Planning

Introduction to Artificial Intelligence

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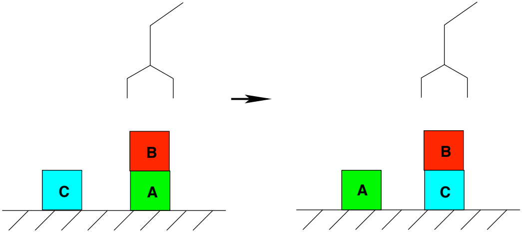
Planning



Given: A (logical) description of the initial state, a description of the goal state, a description of actions (preconditions and effects).

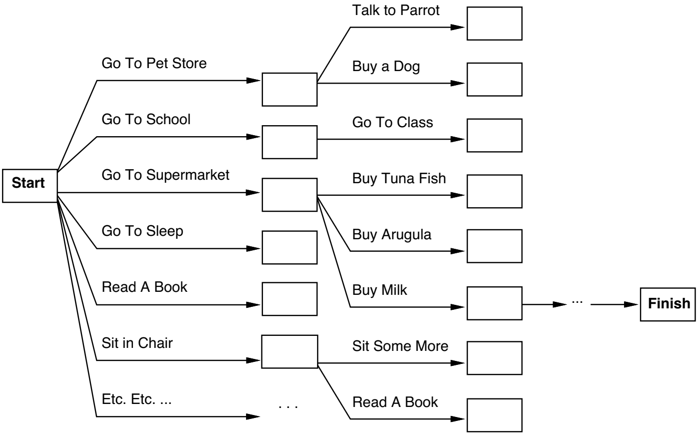
Problem: Find a plan involving these actions that takes you from the initial state to the goal state.

Why is Planning Different from Search?

- In contrast to states in search problems,
  states in planning need not be completely specified.
- Search treats states as black boxes.
  In planning one wants to look at the parts. E.g.: which block is free?
- Search generates all successor states.
  Planning only generates some.
- Search wants to find a sequence of actions leading to a goal.
  Planning looks for a description of a plan, e.g. actions may only be partially ordered.

Why is Planning Different from Search?

There are too many actions to choose from. In general, impossible to generate all successor states.



STRIPS Operators

(PDDL: planning domain definition language)

STRIPS: <u>ST</u>anford <u>R</u>esearch <u>I</u>nstitute <u>P</u>roblem <u>S</u>olver
(Planner of the early Seventies. While STRIPS itself is no longer in use, its operator descriptions are.)

Actions are triples of the following form:

Action name:	Function name with parameters pickup(x,y)
Preconditions:	only positive literals
Effects:	positive und negative literals ↳ Add list ↪ Delete list

In addition:

Initial State:	set of ground literals, no function symbols other than constants.
Goal State:	set of literals (possibly with free variables, implicitly existentially quantified)

Example Strips Operator

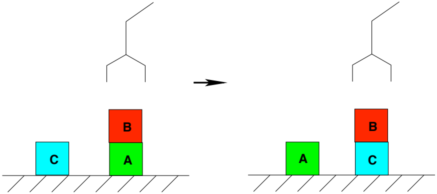
At(here), Path(here, there) , here ≠ there

$\boxed{\text{Go(there)}}$

At(there), ¬ *At(here)*

```
Op(Action: Go(there),
   Precond: At(here) ∧ Path(here,there),
   Effect: At(there) ∧¬ At(here))
```

STRIPS Operators for the Blocks World




```
Op(Action: pickup(x,y),
   Precond: Block(x), On(x,y),
     Clear(x), Empty(hand),
   Effect: Holding(x), ¬Empty(hand), ¬Clear(x),
     ¬On(x,y), Clear(y))
```

(may add Clear(table))

```
Op(Action: puton(x,y),
   Precond: Block(y), Holding(x), Clear(y)
   Effect: ¬Holding(x), ¬Clear(y),
     On(x,y), Empty(hand), Clear(x))

Op(Action: putonTable(x),
   Precond: Block(x),Holding(x),
   Effect: ¬Holding(x), On(x,table),
     Empty(hand), Clear(x))
```

What is a Plan?

Plan step $=$ STRIPS-Operator

A Plan consists of

- a set of partially ordererd ($\prec$) plan steps, where $S_i \prec S_j$ iff S_i must be executed before S_j.
- a set of variable assignments $x = t$, where x is a variable and t is a constant or a variable.
- a set of causal relations, where $S_i \xrightarrow{c} S_j$ means "S_i satisfies the precondition c for S_j."

Complete and Consistent Plans

Complete Plan:

Every precondition of every plan step is satisfied, that is:

$$\forall S_j \text{ with } c \in \mathit{Precond}(S_j)\ \exists S_i \text{ with } S_i \prec S_j \text{ and } c \in \mathit{Effects}(S_i)$$

and for every linearization of the plan we have:

$$\forall S_k \text{ with } S_i \prec S_k \prec S_j, \neg c \notin \mathit{Effects}(S_k).$$

Consistent Plan:

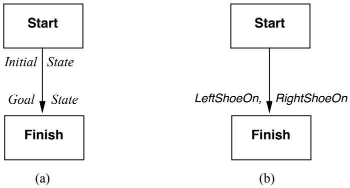
If $S_i \prec S_j$ then $S_j \not\prec S_i$ and if $x = A$ then $x \neq B$ for distinct A and B.
(Unique Names Assumption!)

A complete and consistent plan is called a solution.

Problem Description

Problem description = initial plan

"pseudo actions"

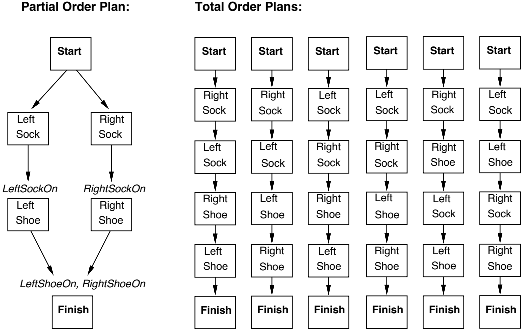


Plan(Steps:
  S_1:Op(**Action:** Start),
  S_2:Op(**Action:** Finish)
    Precond: RightShoeOn $\wedge$ LeftShoeOn)
  Orderings: $\{S_1 \prec S_2\}$
  Bindings: $\{\}$
  Links: $\{\}$)

Features of the Problem Description

- Initial state and goal state are encoded as STRIPS-operators.
- Plan step: take a plan step with ≥ 1 unsatisfied preconditions; insert a new plan step which satisfies one or more of these conditions. (Helps focus the search.)
- Decisions about order, variable assignments, etc. are delayed as long as possible.
- Leads to partially ordered plans.

Partially Ordered Plans




```
Op(Action: RightShoe,
   Precond: RightSockOn,
   Effect: RightShoeOn)
```

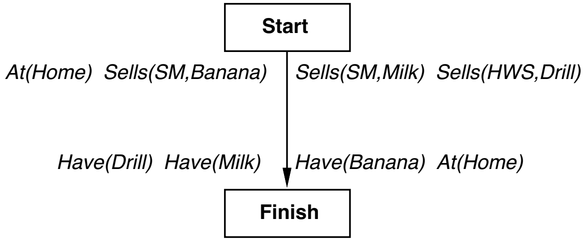
```
Op(Action: LeftShoe,
   Precond: LeftSockOn,
   Effect: LeftShoeOn)
```

```
Op(Action: RightSock,
   Effect: RightSockOn)
```

```
Op(Action: LeftSock,
   Effect: LeftSockOn)
```

Shopping Example

SM : supermarket
HWS : hardware store



Start state:

```
Op(Action: Start,
   Effect: At(Home)∧Sells(HWS,Drill)∧
      Sells(SM,Milk)∧Sells(SM,Bananas))
```

Goal state:

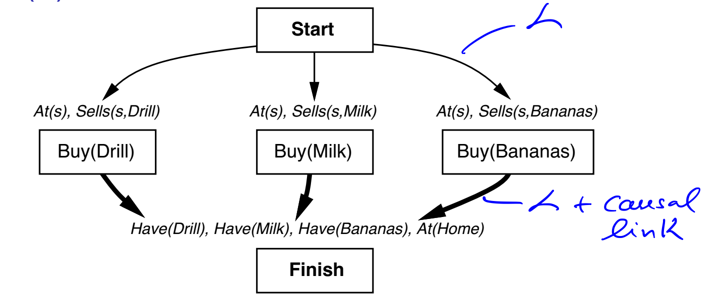
```
Op(Action: Finish,
   Precond: Have(Drill)∧Have(Milk)∧
      Have(Bananas)∧At(Home))
```

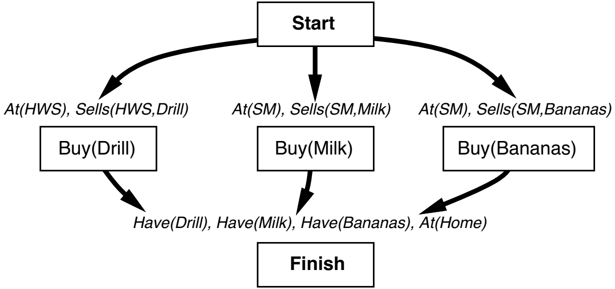
Actions:

```
Op(Action: Go(there),
   Precond: At(here),
   Effect: At(there)∧
      ¬At(here))
```

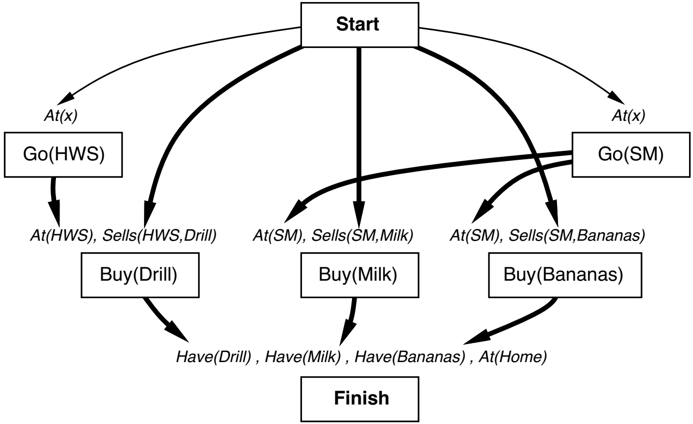
```
Op(Action: Buy(x),
   Precond: At(store)∧
      Sells(store,x)
   Effect: Have(x))
```

Example (2)

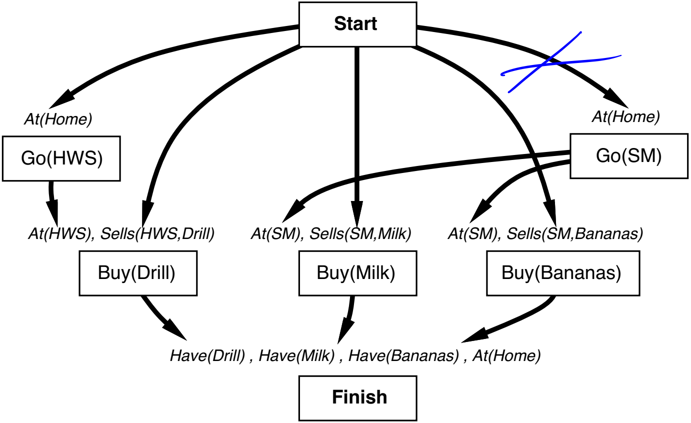

Start
At(s), Sells(s,Drill)
At(s), Sells(s,Milk)
At(s), Sells(s,Bananas)
Buy(Drill)
Buy(Milk)
Buy(Bananas)
Have(Drill), Have(Milk), Have(Bananas), At(Home)
Finish
+ causal link


Start
At(HWS), Sells(HWS,Drill)
At(SM), Sells(SM,Milk)
At(SM), Sells(SM,Bananas)
Buy(Drill)
Buy(Milk)
Buy(Bananas)
Have(Drill), Have(Milk), Have(Bananas), At(Home)
Finish

Example (3)


Start
At(x)
At(x)
Go(HWS)
Go(SM)
At(HWS), Sells(HWS,Drill)
At(SM), Sells(SM,Milk)
At(SM), Sells(SM,Bananas)
Buy(Drill)
Buy(Milk)
Buy(Bananas)
Have(Drill) , Have(Milk) , Have(Bananas) , At(Home)
Finish

Example (4)

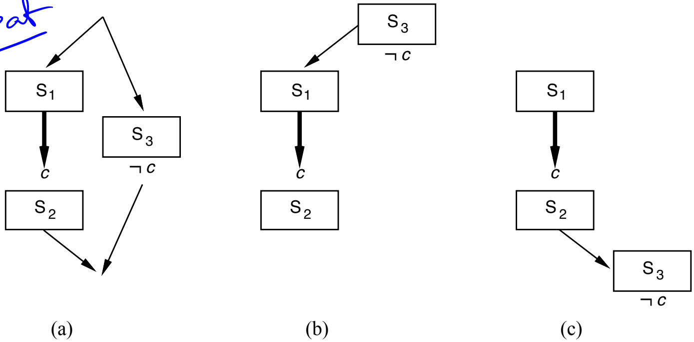


Dead end!

Go(HWS) and Go(SM) block each other because one destroys the precondition of the other.

Protection of Causal Relations

Threat

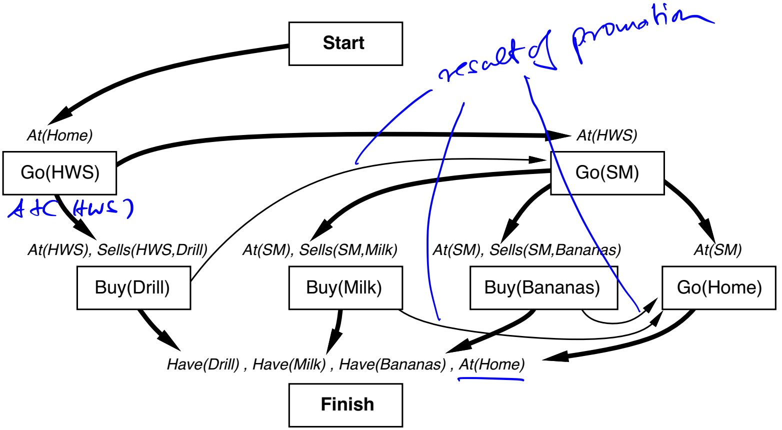


a) Conflict

Conflict resolutions:

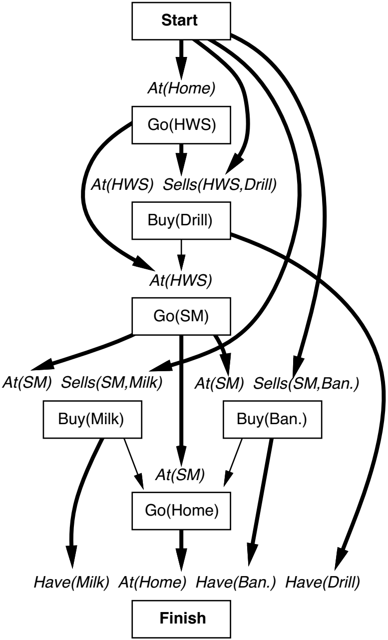
b) Demotion (before S_1)
c) Promotion (after S_2)

Example (5)



Start
result of promotion
At(Home)
Go(HWS)
At(HWS)
At(HWS)
Go(SM)
At(HWS), Sells(HWS,Drill)
Buy(Drill)
At(SM), Sells(SM,Milk)
Buy(Milk)
At(SM), Sells(SM,Bananas)
Buy(Bananas)
At(SM)
Go(Home)
Have(Drill) , Have(Milk) , Have(Bananas) , At(Home)
Finish

End of Example



The POP Algorithm

POP: partial-order planning

function POP(*initial, goal, operators*) **returns** *plan*

  plan ← MAKE-MINIMAL-PLAN(*initial, goal*)
  loop do
    if SOLUTION?(*plan*) **then return** *plan*
    S_{need}, c ← SELECT-SUBGOAL(*plan*)
    CHOOSE-OPERATOR(*plan, operators*, S_{need}, c)
    RESOLVE-THREATS(*plan*)
  end

NO backtracking needed

---

function SELECT-SUBGOAL(*plan*) **returns** S_{need}, c

  pick a plan step S_{need} from STEPS(*plan*)
    with a precondition c that has not been achieved
  return S_{need}, c

set of operators currently in partial plan

---

procedure CHOOSE-OPERATOR(*plan, operators*, S_{need}, c)

  choose a step S_{add} from *operators* or STEPS(*plan*) that has c as an effect
  if there is no such step **then fail**
  add the causal link $S_{add} \xrightarrow{c} S_{need}$ to LINKS(*plan*)
  add the ordering constraint $S_{add} \prec S_{need}$ to ORDERINGS(*plan*)
  if S_{add} is a newly added step from *operators* **then**
    add S_{add} to STEPS(*plan*)
    add *Start* $\prec S_{add} \prec$ *Finish* to ORDERINGS(*plan*)

---

procedure RESOLVE-THREATS(*plan*)

  for each S_{threat} that threatens a link $S_i \xrightarrow{c} S_j$ in LINKS(*plan*) **do**
    choose either
      Promotion: Add $S_{threat} \prec S_i$ to ORDERINGS(*plan*)
      Demotion: Add $S_j \prec S_{threat}$ to ORDERINGS(*plan*)
    if not CONSISTENT(*plan*) **then fail**
  end

← may require backtracking

Problem is PSPACE complete
(even if initial state is complete)