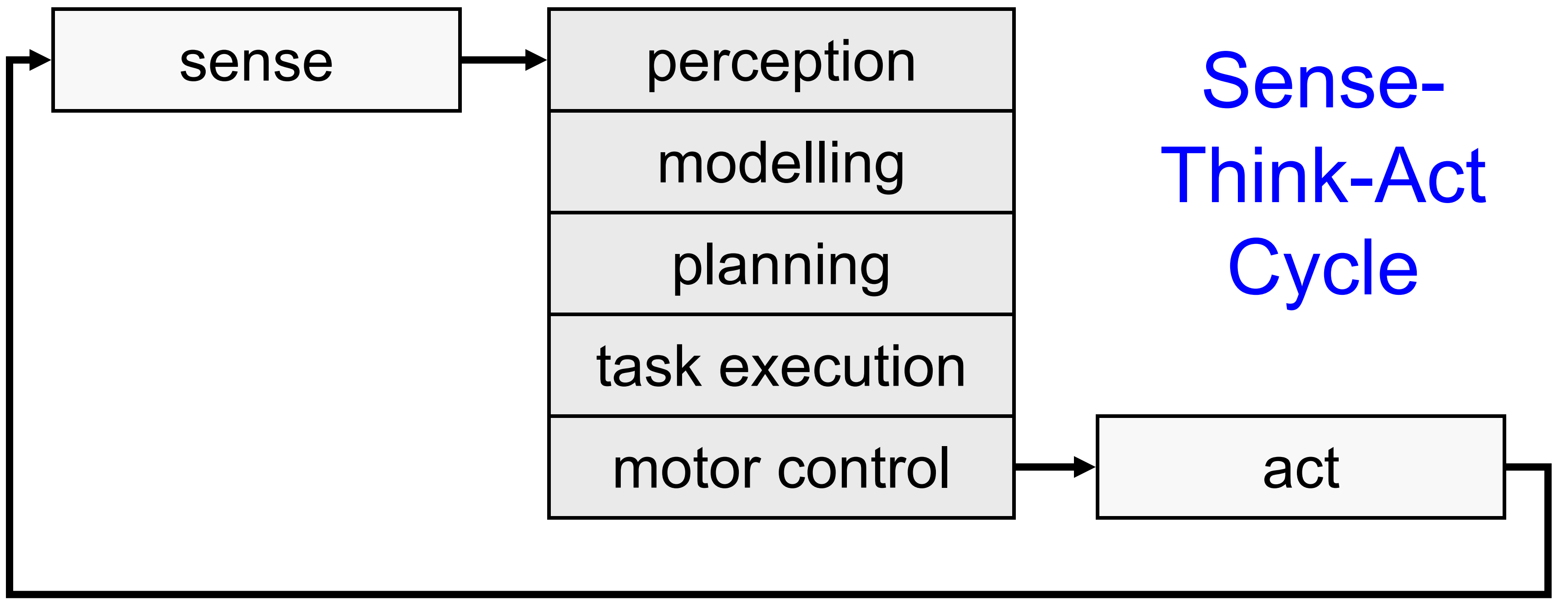
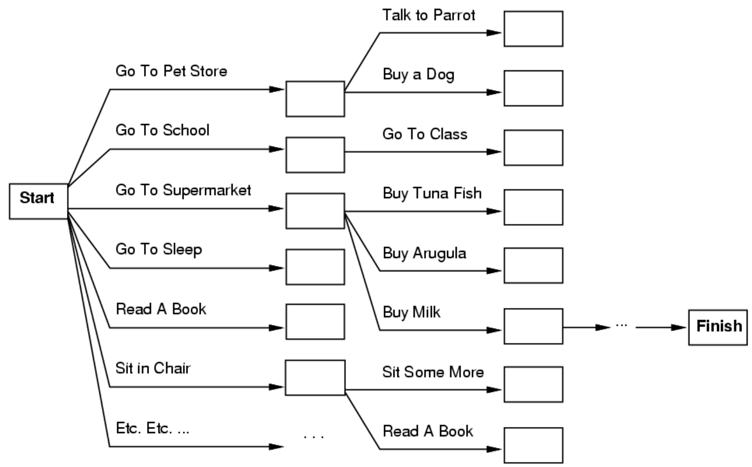
Planning

A Simple Planning Agent



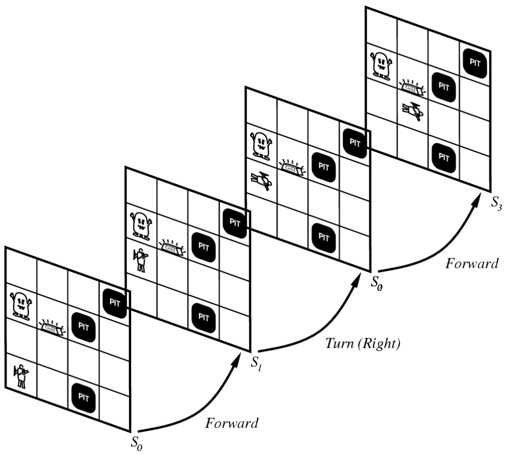
- Minimal interaction with environment
- Batch processing of the plan before any actions are taken

Planning: Haven't we done this already?



- Planning is like search…
  - Consider all the possible actions you could take and build a search tree
  - Rather than labeling individual situations, we describe general operators that change parts of the world state

Planning: Haven't we done this already?



- Situations are indexed
  $At(Agent,[1,1], S_0) \wedge At(Agent,[1\ 2], S_1)$
- Changes from one situation to the next
  $Result(Forward, S_0) \Rightarrow S_1$
  $Result(Turn(R), S_1) \Rightarrow S_2$

- Planning is like inference…
  - Describe actions as operators in a logic, then just prove that the solution that you want exists
  - Need to have some efficiency considerations in dealing with large numbers of actions on complex environments

Planning:
Haven’t we done this already?

- Yes, we can frame the planning problem in different ways
  - But there are some useful things about planning that make both search and inference inefficient
  - It is such a common problem that we study it individually

Key Ideas to Planning

1. “Open Up” the representation of states, goals, and actions
   - Only pick actions that help you achieve the goal… don’t pick at random
2. Planner can add actions wherever they are needed
   - No need to keep to an incremental sequence… can grow the “chain of action” at any point
3. Most parts of the world are independent
   - Divide-and-conquer becomes feasible

STRIPS planner

STanford Research Institute Problem Solver

- “Holy Roman Empire” naming
- Represent states and goals in first-order logic

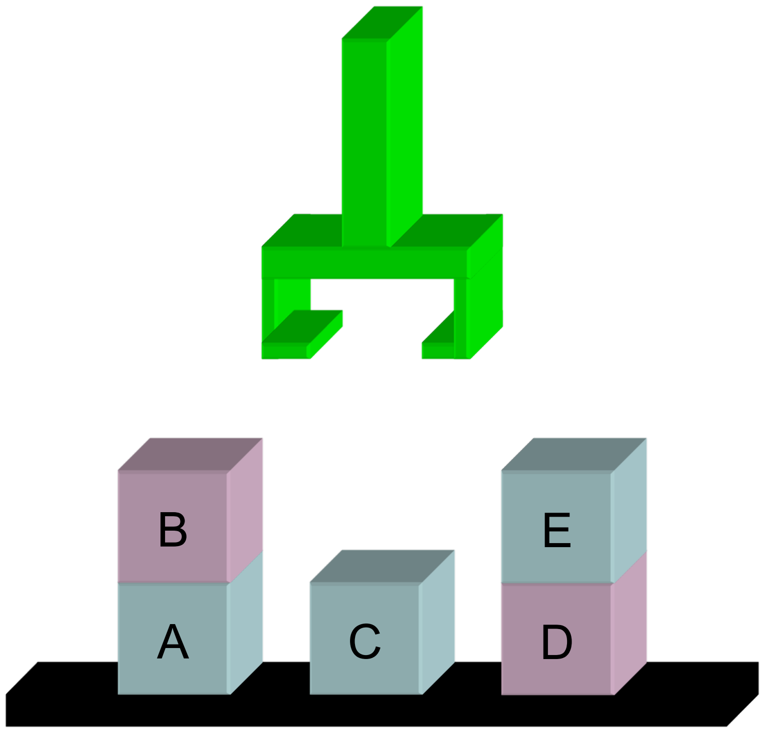
  $At(Home) \wedge Have(Milk) \wedge Have(Drill) \wedge Have(Banana)$

- Assume existential quantification of variables

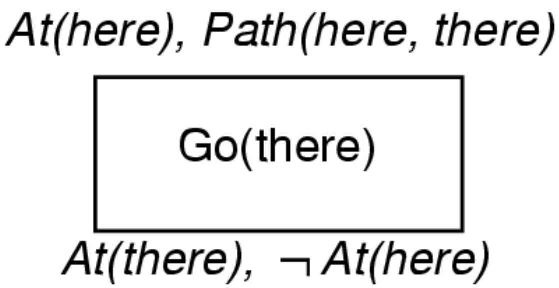
  $At(x) \wedge Sells(x, Milk)$

Blocks World

- Robot Gripper
- Square objects on a perfect, flat table
- Predicates to describe world:
  - On(x,y)
  - TopClear(x)
  - Grip(x)



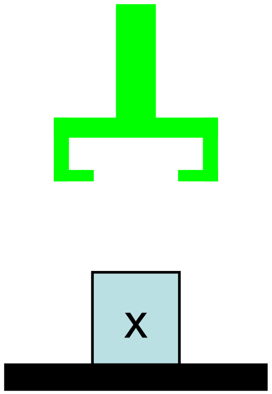
STRIPS Operators



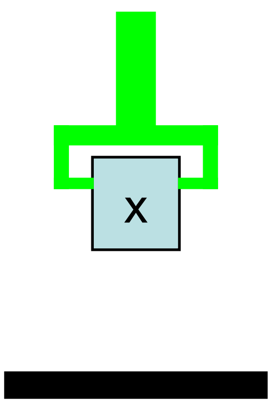
- Operators are triplets of descriptors
  - A set of Preconditions
  - A set of Additions
  - A set of Deletions
- Graphical Representation

Blocks World Operations

- Pickup(x)
  - P: grip(∅) ∧ topclear(x) ∧ on(x,Table)
  - A: grip(x)
  - D: on(x,Table) ∧ grip(∅) ∧ topclear(x)

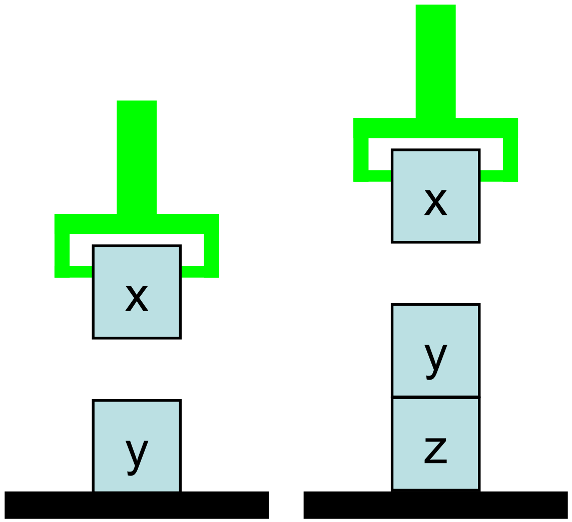


- PutDown(x)
  - P: grip(x)
  - A: on(x,Table) ∧ grip(∅) ∧ topclear(x)
  - D: grip(x)

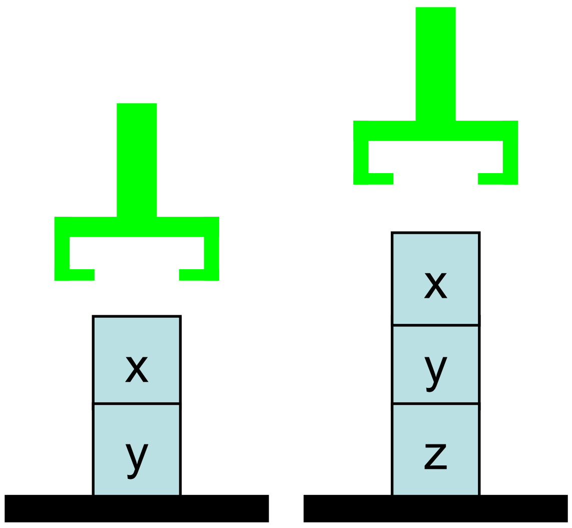


Blocks World Operators II

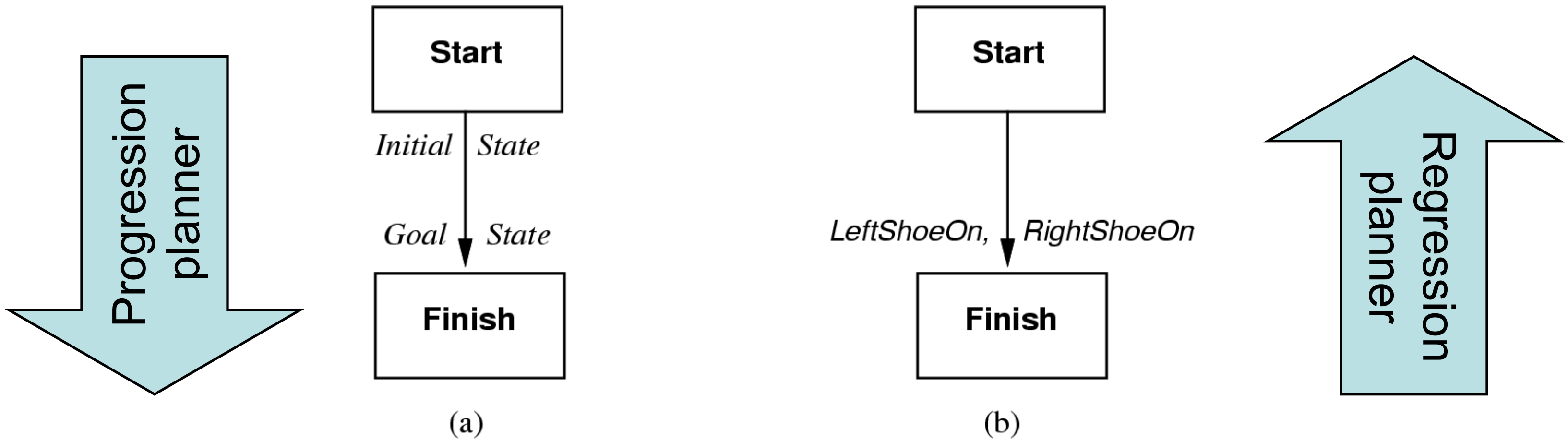
- Stack(x,y)
  - P: topclear(y) $\wedge$ grip(x)
  - A: on(x,y) $\wedge$ grip($\emptyset$) $\wedge$ topclear(x)
  - D: topclear(y) $\wedge$ grip(x)



- UnStack(x,y)
  - P: topclear(x) $\wedge$ grip($\emptyset$) $\wedge$ on(x,y)
  - A: grip(x) $\wedge$ topclear(y)
  - D: grip($\emptyset$) $\wedge$ on(x,y) $\wedge$ topclear(x)

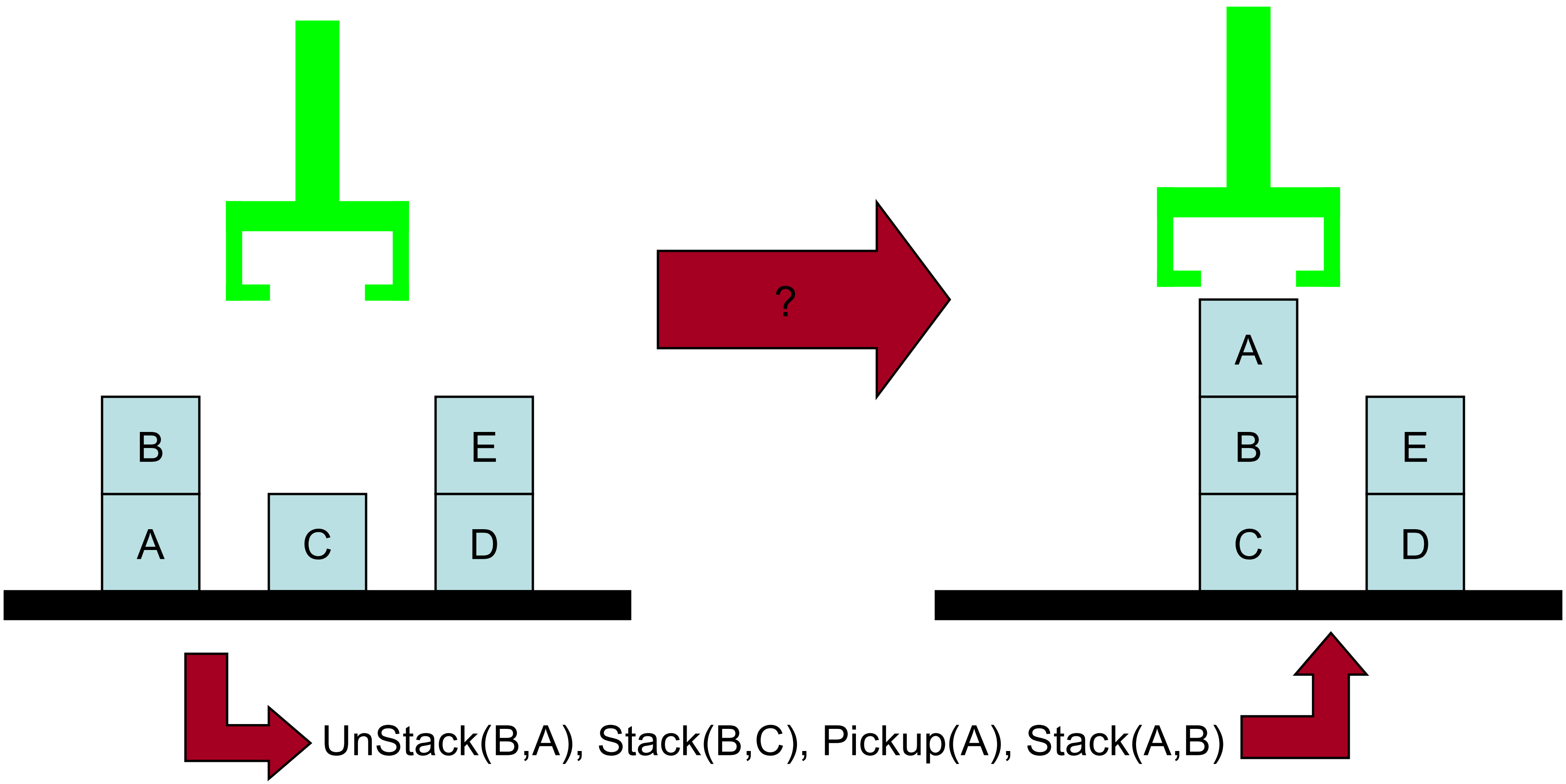


Start and Finish States

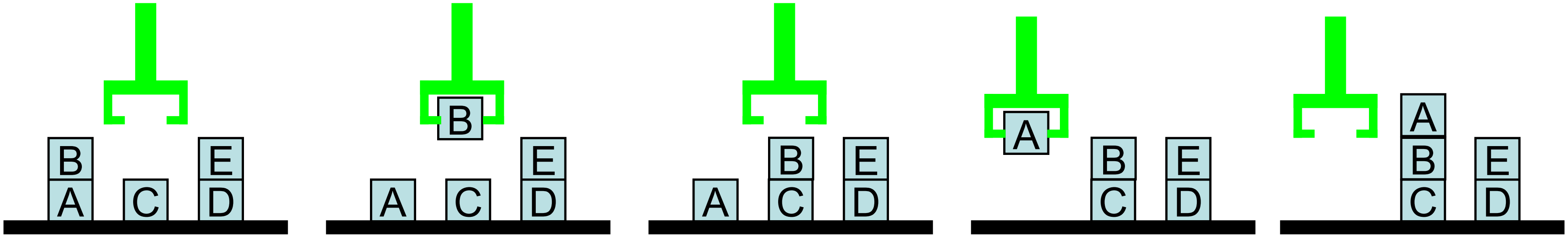


- ***Start*** has no preconditions, and must precede all other actions
- ***Finish*** has no post-conditions, and must not be followed by any other actions
- ***Progressive*** and ***Regressive*** planners

Planning in Blocks World



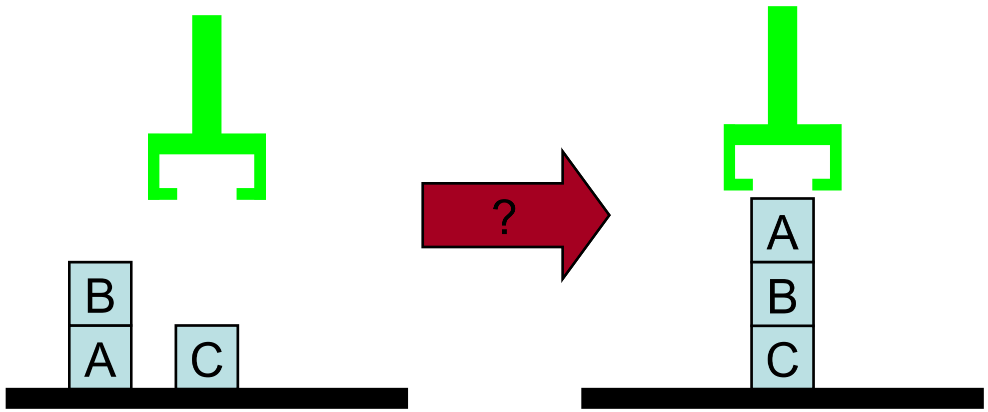
Update of Knowledge



Grip(∅)	Grip(B)	Grip(∅)	Grip(A)	Grip(∅)
On(B,A)	TopClear(A)	TopClear(A)	~~TopClear(A)~~	TopClear(A)
TopClear(B)	~~TopClear(B)~~	TopClear(B)	TopClear(B)	~~TopClear(B)~~
OnTable(A)	OnTable(A)	OnTable(A)	~~OnTable(A)~~	On(A,B)
TopClear(C)	TopClear(C)	On(B,C)	On(B,C)	On(B,C)
OnTable(C)	OnTable(C)	OnTable(C)	OnTable(C)	OnTable(C)
On(E,D)	On(E,D)	On(E,D)	On(E,D)	On(E,D)
TopClear(E)	TopClear(E)	TopClear(E)	TopClear(E)	TopClear(E)
OnTable(D)	OnTable(D)	OnTable(D)	OnTable(D)	OnTable(D)

UnStack(B,A) Stack(B,C) Pickup(A) Stack(A,B)

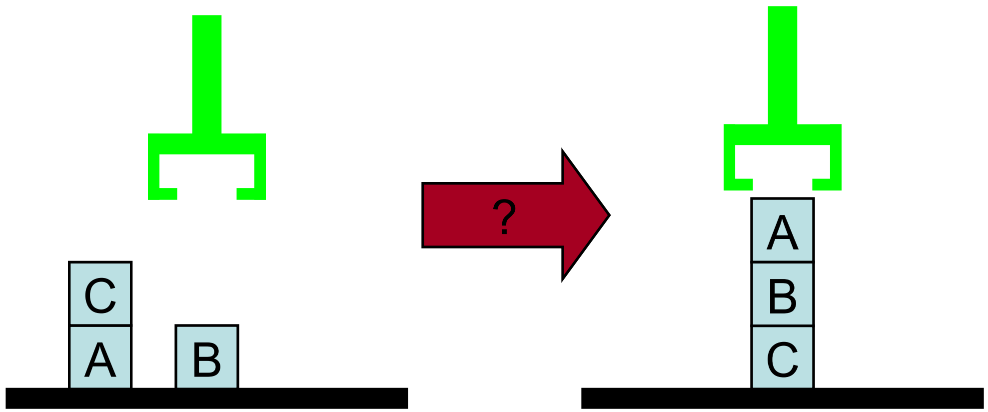
Using Divide and Conquer: Non-interleaved Planners



Sub-goals:
On(B,C)
On(A,B)

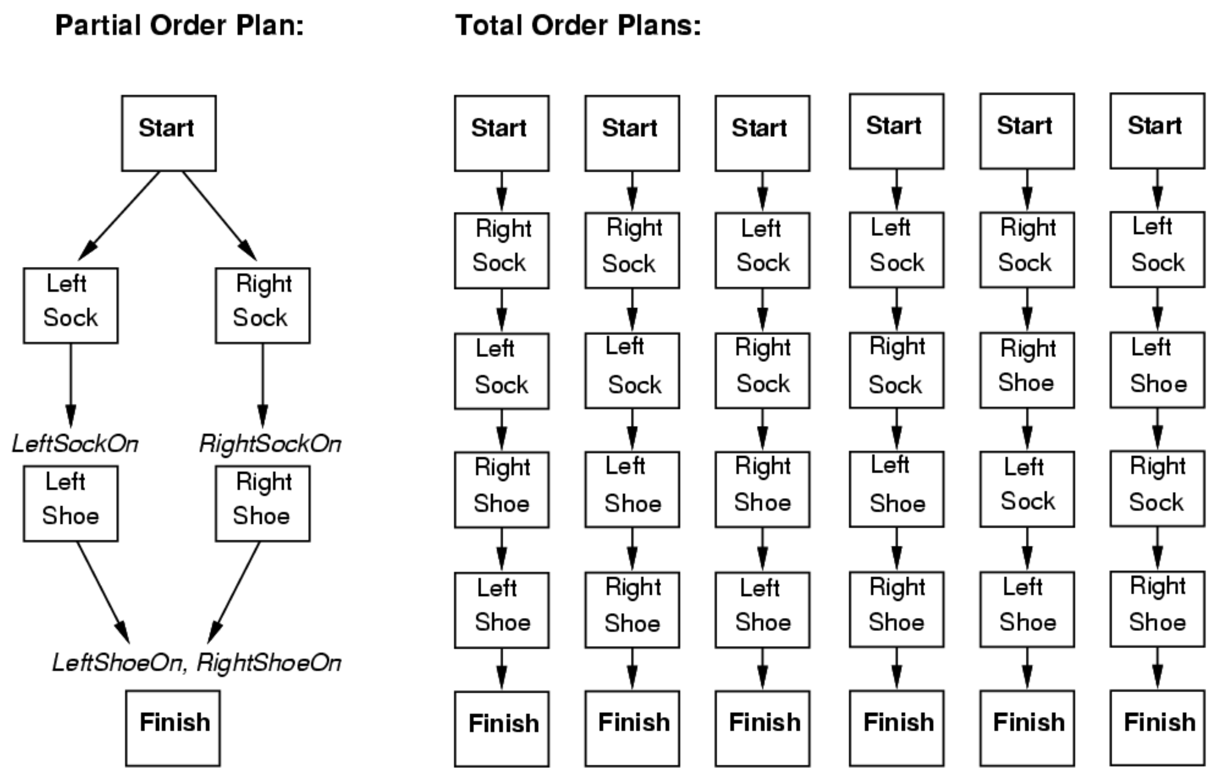
- Divide the problem into subgoals (conjuncts in the goal state) and then plan each of those individually
- Goal : On(B,C) $\wedge$ On(A,B)
- Perform all of the actions to accomplish goal #1, then all the actions to accomplish goal #2, etc.

Problems with Non-interleaved Planners



- Switch the location of B and C in the initial state
- Same Goal : $On(B,C) \wedge On(A,B)$
- If you attempt to solve either one of these first, then you cannot solve the second without breaking the first solution
- Sussman Anomaly

Representations for Plans

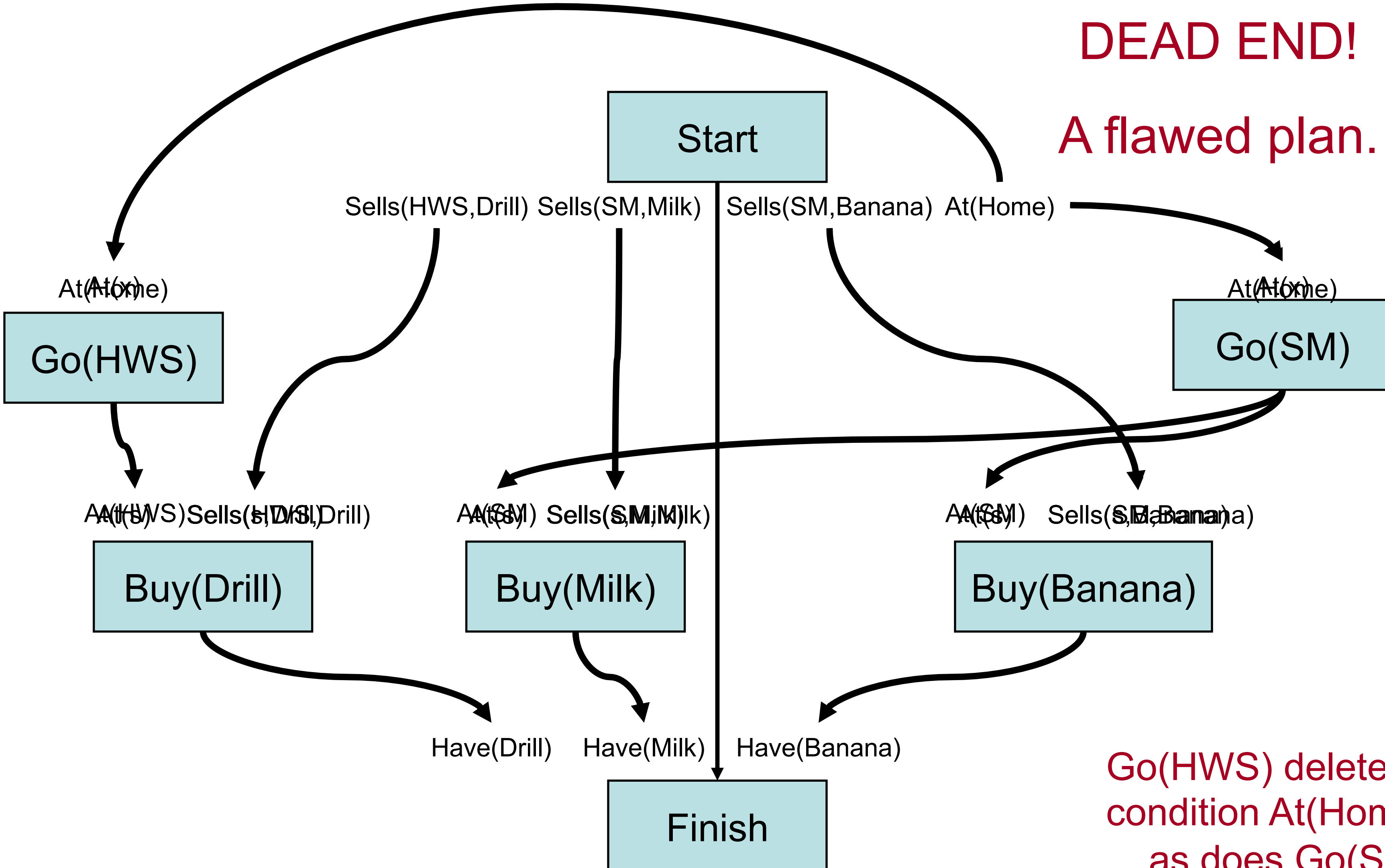


- Causal links (heavy arrows) : achieve a required prerequisite
- Ordering links (light arrows) : semi-arbitrary ordering
- Principle of Least Committment

Partial Order Planning

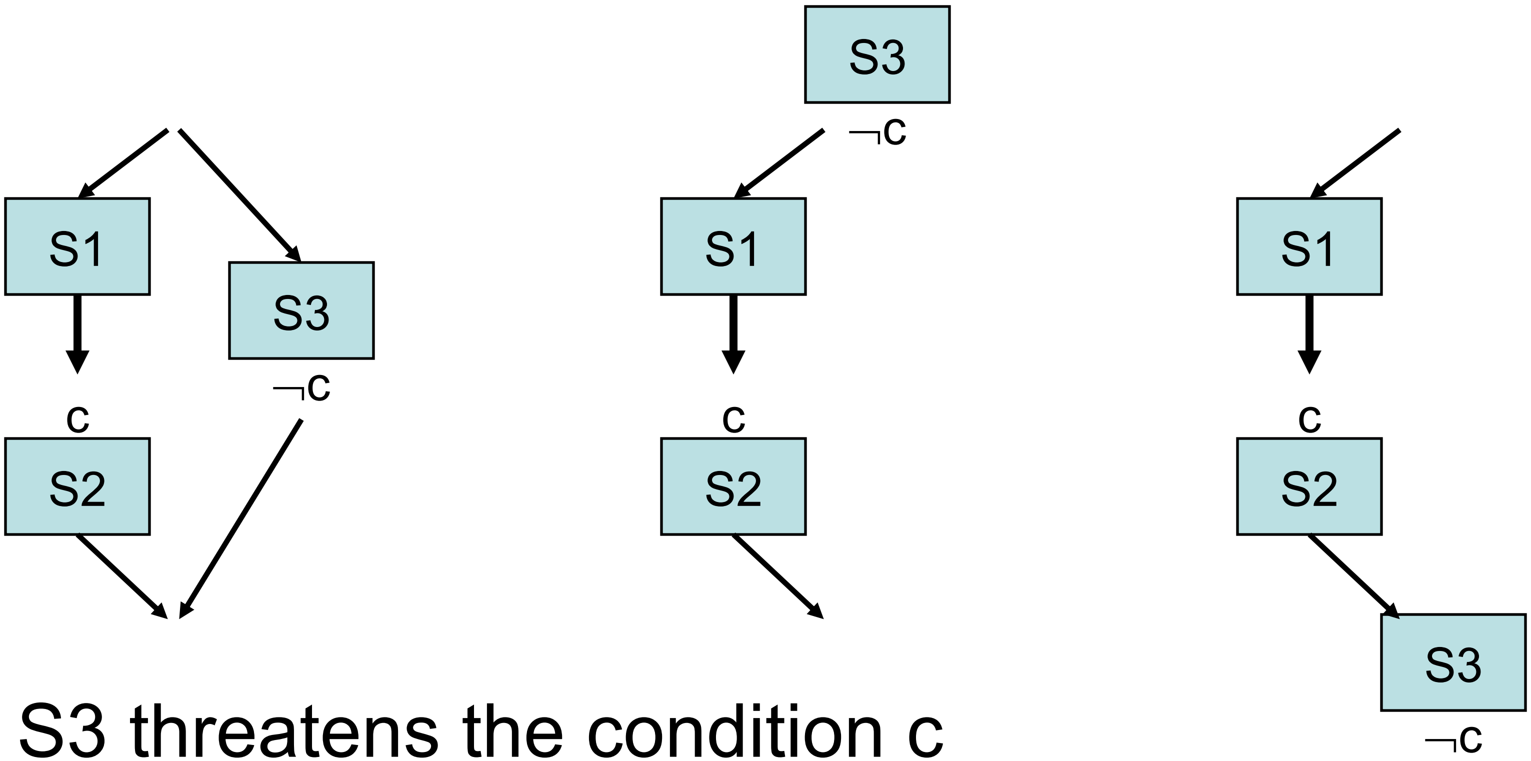
DEAD END!

A flawed plan.



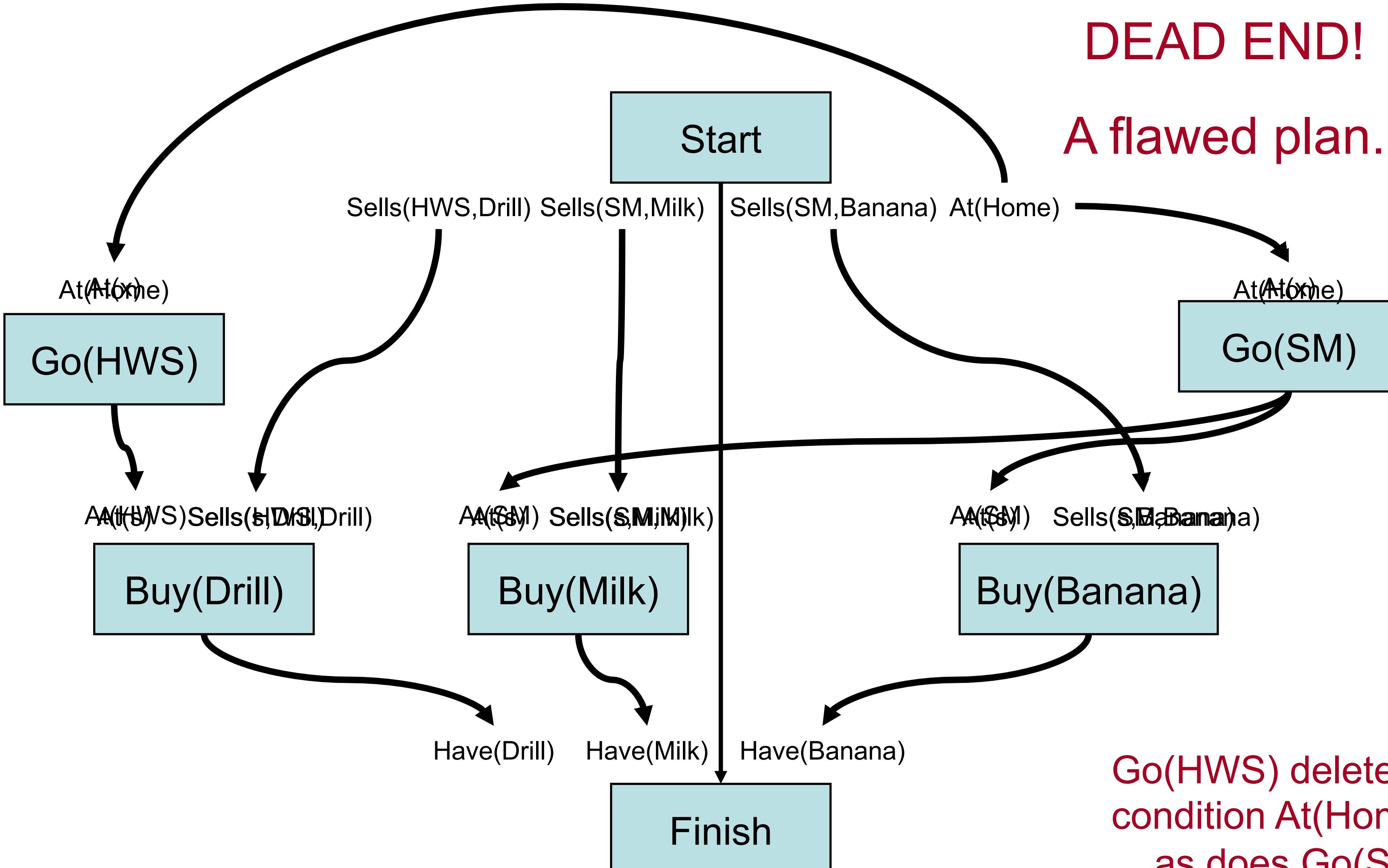
Go(HWS) deletes the condition At(Home)… as does Go(SM)

Protecting Causal Links



- S3 threatens the condition c
- S3 can then either be demoted or promoted to avoid the conflict

Partial Order Planning

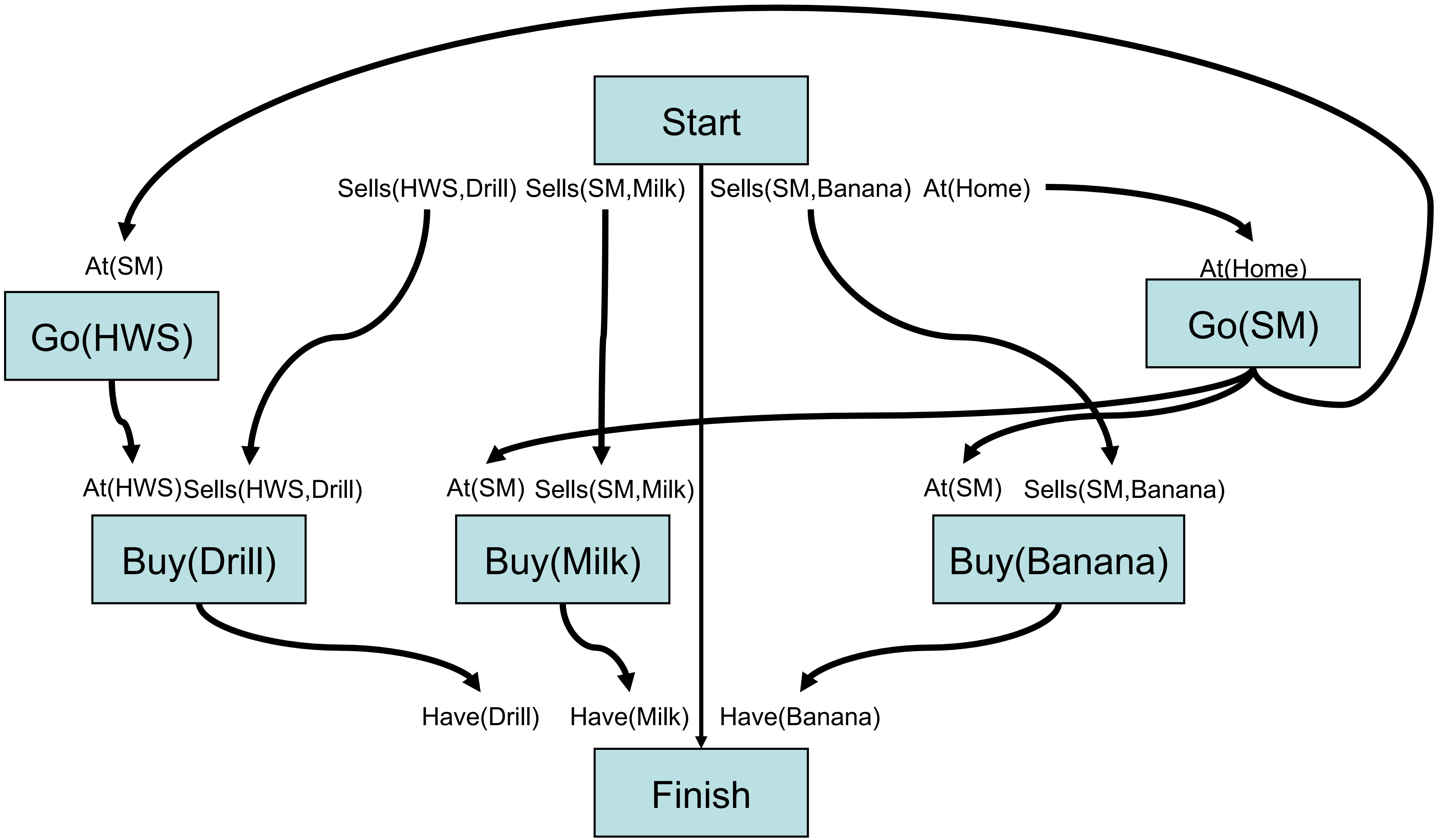


DEAD END!

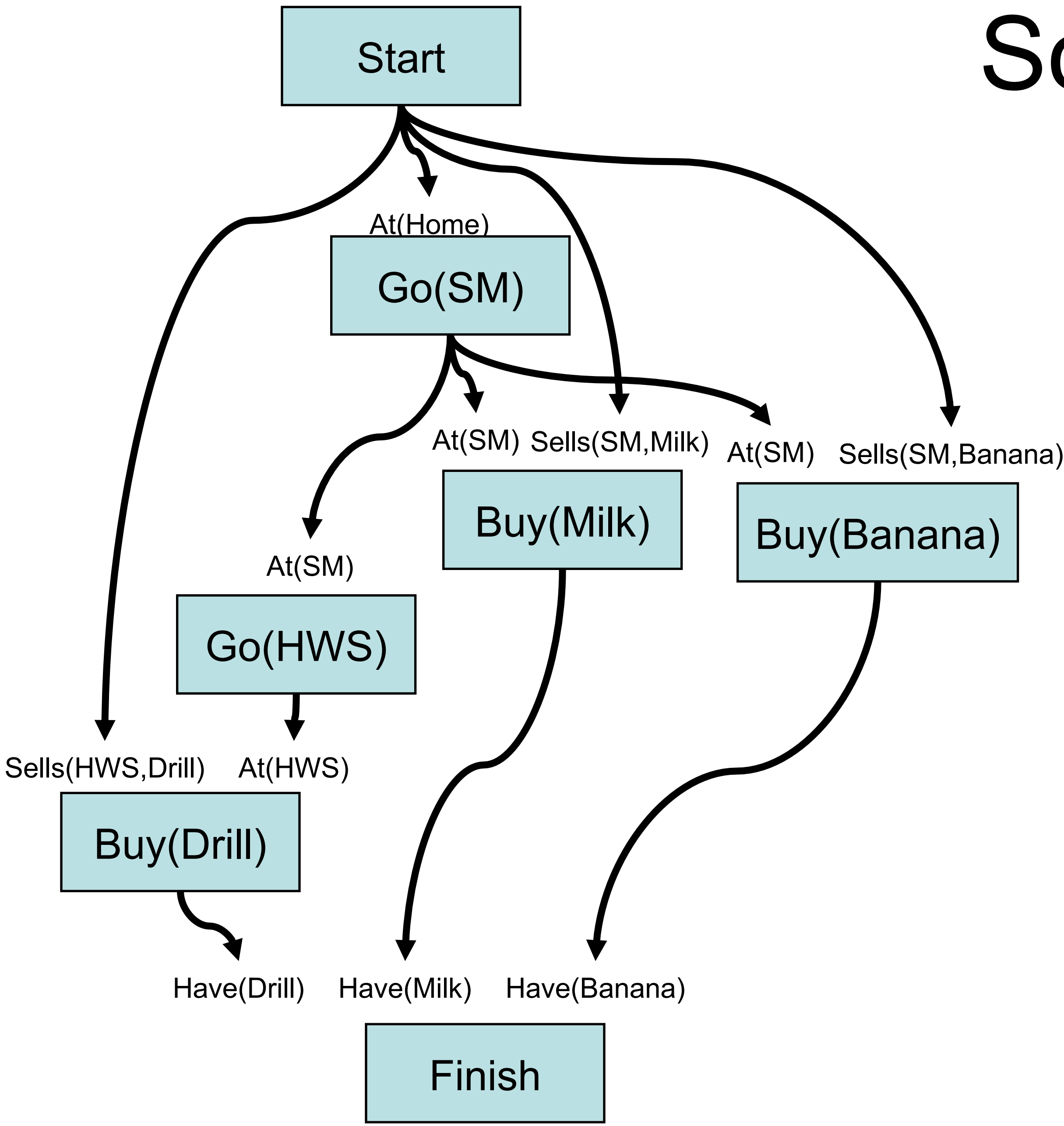
A flawed plan.

Go(HWS) deletes the condition At(Home)… as does Go(SM)

Back to our Example…



Solution



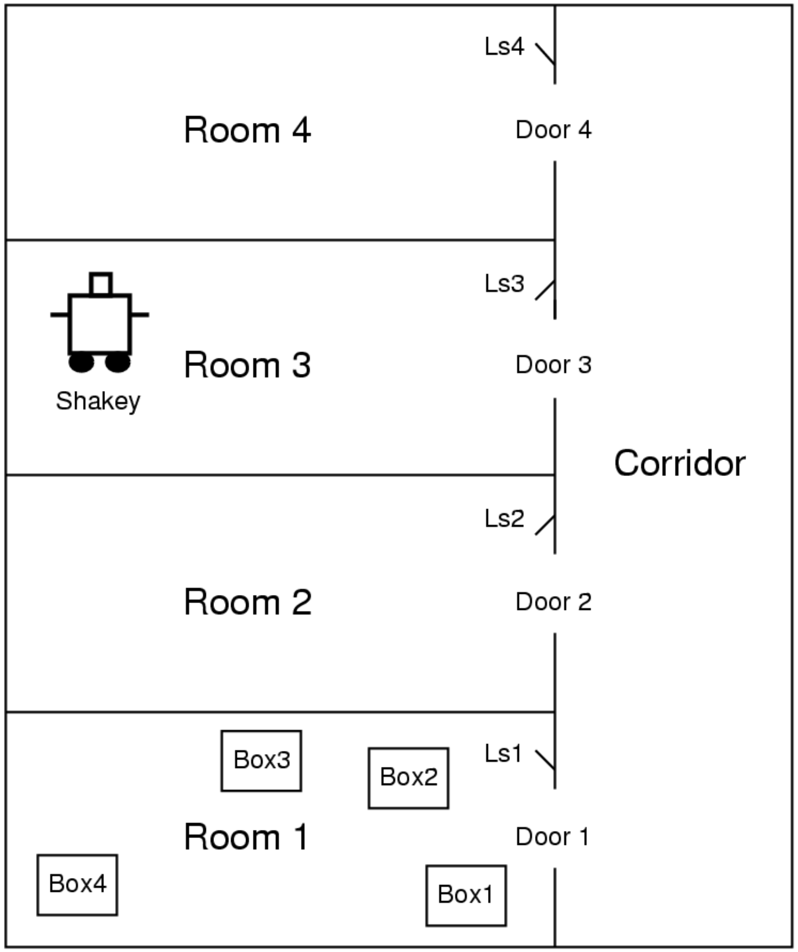
- Showing only causal links

Planning with Existentials and Possible Threats

- Is $\neg At(x)$ a threat to At(Home) ?
- Depends on what x is later instantiated to be…it could possibly be a threat
- Ways to treat possible threats
  - Resolve now with equality (assign x to be something other than Home right now)
  - Resolve now with inequality (introduce the constraint $x \neq Home$)
  - Resolve Later

Shakey the Robot

- Demonstration of STRIPS planning
- Known set of rooms and a connecting corridor
- Light switches could only be reached by climbing on a box



Shakey the Robot (SRI, 1970)

- Sensors
  - Laser Range finder
  - Television Camera
  - Bump Sensors
- Off-board computation
- Environment
  - Static
  - Controlled lighting
  - Polyhedral solids
  - Solid colors