The FF Planning System

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The Fast Forward (FF) Planning System

- Was proposed by Hoffmann & Nebel (2001).
- Was the winner of the 2000 planning competition.
- Its novel elements are the following:
  - Heuristic based on *relaxed plans*.
  - Enforced Hill Climbing Used as the Search Strategy.
- Its core ideas have had substantial impact.

The Relaxed Plan Heuristic: Basic Definitions

Definition (STRIPS planning problem)

Let $P = \langle \mathit{Init}, \mathit{Ops}, \mathit{Goal} \rangle$ be a STRIPS planning problem where:

- *Init* is the initial state.
- *Goal* is the goal condition.
- Each $o \in \mathit{Ops}$ of the form $o = (\mathit{prec}(o), \mathit{add}(o), \mathit{del}(o))$

Definition (Delete-Relaxation)

The delete relaxation of P, denoted P^+, is a instance just like P but in which operators in *Ops* have an **empty** delete list.

Definition (Relaxed Plan)

A *relaxed plan* for P is any plan for P^+.

Computing a Relaxed Plan

For a planning state s:

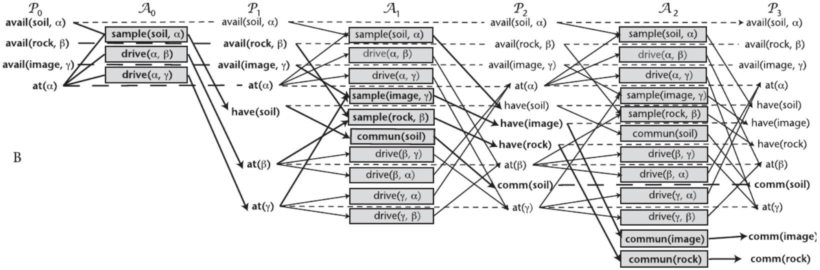
$h_{FF}(s) =$ **"number of actions in a relaxed plan from s"**

The relaxed plan computed by FF:

- Is obtained using a version of Graphplan on P^+.
- Is not a shortest relaxed plan (since this is already NP-hard).

Computing a Relaxed Plan: Intuition

For the general picture, we use Bryce & Kambhampati's figure:



Highlights of the relaxed plan extraction algorithm:

- Plan is extracted by regressing the goals (i.e. backwards)
- Iterates from the highest to the lowest level.
- Earliest achievers are always preferred.

Computing a Relaxed Plan: Algorithm

Extraction algorithm (Hoffmann & Nebel, 2001)

```
function ExtractPlan(plan graph P_0 A_0 P_1 ··· A_{n-1} P_n, goal G)
    for i = n ... 1 do
        G_i ← goals reached at level i
    end for
    for i = n ... 1 do
        for all g ∈ G_i not marked TRUE at time i do
            Find min-cost a ∈ A_{i-1} such that g ∈ add(A_{i-1})
            RP_{i-1} ← RP_{i-1} ∪ {a}
            for all f ∈ prec(a) do
                G_{layerof(f)} = G_{layerof(f)} ∪ {f}
            end for
            for all f ∈ add(a) do
                mark f as TRUE at times i − 1 and i.
            end for
        end for
    end for
    return RP
end function
```

"Min-Cost" Actions

The "min-cost" action referred to in line 7 is the one that minimizes the following function:

$$Cost(a) = \sum_{p \in Prec(a)} level(p),$$

where $level(p)$ is the first layer at which p appears, and $Prec(a)$ are the preconditions of a.

Helpful Actions

Helpful actions are essential for FF's performance. Helpful actions are those that appear at the first level of the relaxed plan.

Definition (Helpful action)

An action a of a relaxed plan from s is *helpful* iff if is a member of RP_0.

Note that helpful actions are a *subset* of the actions executable in s.

Enforced Hill Climbing

Enforced Hill Climbing (EHC) (Hoffmann & Nebel, 2001)

function EHC(initial state I, goal G)
    $plan \leftarrow EMPTY$
    $s \leftarrow I$
    while $h(s) \neq 0$ **do**
        from s, search for s' such that $h(s') < h(s)$.
        if no such state is found **then**
            return fail
        end if
        $plan \leftarrow plan \circ$ "actions on the path to s'"
        $s \leftarrow s'$
    end while
    return $plan$
end function

Breadth-First Search for a New State

The breadth-first search (line 5) from s is implemented as follows:

$queue \leftarrow$ empty-queue
$closed \leftarrow \{$states visited by the plan$\}$
PUSH(queue,$\{$helpful successors of $s\}$)
while $queue$ is not empty **do**
    $t \leftarrow pop(queue)$
    if $t \in closed$ **then**
        continue ▷ discard t and continue the iteration
    end if
    if $h(t) < h(s)$ **then**
        $s' \leftarrow t$
        break ▷ better state found, exit loop
    end if
    PUSH(queue,$\{$helpful successors of $s\}$)
    $closed \leftarrow closed \cup \{t\}$
end while

FF's search strategy

EHC is an **incomplete** search algorithm and thus prone to failure. If EHC fails, FF falls back into *best-first search* (A search), in which the evaluation function for a state is:

$$f(s) = h_{FF}(s)$$

Note that this search is complete but greedy since the length of the plan is not considered.

Now let's see how FF works in practice !

References I

Hoffmann, J., & Nebel, B. (2001). The FF planning system: Fast plan generation through heuristic search. *Journal of Artificial Intelligence Research*, *14*, 253–302.