Combining CBR and Constraint Reasoning in Planning Forest Fire Fighting[1]

P. Avesani, A. Perini and F. Ricci
Istituto per la Ricerca Scientifica e Tecnologica
38050 Povo (TN)
Italy
e.mail: {avesani,perini,ricci}@irst.it

Introduction

In this poster we shall illustrate a work in progress aimed at developing an integrated system for planning first attack to forest fires. It is based on two major techniques: case based reasoning and constraint reasoning. The architecture we propose is part of a more extended system that is aimed at supporting the user in the whole process of forest fires management. The novelty of the proposed system is mainly due to the use of advanced techniques for the development of the man/machine interface based on the representation of the user tasks' structure, the integration of more traditional techniques for data analysis with up to date techniques for data classification developed in the AI community, the extensive application of the Case Based paradigm to the planning of the first attack and the integration of the case based reasoner with a constraint solver, mainly in charge with temporal reasoning.

Many computerised systems have been proposed and developed to help the responsible organisations in dealing with some of the phases of forest fire management: prevention, suppression, control. A part from many systems based on traditional techniques (GIS, Spreading fire models, resources management with data base) very few AI rooted applications have been developed. We cannot avoid quoting the Phoenix project [CGHH89], which is real-time adaptive planner that manages forest fires in a simulated environment, and the system developed by P. Kourtz that addresses the problem of dispatching waterbombers, helicopters and crews for fire control in Quebec [Kourtz87]. None of them use CBR techniques, the first one is a research on the design of intelligent agents and the second is a classification system based on rules implemented in PROLOG.

In this extended abstract we shall illustrate the operational context in which the system will be deployed and the intervention planning approach. At the moment we are terminating the design phase and we shall start the development in the next September.

The operational context

In this subsection we shall address the operational context in which the system will be deployed. This description will make the reader familiar with the typical tasks in charge to the user. The user of the system is the controller based in a provincial centre. His tools are: a workstation, a dedicated line to acquire data from infrared sensors and meteo sensors, a radio, a fax, a telephone and a printer. The system running on the workstation comprises a Geographic information System, a graphical simulator of the fire evolution, tools for territorial, meteo and resource assessment and a module for supporting the intervention planning and control.

When a new fire is reported, the alarm is promptly validated and the situation assessed by the user possibly running the propagation module. On the screen the operator can look at the output of the propagation module and access, through a graphical interaction, information on the graphical symbols showed by the map. At the end of this phase the operator has acquired enough information for drawing on the map a number of line sectors that subdivide the original fire front. The system runs a set of functions that compute the relevant data for each sector. The system presents these data to the operator and the operator may confirm this segmentation or revise his choice.

Once the sector has been identified on the map the operator is now looking for a plan to fight the fire in each sector and that achieves some objectives. The plan may use air forces and/or ground means, and they have to adopt a specific scheme of work. Searching in a data base of past sector plans, the system retrieves a set of plans that achieves these objectives. Follows a modification phase to fit these plans to the current situation. The plans are showed to the operator by means of a predefined form. After this phase of sector plan evaluation the operator may choose to repair a plan editing some subpart. Otherwise he may propose a new one, that seems applicable, based on his experience. The system will provide to check the numeric consistency of the repaired plan: that is verify the constraint on temporal relation, water quantity and resource availability.

The operator now has a set of alternative sector plans for each sector. The system may suggest some combinations and may also verify the combination chosen by the operator. The operator composes on the screen the sector plans using the system as a constraint checker. Furthermore we may also require the system to propose complete plans and to compare different approaches. The system does not select a unique plan, but list a number of plans that differ on the cost, on the expected territory burned by the fire, on the use of specific resources such as water bomber or helicopters.

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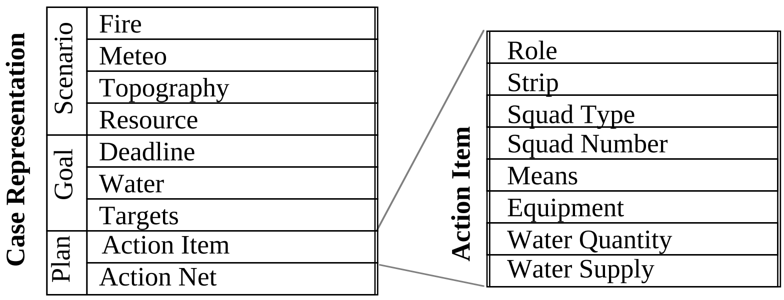
At this point the operator has to assign specific actions to specific means. He selects the squads, choosing the base and the leader, he must assign to each squad the necessary means. He sets up a contact with the external organisations that are needed for help. He requests the cooperation of the Regional Centre asking for state owned air resources and further resources from other Provinces or Compartments. He requests the cooperation of the Prefecture for the intervention of the Army. He assures himself of their readiness to help. The operator finally takes a decision: selects a plan and sends the appropriate orders to the bases closing the planning of the first intervention.

The Intervention planning approach

The intervention planning system rests on a CBR module integrated with a Constraint Reasoner module. It works on sector plans whose representation consists of two main parts. The first one allows to efficiently associate the current situation to an old, similar one among those recorded in the historical database of interventions. The second one contains a description of the structure of the plan in terms of action and their temporal relations. Constraint propagation techniques are applied to this part of the plan representation in order to support adaptation and repairing of a sector plan. Moreover constraint reasoning techniques support composition of sector plans into a global plan and resource allocation providing a plan instance specific to the current situation.
In the following we shall discuss provisional representational choices for plan representation and describe how the system will support the main decisional steps of the planning process above stated.

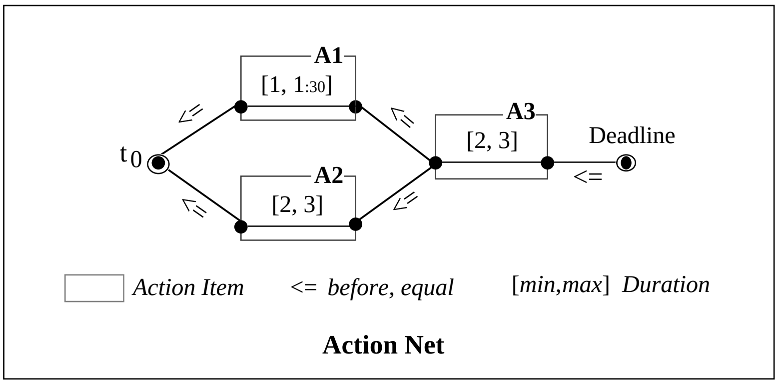
Sector plans

A sector plan is defined by a set of features describing the physical environment and by the structured set of actions that have to be performed, as depicted in Figure 1a.
The sector plan features include a description of the scenario and the goal. The scenario is defined by a set of fire parameters, the most critical to evaluate the fire danger, the meteo conditions, the topography of fire location and the available resources that are located in the bases close to the fire. The goal includes three basic objectives of the global plan: the intervention deadline, the water equivalent of the fire fight, the targets of the fire. The intervention deadline is the maximum time in which the plan has to be completed. The water equivalent of the fire fight is an estimate done by the fire expert to evaluate the global intervention. The targets of the fire are a set of valuable things to protect, for instance a building or a well.



Figures 1a, 1b

The scenario corresponds to the initial condition and the goal to the final condition in classical planning formulation. Sector plan actions identify the fire fighting tasks that should be performed by a set of squads with appropriate equipment or means, see picture 1b. Fire suppression by ground attack using nozzles or air attack with helicopters are typical examples of fire fighting actions. The structured set of actions describes the temporal dimension of the plan. It contains information on action duration, possible time constraints respect to the starting and ending times of the plan, and temporal relation between actions. We represent it by a graph whose nodes correspond to starting and ending times of actions and whose arcs are labelled with the temporal relation between the connected nodes following the approaches presented in [DMP91], [vanBeek92]. We shall call this structure action net (see Figure 1c for an example). For instance the arc connecting t_0 and the starting time of the action A_1 is labelled with {<, =} representing the information that A_1 must start at or after t_0. The arc connecting the starting time of A_1 with its ending time is labelled by the interval [1 1:30] meaning that the duration of A_1 will take a value belonging to that interval, i.e. $1 \leq t_{end} - t_{start} \leq 1{:}30$ hours.



Figures 1c

The intervention planning steps

In the following we shall describe how the system supports the main decisional steps of the planning process, as illustrated in Figure 2 and described in a previous section. The first four steps are a direct derivation of the reference schema of CBR planning architecture developed by Hammond in [Hammond89]. The Figure 2 also highlights the fact that constraint reasoning techniques are continuously exploited in all the reasoning steps a part from the retrieval.

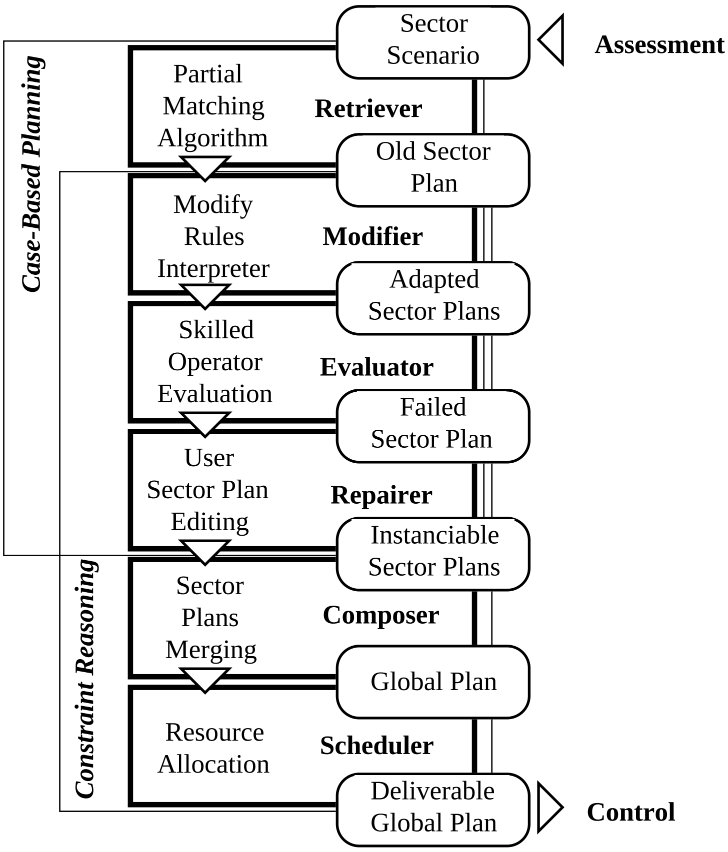


Figure 2

The Retrieval and the Adaptation of an old plan.

The fire front segmentation performed by the operator as described above produces the description of one or more sectors in terms of a scenario and the related goal. This description drives the search, into the plan memory, of similar cases where the same kind of goal in a similar scenario has been dealt with.

The search process is performed by using a partial matching algorithm which computes and compares similarities among features of the plan description. It is only possible a partial match because of the typical incompleteness of the information gathered during the alarm verification.

In fact this is a common problem in applying CBR techniques. This problem is taken into account in some CBR systems, among these we are analysing the COBWEB system [Fisher87] which seems the most appropriate to our application. COBWEB is based on an category utility function that identifies a trade-off between inter-class similarity and inter-class dissimilarity of cases. Inter-class similarity is the probability that two cases in the same category share their values and inter-class dissimilarity is the probability that two cases in different category share their values.

But, since some features are more relevant then others, this kind of match does not guarantee that the plan associated to the most similar case is the most appropriate to the current situation. This calls for an enhancement of this method introducing a supplementary technique in order to take into account also the partial order relation among the features that describe the scenario.

The retrieval process on each sector produces a set of old sector plans. A further selection phase refines this set yielding a subset of plans that implement structurally different fire fighting strategies. Two strategies are structurally different if they don't use the same actions or if they order the actions differently.

According to the reference case-based planning architecture a modification phase follows the retrieval. A specific set of constraint, based on the domain knowledge, are associated to the features describing the old plan actions and the new current scenario. These constraints represents for instance how the number of squads, the type of action (role) they perform and the sector length define a constraint on the action duration. Adapting an old sector plan means to change some action parameter values according to the features of the current scenario and then to recompute the constraints involving them. At this level constraints are mainly used for deducing consistent values for constrained parameters.
Constraint propagation and consistency check guarantee the respect of the goal statements (for example deadline and water quantity).

Usually in the full automated case-based planner the plan validation is performed by simulation. It is out of the scope of our work to address the complex problem of simulating actions and environment evolution in the forest fire domain (see [CGHH89] for a significant work in this direction). The expert, on the base of his experience and the data on the current situation, is generally able to repair the plan. He can perform changes into the plan structure using a sector plan editor. For example substituting an action with a different one or changing the temporal relation between two actions. Repairer is supported by the system running constraint propagation algorithms on the modified action net. These two last steps, evaluator and repairer, can be repeated till a satisfactory sector plan is obtained.

The composition of a global plan and its resource scheduling.

Sector plans are merged into a global plan during the composition phase. At this level the operator can decide to consider only the highest risk sectors among the originally planned sectors, in order to avoid resource allocation failure. This merging process corresponds to the composition of the single sector action nets into a global, time consistent, net.

The scheduling phase deals with the selection and allocation of the resources to the resulting global plan. This process starts by considering the action time net of the global plan from the point of view of the resource requests associated to each action. In other words the action time net is mapped to the corresponding resource time net where the variables are the resources required by each action. The temporal constraints representing action duration in the action net are mapped to constraints on the duration of the allocation status of the associated resources. Additional constraints representing resource characteristics (such as shifts or maximum operating periods) will enrich the resource time net. Appropriate resource schedules for the global plan are solutions of this constraint network which will be obtained by running Constraint Satisfaction Problem solution algorithms driven by heuristic criteria on resource selection (see for instance [Fox87] [VanHentenryck92]). Possible failures are taken into account and could require to consider a different global plan (i.e. redo the composition step) or require the user to make extra resource available for instance releasing them from different fires or requesting them to the Regional Centre.[2]
The resulting resource schedule will be represented by a resource time map where the allocation period of each resource instance is recorded as well as their relative dependencies (for instance between squad n.1 and tanktruck n.3 which will support its activity). The resource time map will support the plan control activities which could require to consult and update it.
At this stage also the CBR process closes storing all the adapted sector plans which have been composed into the successfully scheduled global plan.

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[2] A precise definition of the failure that will be dealt is still object of discussion.

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