kolodner, 1987), or else are retrieved from the set of goals initially set for the program (Hammond, 1986; Simpson, 1985).

The third step, making the case-based inference(s), is the purpose of the others. Recall that at this point, we have an old case, we have a problem solver goal, we have focused on a part of the old case that is to be used in achieving that goal, and we have the case we are currently working on. The purpose of the case-based inference is to achieve the goal for the new case based on the old one. The process for doing this depends on a lot of considerations: Was the previous case a success or a failure? Was the part we are focussing on responsible for the failure or not? Did it change as a result of re-evaluation? Is there a value that, when derived, will achieve the goal, and if so, is that value available in the old case? Do we know how that value was derived for the old case? Was it by an "easy" or a "complex" set of reasoning steps? Do we know why the value from the previous case was appropriate? Do we know why the method of deriving that value previously was appropriate? If achievement of the goal is not done by simple derivation of a value, do we have a generalized schema that explains how the goal was achieved previously? If no schema, do we have the set of steps? Is our goal to derive a plan or is it to derive a feature value?

The answers to this set of questions determine which of a variety of case-based inference methods ought to be used. Transfer and modification of a value or a frame is one method. It is the method employed in Carbonell (1983), Hammond (1986), Simpson (1985), Sycara (1985), Kolodner, et al. (1985). Alternatively, the conditions under which a previous decision was made can be taken into account, in which case the case-based inference tends to be a transfer of the method of decision making or the inference rules used previously rather than a value. These methods were initially described in Carbonell (1983) and (1986) and called *transformational* and *derivational* analogy, respectively. He proposed them as methods for deriving a plan. We propose that both methods can be used any time case-based inference is called for, give a set of steps for each, and give heuristics for choosing between them. Answers to some of the questions above determine which should be used at any time. Because derivational analogy is more time-consuming than transformational analogy, for example, it is used only if transformational analogy can be easily ruled out or if problems are obviously from different domains.

Another case-based inference method is more schema-based (see, e.g., Holyoak (1984)). In this method, the current and previous cases are compared and a schema describing the similarities of the problem statements is described (Shinn, 1987). The schema must be such that it can be used to describe both problem statements. The schema is then broadened to describe the solution to the previous problem, and the new problem is solved by applying the schema to that problem. In principle, it should be possible through this method to derive real problem solver shortcuts by storing the derivations of the reasoning steps in the schema where they do not have to be considered during later problem solving except when something goes wrong. This is not possible with transformational or derivational analogy by themselves.

While these three methods are the ones that are applicable when the previous case resulted in success, additional reasoning must go on when the previous case resulted in failure (Carbonell, 1986, Kolodner, 1987). In this case, the conditions under which previous values were computed and the set of steps used to make decisions are checked against the new case to see if the same potential for failure exists. The previous case may also provide suggestions to the problem solver of how to proceed. In essence, the reasoning that goes on here is a special case of derivational analogy.

In short, the steps that must be followed to capitalize on a previous failure are\*: (1) determine what was responsible for the previous failure, if possible (this may already be recorded, and if not, some short amount of time is spent attempting to derive it), (2) direct reasoning focus to the decision in the new problem that is analogous to the one that caused the failure in the previous one (this may be the one currently being focussed on or one that its correct solution is dependant on), (3) check for the potential for the same failure in the new case, either by seeing if the explanation of the previous failure holds in the new case or by checking the reasons why the previous decision was made and seeing if the same justifications might apply in the new case (this step may require additional information gathering), (4) if not, potential for error is not there, so return to the interrupted step and keep going, (5) if so, rule out the previous errorful decision as a possibility for the current case, and if the previous case was finally resolved correctly, determine if the decision made when it was resolved correctly is applicable to the new case, (6) if so, use it as a suggestion for a case-based inference, (7) if step 2 redirected focus, then redo whatever decisions must be redone as a result (i.e., follow dependencies) and return to the reasoning step that was interrupted.

\*Of course, it is more complex than the set of steps shown here, but these steps form the core of the processing. See Kolodner (1987) for more detail.



Because this processing requires knowing why previous decisions were made, what other decisions previous decisions were dependent on, and what was responsible previous failures, there must be both a representational system and a bookkeeping system that keep track of this knowledge. Our solution to the representational problem is to have "value frames" (Kolodner, 1986) associated with each value recorded by the system\*. Each time the problem solver makes a decision, it records its decision in the appropriate place and also records what led it to that decision. Value frames include facets for a value, other values that were suggested as alternatives, ruled out values, conditions that were considered in choosing the value, and the inference rule or method or set of steps used to make the decision. Each inference rule that is recorded has three parts to it: the rule body, the bindings that were used in this instance, and the source of those bindings (i.e., where in the problem description can the values used in the bindings be found). In addition to supporting the processing described above, the knowledge found in value frames also supports case-based inference in general.

While value frames keep the justifications for each decision, pointers in the other direction are needed when the problem solver needs to retract an already-made decision. Our solution has been to integrate a truth-maintenance type system with our problem solver (Kolodner, 1987).

### 3. Implementations

In an attempt to be able to come up with results that cut across several different problem solving methods and styles, we have looked at expert task domains, such as psychiatric diagnosis and labor mediation, and common-sense task domains, such as solving everyday resource problems, giving advice about acquiring household appliances, and most recently, medical design.

An early implementation of a case-based reasoner to come out of our group is the MEDIATOR (Simpson, 1985, Kolodner, et al., 1985), a program that uses case-based reasoning to understand and resolve disputes in a common-sense way. There are several major points illustrated by the MEDIATOR project. First, it showed that case-based inference is appropriate for any kind of inference that needs to be made, provided the appropriate previous cases are available. Second, it showed how at least some reasoning shortcuts are allowed with case-based reasoning. Third, the MEDIATOR

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\*Value frames hold essentially the same things Carbonell (1986) claims are necessary for derivational analogies.

illustrated that if the reasoning process keeps its reasoning goals explicit, then the case-based reasoning process can be directed by those goals. While reminding depends on the description of the whole case, access to parts of the previous case was described as *demand-driven*, where demand is supplied by the reasoner's goals.

There are many problems that the MEDIATOR did not address, however, and much of what appears in this abstract is a result of analysis of the MEDIATOR's strengths and weaknesses. We are currently addressing the problems described in this paper and others in the context of two projects. Our JULIA project (Cullingford & Kolodner, 1986, Kolodner, 1987), an attempt to design an automated colleague that acts as a caterer's assistant. JULIA's case-based reasoner allows interacts with a problem reduction problem solver that maintains a network of JULIA's reasoning goals and a very limited reason maintenance system that keeps track of the dependencies between decisions that have been made. When JULIA is more complete, the problem reduction problem solver will also know how, in general, to achieve those goals, and will also include a constraint propagator; a more sophisticated condition checker and reason-maintenance system; and a full natural language system. Our car mechanics project is an attempt to look at learning from experience in a real world domain.

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