# Planning

## Introduction to Artificial Intelligence

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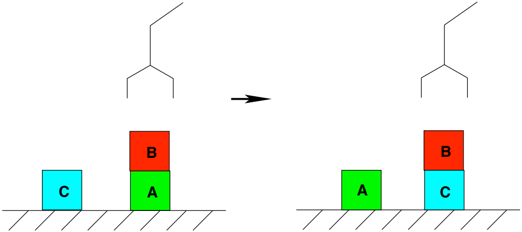
Winter Term 2018/19

# Planning



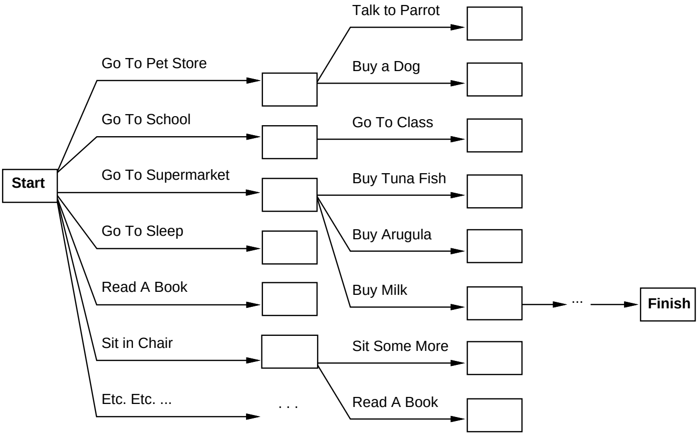

| | |
|---|---|
| Given: | A (logical) description of the initial state, a description of the goal state, a description of actions (preconditions and effects). |
| Problem: | Find a plan involving these actions that takes you from the initial state to the goal state. |

# 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.)

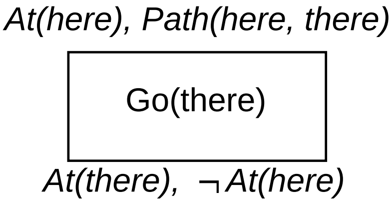
Actions are triples of the following form:

| | |
|---|---|
| Action name: | Function name with parameters |
| Preconditions: | only positive literals |
| Effects: | positive und negative literals |

In addition:

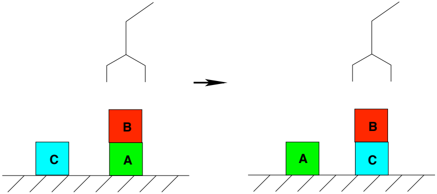
| | |
|---|---|
| Initial State: | set of ground literals, no function symbols other than constants. |
| Goal State: | set of literals (possibly with free variables, implicitly existentially quantified) |

# Example Strips Operator




```
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))

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:

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

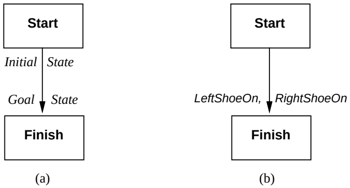
## Consistent Plan:

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**

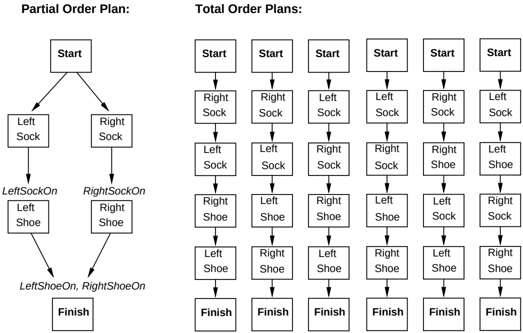



```
Plan(Steps:
    S1:Op(Action: Start),
    S2:Op(Action: Finish)
          Precond: RightShoeOn ∧ LeftShoeOn)
    Orderings: {S1 ≺ S2}
    Bindings: {}
    Links: {})
```

# Features of the Problem Description

- Initial state and goal state are encoded as STRIPS-operators.
- Plan step: take a plan step with $\geq 1$ 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



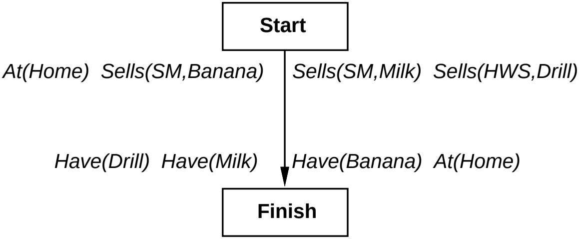

```
Op(Action: RightShoe,
   Precond: RightSockOn,
   Effect: RightShoeOn)

Op(Action: 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:

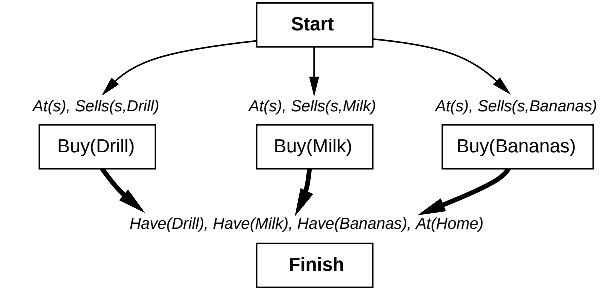
```
Op(Action: Finish,
   Precond: Have(Drill)∧Have(Milk)∧
       Have(Bananas)∧At(Home))
```

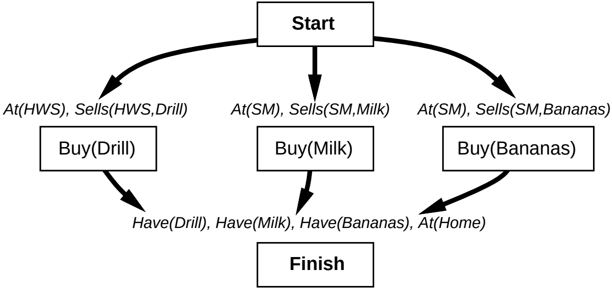
Actions:

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

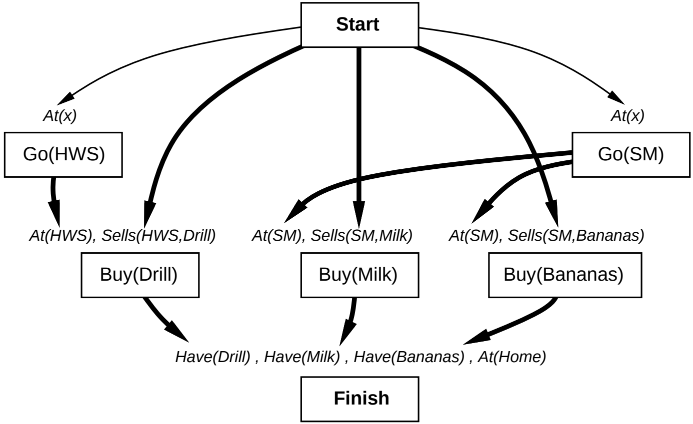
```
Op(Action: Buy(x),
   Precond: At(store)∧
      Sells(store,x)
   Effect: Have(x))
```

# Example (2)


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


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)

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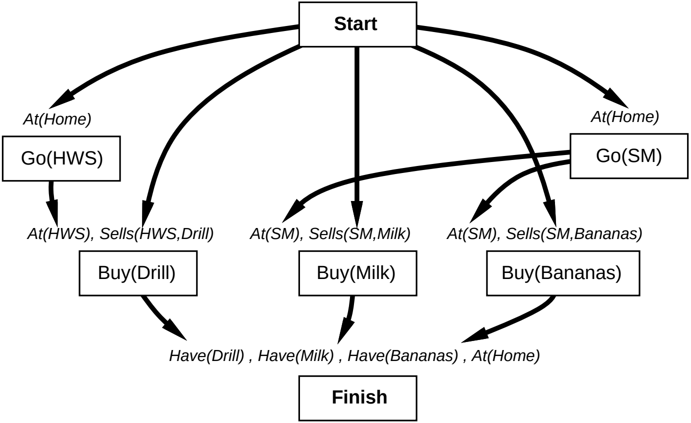
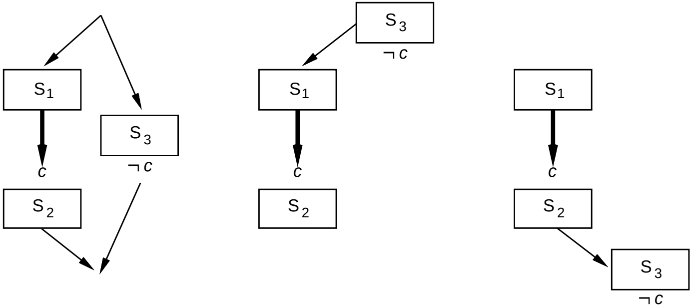
# Example (4)




## Dead end!

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

# Protection of Causal Relations



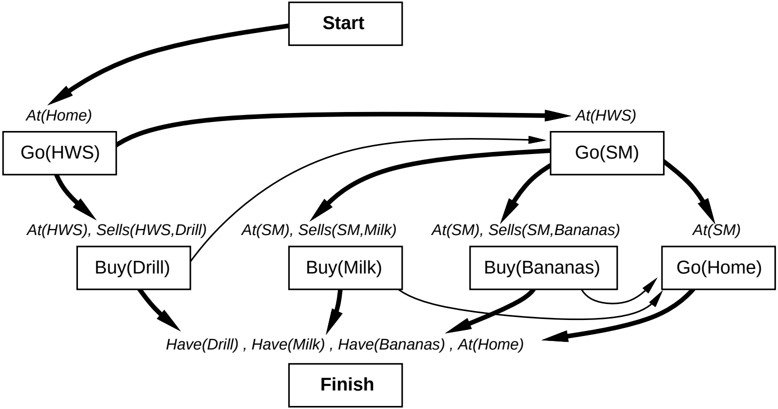

(a) (b) (c)

a) Conflict

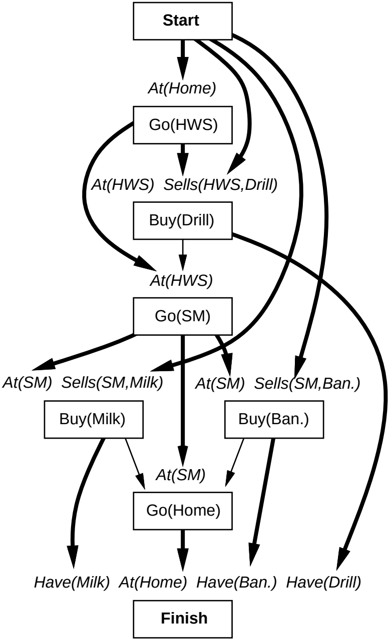
   Conflict resolutions:

   b) Demotion
   c) Promotion

# Example (5)


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

# End of Example



# The POP Algorithm

**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** $S_{need}$, $c$

---

**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**