Planning

Introduction to Artificial Intelligence

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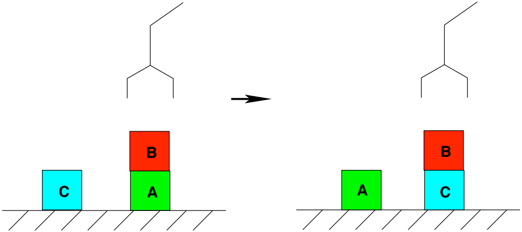
Planning



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

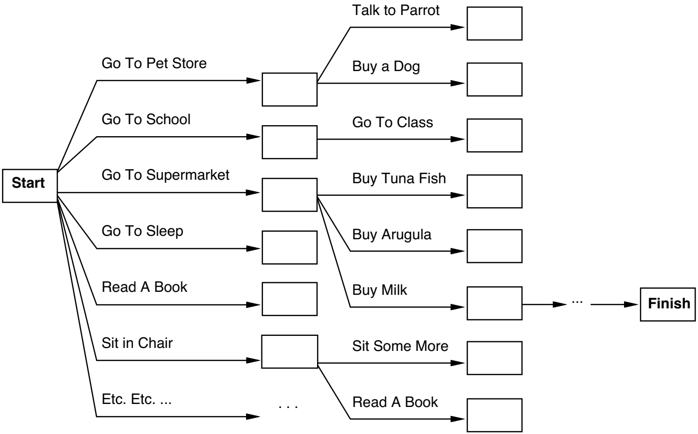
Problem: Find a plan involving these actions that takes you from the initial state to the goal state.

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

STRIPS: STanford Research Institute Problem Solver
(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)
Preconditions:	only positive literals	Empty(hand)
Effects:	positive und negative literals	

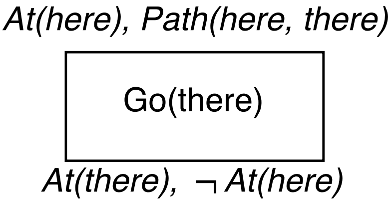
Holding(x), ¬ Empty(hand)

In addition:

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

ADD DELETE list

Example Strips Operator

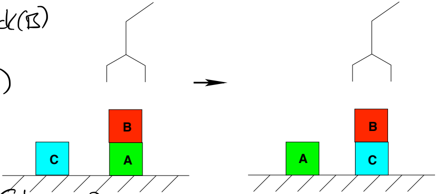



```
Op(Action: Go(there),
   Precond: At(here) ∧ Path(here,there),
   Effect: At(there) ∧¬ At(here))
```

STRIPS Operators for the Blocks World

Goal:
On(B, C)
On(C, table)
On(A, table)

Init Block(A), Block(B)
Block(C)
On(C, table)
On (A, table)
On (B, A)
Clear(C), Clear(B)
~~¬Clear(A)~~, Empty(hand)



plus closed-world assumption: lits not mentioned assumed false

```
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))
```

funny if y = 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))
```

"classical planning problem"

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:

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

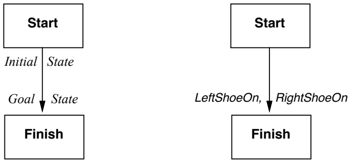
Consistent Plan:

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



(a) (b)

```
Plan(Steps:
    S1:Op(Action: Start),
    S2:Op(Action: Finish)
          Precond: RightShoeOn ∧ LeftShoeOn)
    Orderings: {S1 ≺ S2}
    Bindings: {}
    Links: {})
```

state space
= partial plans

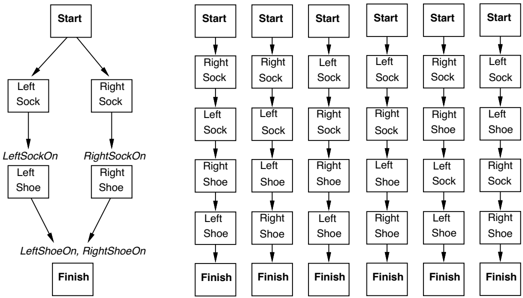
Features of the Problem Description

- 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

every linearization of a solution need to be executable

Partial Order Plan: **Total Order Plans:**



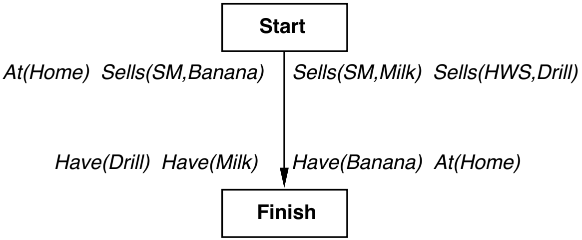

```
Op(Action: RightShoe,
   Precond: RightSockOn,
   Effect: RightShoeOn)

Op(Action: RightSock,
   Effect: RightSockOn)

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

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

Shopping Example

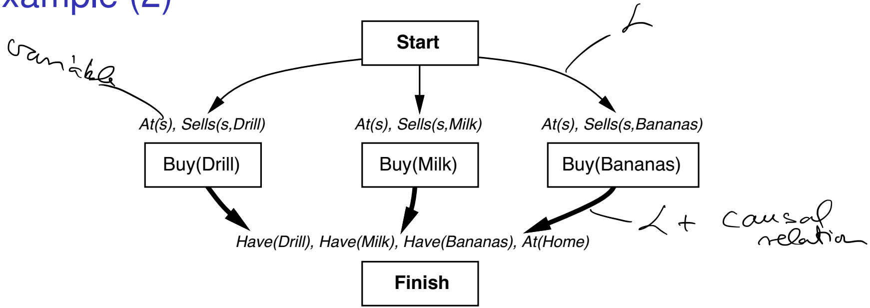


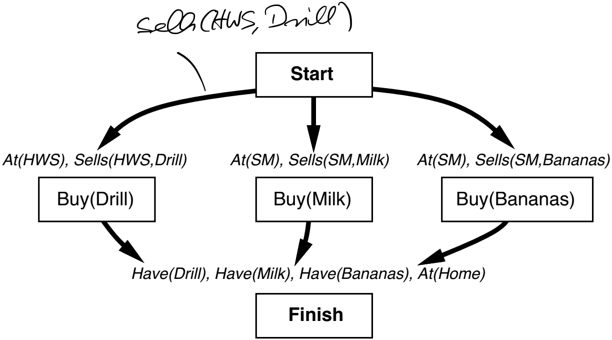
Start state:
```
Op(Action: Start,
   Effect: At(Home)∧Sells(HWS,Drill)∧
      Sells(SM,Milk)∧Sells(SM,Bananas))
```

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

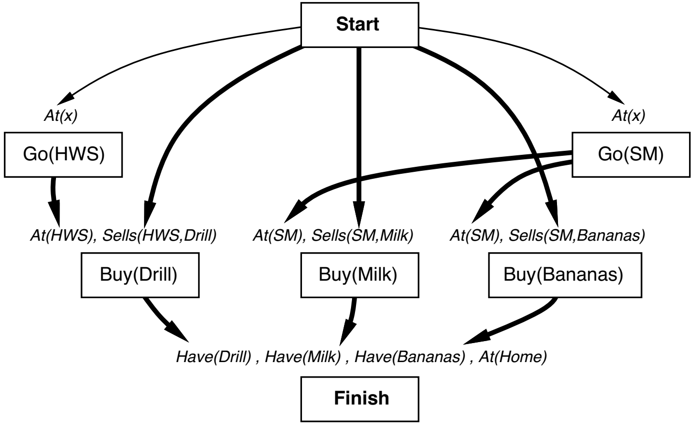
Actions:
```
Op(Action: Go(there),
   Precond: At(here),
   Effect: At(there)∧
      ¬At(here))
```
```
Op(Action: Buy(x),
   Precond: At(store)∧
      Sells(store,x)
   Effect: Have(x))
```

Example (2)


variable
L
L + causal relation
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

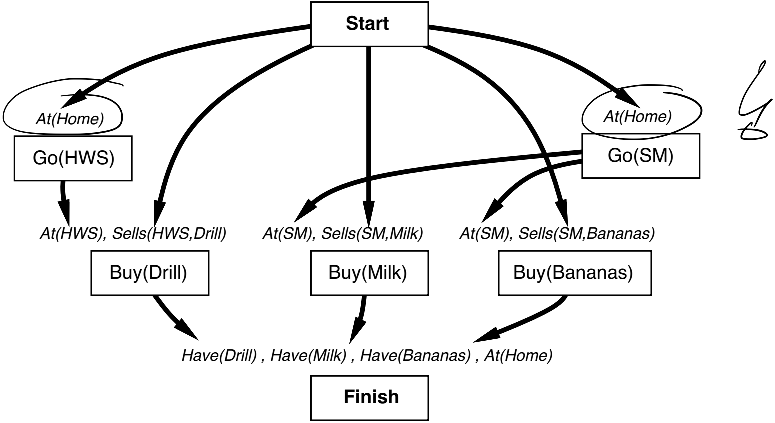

Sells(HWS, Drill)
Start
At(HWS), Sells(HWS,Drill)
At(SM), Sells(SM,Milk)
At(SM), Sells(SM,Bananas)
Buy(Drill)
Buy(Milk)
Buy(Bananas)
Have(Drill), Have(Milk), Have(Bananas), At(Home)
Finish

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

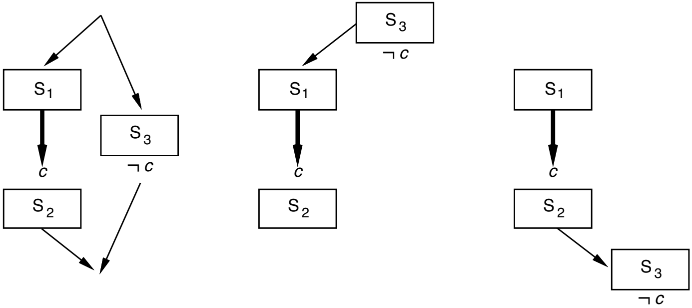
Example (4)



Dead end!

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

Protection of Causal Relations



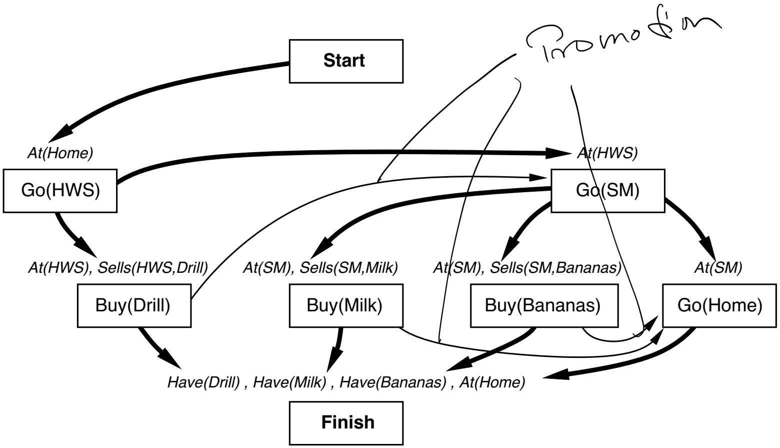
(a) (b) (c)

a) Conflict

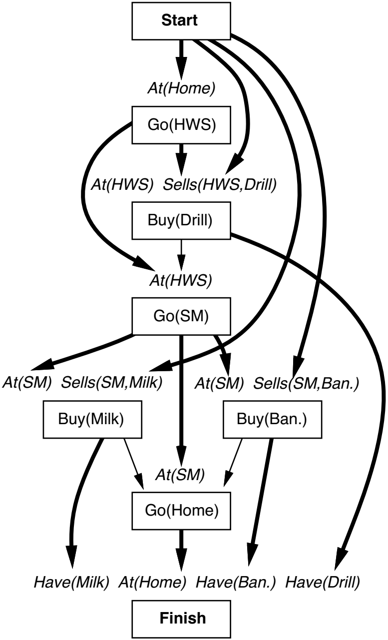
Conflict resolutions:

b) Demotion
c) Promotion

Example (5)


Promotion
Start
At(Home)
Go(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

"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

---

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

no backtracking needed

---

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*)

backtracking

---

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

backtracking

will find a solution if one exists.
(may not be optimal)

$\boxed{\text{PSPACE complete}}$