PATCHING UP OLD PLANS

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ABSTRACT

Recent research has demonstrated the value of re-using old plans rather than creating plans from scratch. This approach to planning creates the need for efficient and flexible plan adaptation methods to transform a past plan to fit the current problem. A characteristic of plans is that they often fail. This creates the need for efficient and flexible plan repair methods. We propose a uniform treatment of the two issues, plan adaptation and repair, based on a combination of Case-Base Reasoning and heuristics. Plan adaptation involves incremental modification of the old plan, and fixing of anticipated problems through similarity-based retrieval of cases that supply appropriate modifications. Plan repair involves explanation-based retrieval of previous failures that supply possible repairs. A selected repair is then adapted to fit the current failure. The proposed approach gives a planner the flexibility to access a broad range of adaptation and repair strategies not available to planners that use either of the two methods in isolation. The approach has been implemented in the PERSUADER, a case-based planner that generates and repairs plans to resolve labor management disputes.

INTRODUCTION

Recent research has demonstrated the value of re-using old plans rather than generating plans from scratch [Alterman 87, Hammond 86, Simpson 85, Kolodner et al. 85, Turner 87]. If a planner wants to re-use plans effectively it must have ways of *adapting* a previous plan to fit the current situation. Re-using plans is especially useful in domains that are ill-defined and have no strong causal theories or well-understood empirical regularities. One consequence of these characteristics is that solutions may fail and may need *repair*. This paper addresses the issues of plan adaptation and repair. The proposed approach involves the integration of Case-Based Reasoning (CBR) and heuristics.

Adaptation in the past has been done using only heuristics (e.g., [Hammond 86]). We are using CBR in a novel way: to suggest means of adaptation. The proposed process of coming up with an initial solution is an incremental process of adjusting the previous plan using CBR and heuristics, and anticipating possible failures by examining the case memory for failures that have the same features as the features in the current problem. Using CBR for adaptation adds flexibility since, as more experiences are acquired, the planner has an increasingly larger repertoire of adaptations that it can choose from. In planning for the satisfaction of multiple goals, the precedent plan selected might not make provisions for all input goals. CBR provides means of adapting a plan that satisfies some of the goals, to satisfy the rest. In addition, since cases incorporate accumulated expertise and changing circumstances, the proposed adaptations are more closely suited to a current problem.

After a plan has been created, it is tried out in the world. If the plan fails, it needs to be repaired. Our approach to repair uses an explanation for the failure provided by environmental feedback. This explanation is used to index into the case memory to retrieve and adapt the repair of previous similar failures to the repair needs of the current situation. In other words, Case-Based Reasoning in the space of failures is employed.

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The spectrum of situations where plans will fail cannot be anticipated. Thus, use of heuristics or hardwired TOPs alone [Hammond 86, Turner 87] do not provide a flexible enough methodology for dealing with failed plans. CBR is more flexible, since, as memory is enriched with new experiences, new ways that plans can fail and new repairs become available. Simpson [Simpson 85] also has used CBR for failure recovery and repair. His approach differs from ours in that he uses similarity-based retrieval of failed cases. Hammond [Hammond 86] finds an explanation of a plan failure via a set of causal rules that describe effects of actions under different circumstances. The explanation is then used to find a planning TOP with repair strategies. In our model, the explanation is provided via environmental feedback. This is realistic for problem domains with incomplete and changing knowledge and no strong domain model. For such problems, automatic failure explanation methods are not applicable. The features of the explanation are used as indices to retrieve previous failures and access the associated repairs.

Our approach is embedded in the computer program PERSUADER, which, acting as a labor mediator, resolves conjunctive conflicting goals of a union and company by finding compromises acceptable to them. Although the program operates in the domain of labor relations, the techniques it uses are domain independent.

THE PERSUADER

The PERSUADER is a planner that integrates Case-Based Reasoning with Preference Analysis (a planning method based on multi-attribute decision theory [Sycara 87, Sycara 88]) to create acceptable compromises in labor management contract negotiations. The PERSUADER acts as a labor mediator. Its task is to help the disputants arrive at a mutually acceptable compromise plan (contract). To reach its goal, the PERSUADER must plan actions to achieve instrumental reductions in the difference between the parties' positions. Planning must be iterative and reactive because knowledge is incomplete (e.g., models of the agents' intentions must be inferred), and dynamically changing (success is met by shifts in positions which necessitates further planning).

The PERSUADER's input is the set of conflicting goals (e.g., wages, pensions, holidays, seniority language, management rights) of the company and its local union, and the context of the dispute (e.g., economic conditions in the industry, general economic conditions, information about the disputants). Its final output is either an agreed upon compromise, or an indication of inability to solve the problem if the parties to the dispute did not reach agreement within a particular number of proposals (to simulate the inability of the parties in the real world to reach agreement before a strike deadline). To perform its tasks, the PERSUADER uses knowledge of past negotiations and settlements (cases), knowledge of the labor domain, and commonsense knowledge of human goals and behavior. Cases are indexed in memory via salient domain features, such as the industry to which the company belongs, the international union to which the local belongs, the geographical location of the company, the union members' job classification, and the final contract.[2] In labor mediation, the most important feature is the industry to which the company belongs. Hence, if a current case involving a competitor is in the set of retrieved cases, it is the one used as a basis for reasoning. The concept of a negotiation failure is an *impasse*, a situation where the planner has proposed a compromise that has been rejected by at least one agent. A list of impasses represent the negotiation process. In addition to salient domain features, impasses are indexed by the failure reason and objectionable negotiation issue. Associated with impasses are plans used to repair them.

To construct an initial compromise, the PERSUADER (a) retrieves appropriate precedent cases from memory using the features as memory probes, (b) selects the most appropriate case(s) from those retrieved using an evaluation function based on a prioritization of the features, (c) accesses the plan used in the selected case, and (d) adapts the precedent plan to fit the current situation.

Once a proposal has been generated, the PERSUADER proposes it to the parties. If the parties agree, the case memory is updated with a successful episode. If at least one party disagrees, the PERSUADER iteratively performs the following tasks: it generate persuasive arguments to change the evaluation of the

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[2]The PERSUADER's memory is based on *generalized episodes* [Kolodner et al. 85].

objecting party with respect to the proposed compromise, or incrementally repairs the rejected compromise to increase its acceptability.

The PERSUADER also stores failures along with the reason for failure (if one can be found) as well as dependencies among decisions taken at different times of the negotiation. Failures are stored so that they can be recalled in situations with similar features to the one where the failure occurred, thus warning the problem solver about potential problems, as well as providing appropriate repairs. Unlike other case-based planners (e.g. [Hammond 86]) that only avoid problems that they can anticipate at the beginning of planning, in the PERSUADER, warning/avoidance of problems occurs at each decision point.

PLAN ADAPTATION

The plan adaptation process consists of the following steps:

- Adjust the accessed precedent plan to compensate for its dissimilarities from the "ideal" precedent for the current problem
- Modify the adjusted plan to take into account detailed information about the current problem
- Anticipate failures of the modified plan and fix it appropriately

Although we present the steps involved in plan adaptation as sequential, a reasoner may go through many iterations of the loop in order to construct a suitable plan. This happens because a contemplated modification may interact with the already existing part of the plan. If this interaction cannot be fixed, another case may need to be retrieved to suggest a more suitable modification.

Precedent Adjustment

The ideal precedent plan is one that was used in a case whose indices have the same values as in the current case. In labor mediation, for construction of an initial proposal, the ideal precedent is a case where the disputant company is a competitor of the current disputant company, the geographical location of the companies is the same, the local unions belong to the same international union, the job classification of the union members is the same, and the two companies have the same size and organizational structure. Since a retrieved precedent case usually differs from the ideal, the plan used has to be adjusted. For example, if a precedent case from a similar industry (not a competitor) is available, then an adjustment of the values of wages has to be made to compensate for dissimilarities along the industry dimension. In labor mediation, this adjustment is called the industry differential. If the company in the precedent case is in a different geographical location than the company involved in the current dispute, then the proposed wages have to be adjusted by the difference in the cost of living in the two locations. This is called the area differential.

Precedent adjustment is done using a library of heuristics. The difference between the current precedent and the ideal along the important problem dimensions (e.g., industry, geographical location) is used to index into the library of heuristics to find the one to apply.

Consider, for example, the PERSUADER trying to find a compromise for Thompson Inc, a company producing airplane frames and its union. The union wants 15% wage increase, 7% increase in pensions, no subcontracting, and strict seniority governing promotions and layoffs. The company wants no wage increase, no pension increase, unlimited subcontracting, and no seniority (i.e., promotions and layoffs to be determined by criteria chosen by the company). The PERSUADER searches memory for similar past contracts. It cannot find contracts of competitors but finds contracts of similar industries. Out of those, it selects the contract of Baker Inc. company since its product (car chassis) is most similar to the products of Thompson Inc., and since its location (Oregon, a northwestern state) is similar to Thompson's (Northern California). The Baker Inc. contract provided 10% wage increase, 4% pension increase and subcontracting for limited time periods. Since the Baker Inc. contract makes no provisions for promotions and layoffs, another contract making such provisions is sought. The contract of Schmidt Inc., a company that makes steel cases is selected out of those retrieved. It stipulates that in layoffs and promotions the company should observe the principle of seniority in conjunction with the worker's ability

to perform the work.

The information from the Baker Inc. and Schmidt Inc. contracts is combined to form a candidate contract for Thompson Inc. This contract is adjusted by applying to it industry and area differentials between Oregon and California. These adjustments result in 12% wage increase, 5% pension increase, subcontracting for limited time periods, and seniority and ability as co-determinants for promotions and layoffs.

The result of precedent adjustment is a base-line plan, called the "ballpark" plan. A ballpark plan is the best that can be constructed without taking details into account. The ballpark plan is modified further taking into consideration important particulars of the current problem.

Modification of the Ballpark Plan

After constructing a ballpark plan, it has to be evaluated for appropriateness to the current case. There are three categories of knowledge that the PERSUADER takes into consideration when criticizing a ballpark plan:

- Knowledge of unacceptability conditions
- More detailed knowledge of the situation of the disputants
- Knowledge of the dispute context and its effects on the situation

During evaluation, critics associated with these knowledge sources are activated. These critics are prioritized and considered in order of importance. A critic is most important if failure to apply it would result with greater probability in plan unacceptability. For example, a check is always made to see whether the company will be able to afford the ballpark economic package. This check is important since, if a company cannot afford the economic package, it most probably will reject the proposed settlement. If it is found that the company can afford the economic package, then critics associated with possible states of the company finances are applied. Such financial considerations include whether the company has suffered losses in the recent past, and whether the company has traditionally paid above, below, or industry average. A set of critics associated with the context of the dispute is then applied. In labor mediation context knowledge is almost entirely economic. Such knowledge includes considerations for the whole economy (recession, inflation etc), economic conditions of the industry to which the disputant company belongs, economic conditions of the geographical location of the company, and labor supply in the area.

If the application of a critic suggests that the plan needs further modification, salient features associated with the critics are used to search memory. The evaluation function is used to select the best out of the retrieved cases. The plan used in that case is checked for applicability. If the considered plan's preconditions match the current situation, then the plan is applied. If not, either the plan is modified using heuristics, or the next best case from those retrieved is considered.

Case-Based Reasoning is the preferred modification method in the PERSUADER. The rationale is that a previous case best reflects the interactions present in the situation. Moreover, the fact that the suggested modification has worked in a similar situation can be used as justification more convincing to the agents than invocation of a rule. If previous cases are not available, then rules associated with the critics are used for modification.

In trying to modify the ballpark plan for Thompson Inc., the PERSUADER finds out that the company cannot afford the contemplated economic package. The case memory is now searched for cases where the same situation (inability of the company to afford the economic package) had occurred for similar companies. The case of Ironside Inc., a company making truck frames, is selected out of the set of retrieved cases as most similar because of similarity of the product, same geographical area, and similarity of the issues involved in the negotiation. In that case, the plan "pass the extra cost to the consumer" had been applied. A precondition of this plan is that the market for the product is not sensitive to price increases. Since the precondition is satisfied in the case of airplane frames, the plan is applied (i.e. the contemplated contract is not changed).

Searching memory with index INABILITY-TO-PAY and ECON-PKGE
3 cases found... Select case3,
since it is similar product, same area, same issues in economic package
Looking at the plan "pass the extra cost to the consumer" from case3
Check preconditions of plan used in this case

Since the market is insensitive to product price change
for airplane frames, plan applicable
Apply plan used in case3 to economic package

The PERSUADER now finds that Thompson Inc. has had losses of 3% in recent years. The case memory is now searched for similar situations. Since no pertinent cases are found, the PERSUADER uses a heuristic associated with the condition of recent losses that supplies the advice to reduce the contemplated increases for wages and pensions by half of the percentage losses. This results in 10.5% wage increase and 3.5% increase in pensions.

Failure Anticipation

Before proposing the generated compromise, the PERSUADER checks to see whether the solution might engender some unforeseen problems. The knowledge that a plan has failed in the past can suggest to the planner the potential for failure if the plan is adopted in the current situation. In contrast to other case-based systems (e.g., [Hammond 86]) that anticipate problems *before* constructing a plan, the PERSUADER anticipates failures as the *final step* in plan construction. This is appropriate in domains where the sought after plan is a compromise plan and thus, it is not apparent at the beginning of planning what exact form this compromise will take.

Failure anticipation is done through *intentional reminding* [Schank 82] of failures. This is appropriate since the PERSUADER does not assume a strong domain model that could be used to index failures only via the features that contributed to the failure. The conjunction of the plan's features and the index "FAILURE" are used as a memory probe. This probe returns cases where the contemplated plan has failed. The most similar case is selected and the repair used in that case (if present) is accessed. The process (knowledge extraction, evaluation) is applied to the selected repair to yield an appropriate adaptation to avoid the potential problem.

Having the repair stored in memory is best. This is not always possible. Often, it may be known that a plan was inadequate but no explanation or repair was found. In this case, the knowledge of a past failure can still warn the planner of the presence of a potential failure.

Before proposing the updated compromise to the Thompson Inc. labor dispute, the PERSUADER searches memory to discover potential problems. It finds problems with the contemplated subcontracting language. It retrieves a case where the union had filed a grievance protesting that the company resorted to subcontracting instead of recalling laid off workers. The arbitrator in that case did not vindicate the union since the subcontracting clause restricted the company only as to the duration of subcontracting. The arbitrator, however, mentioned in the award the language needed to safeguard the union against such practice. The language was "The company has the right to subcontract for limited periods of time, and when it is clear that no work will be lost to union members".

Searching memory with index FAILURE, SUBCONT-LANG, LIMITED-TIME
1 case found...
Looking at the modification "no work lost to union members" from case1

No precondition to check
Apply modification used in case1 to subcontract language

PLAN REPAIR

It is a known fact of life that plans fail and need repair. In labor mediation, failure of a proposed compromise means that an agent has rejected it. Repair is needed to improve the acceptability of the

rejected plan. The PERSUADER has two ways of reacting to plan failure/rejection: changing the rejecting agent's evaluation of the plan through persuasive argumentation, and modifying/repairing the plan so that it will be more acceptable. Persuasive argumentation is tried first, since, if the objecting agents can be convinced to change their utilities and accept the compromise, then a successful resolution has been found. If, on the other hand, a rejected compromise is modified/repaired, the repair may make it objectionable to agents that had agreed before. Thus, only after persuasive argumentation is no longer judged effective by the planner (i.e. all applicable arguments that the planner could generate have been tried and rejected), is repair tried. For details of generating persuasive arguments see [Sycara 87, Sycara 85a, Sycara 85b].

When a failed compromise plan needs to be improved, the PERSUADER ascertains from the rejecting agent's feedback the objectionable goals, the reason for the rejection and the importance the agent attaches to the goals. Each objectionable goal/issue and reason are used as probes to select impasses with the same stated impasse goal and impasse cause as in the present failure. In other words, CBR is employed in the space of impasses. The selected impasse supplies repairs that will hopefully improve the rejected solution. If no appropriate impasses can be found, the PERSUADER uses standard heuristics that it knows about.

In multivariate planning there are many ways a plan could be modified/repaired. A planner seeks not only a plausible repair but one that with some confidence *improves* the rejected plan. After a repair is applied, the resulting compromise is evaluated using the parties' satisfaction with the compromise.[3]The criterion of plan improvement that the PERSUADER uses is whether the contemplated repair increases the rejecting agent's satisfaction more than it might decrease the satisfaction of the agent(s) who have agreed to the compromise. Without an ability to predict which repair has a chance of being accepted, the planner could propose repairs that do not converge to a mutually acceptable compromise.

The PERSUADER's strategy for repair is explanation-based where the explanation (reason for rejection) is supplied by the rejecting agent. This is realistic for complex domains where there is no strong domain model, and plan failure depends in part on idiosyncratic behavior of the agents. In such domains, automatic failure explanation methods are not applicable.

When presented with the compromise resulting from the adaptation process, Thompson Inc. objects to the seniority language saying that, since many of its key employees are junior, they will be the first to be laid off. Having this explanation the PERSUADER retrieves a case where the same objection was raised. The seniority language in that case was amended to read: "Key employees will be excepted from the seniority rule for layoffs; the company will designate whom it considers key employees".

Searching memory with index FAILURE, SENIORITY, KEY-EMPLOYEES
2 impasses found... Select impasse1,
since it is same industry, same area, same job classification
Looking at the repair "except key employees" from impasse1

No precondition to check
Apply repair used in impasse1 to seniority language

SUMMARY AND CONCLUSIONS

We have advocated the integration of CBR and heuristics for plan adaptation and repair. Such integration gives a planner the flexibility to consider a broad range of adaptation and repair strategies that planners that use either of the two methods in isolation cannot have access to. The use of CBR allows the planner to check and select strategies that do not introduce additional problems. Since cases incorporate accumulated expertise and changing circumstances, the proposed adaptations and repairs are closely suited to a current problem. Repairing plans using CBR is particularly suitable for domains with incomplete and changing knowledge and no strong domain model. These characteristics typify most "real

[3]An agent's satisfaction with a compromise, called his payoff, is calculated using a method based on multi-attribute utility theory. For details of this, see [Sycara 87, Sycara 88].

world" domains. In addition, a planner has the flexibility to try multiple strategies suggested by cases and choose the most appropriate. Integration of CBR and heuristics for adaptation and repair gives a planner the choice of using knowledge in either form: generalized (inferential rules) or specific (cases).

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