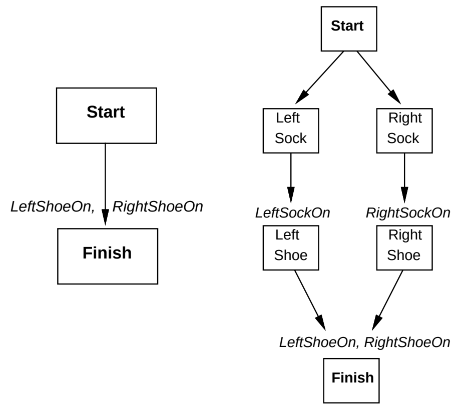
PARTIAL-ORDER PLANNING

Partial Order Planning

- The answer to the problem we ended the last lecture with is to use partial order planning.
- Basically this gives us a way of checking before adding an action to the plan that it doesn't mess up the rest of the plan.
- The problem is that in this recursive process, we don't know what the rest of the plan is.
- Need a new representation *partially ordered plans*.

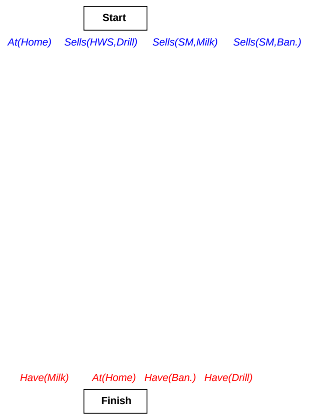
Representation



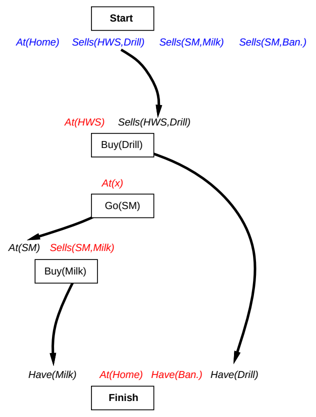
Partially ordered plans

- *Partially ordered* collection of steps with
  - *Start* step has the initial state description as its effect
  - *Finish* step has the goal description as its precondition
  - *causal links* from outcome of one step to precondition of another
  - *temporal ordering* between pairs of steps
- *Open condition* = precondition of a step not yet causally linked
- A plan is *complete* iff every precondition is achieved
- A precondition is *achieved* iff it is the effect of an earlier step and no *possibly intervening* step undoes it

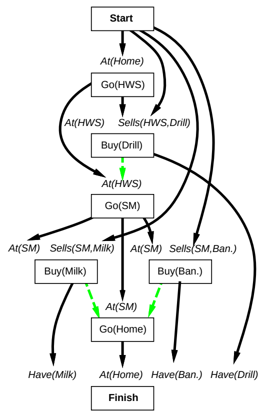
Plan construction



Plan construction (2)



Plan construction (3)



Planning process

- Operators on partial plans:
  - *add a link* from an existing action to an open condition
  - *add a step* to fulfill an open condition
  - *order* one step wrt another to remove possible conflicts
- Gradually move from incomplete/vague plans to complete, correct plans
- Backtrack if an open condition is unachievable or if a conflict is unresolvable

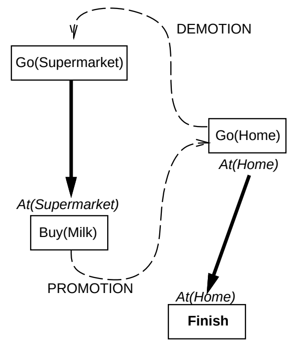
POP algorithm

```
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
          Demotion: Add $S_{threat} \prec S_i$ to ORDERINGS(plan)
          Promotion: Add $S_j \prec S_{threat}$ to ORDERINGS(plan)
      if not CONSISTENT(plan) then fail
  end
```

Clobbering

- A *clobberer* is a potentially intervening step that destroys the condition achieved by a causal link. E.g., $Go(Home)$ clobbers $At(Supermarket)$:



Demotion: put before $Go(Supermarket)$

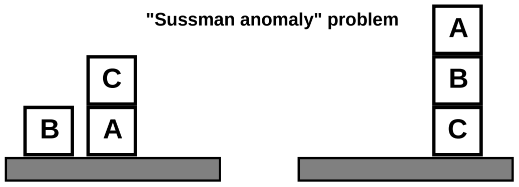
Promotion: put after $Buy(Milk)$

Properties of POP

- Nondeterministic algorithm: backtracks at *choice* points on failure:
  - choice of S_{add} to achieve S_{need}
  - choice of demotion or promotion for clobberer
  - selection of S_{need} is irrevocable
- POP is sound, complete, and *systematic* (no repetition)
- Extensions for disjunction, universals, negation, conditionals
- Can be made efficient with good heuristics derived from problem description
- Particularly good for problems with many loosely related subgoals

Example

"Sussman anomaly" problem



Start State Goal State

Clear(x) On(x,z) Clear(y)

PutOn(x,y)

~On(x,z) ~Clear(y) Clear(z) On(x,y)

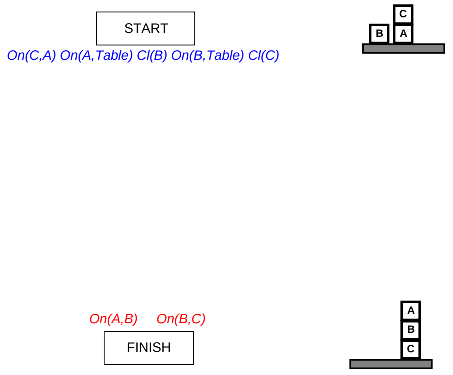
Clear(x) On(x,z)

PutOnTable(x)

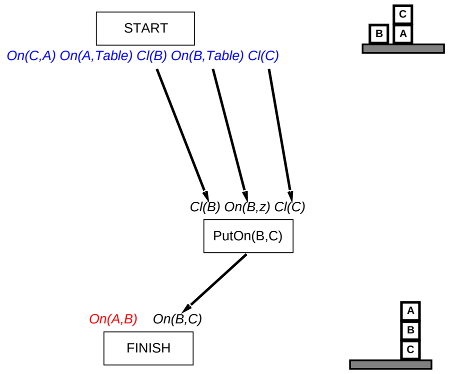
~On(x,z) Clear(z) On(x,Table)

+ several inequality constraints

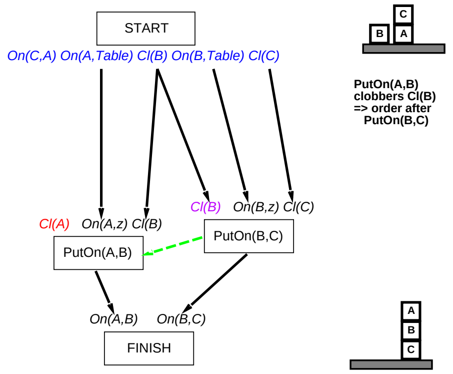
Example (2)



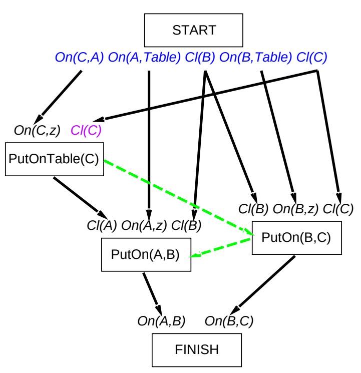
Example (3)

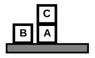


Example (4)


START
On(C,A) On(A,Table) Cl(B) On(B,Table) Cl(C)
C
B
A
PutOn(A,B) clobbers Cl(B) => order after PutOn(B,C)
Cl(A)
On(A,z) Cl(B)
PutOn(A,B)
Cl(B)
On(B,z) Cl(C)
PutOn(B,C)
On(A,B)
On(B,C)
FINISH
A
B
C

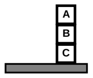
Example (5)





PutOn(A,B) clobbers Cl(B) => order after PutOn(B,C)

PutOn(B,C) clobbers Cl(C) => order after PutOnTable(C)



Summary

- This lecture has looked at a more advanced approach to planning.
  - Partial order planning
- This requires a new way of looking at the world, but the payoff is a more robust approach.
- We also looked at the POP algorithm, . . .
- . . . and saw how it could solve the Sussman anomaly.