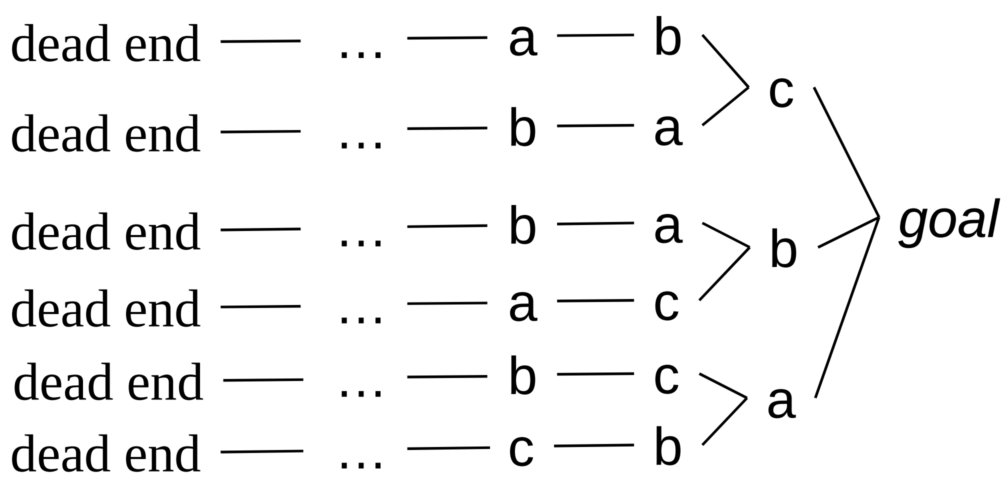
Lecture slides for

Automated Planning: Theory and Practice

Plan-Space Planning

Motivation

- Problem with state-space search
  - In some cases we may try many different orderings of the same actions before realizing there is no solution



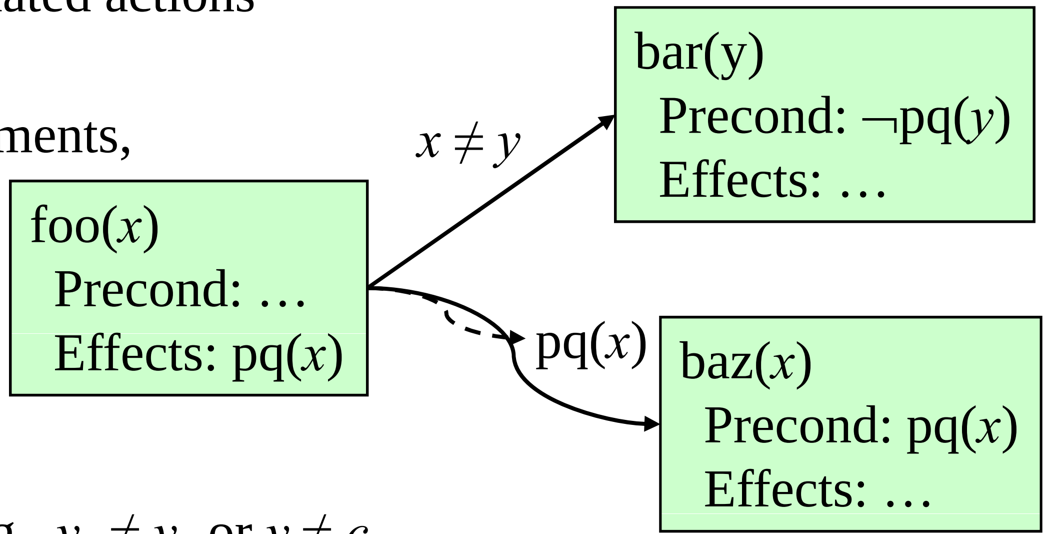
- *Least-commitment strategy:* don't commit to orderings, instantiations, etc., until necessary

Outline

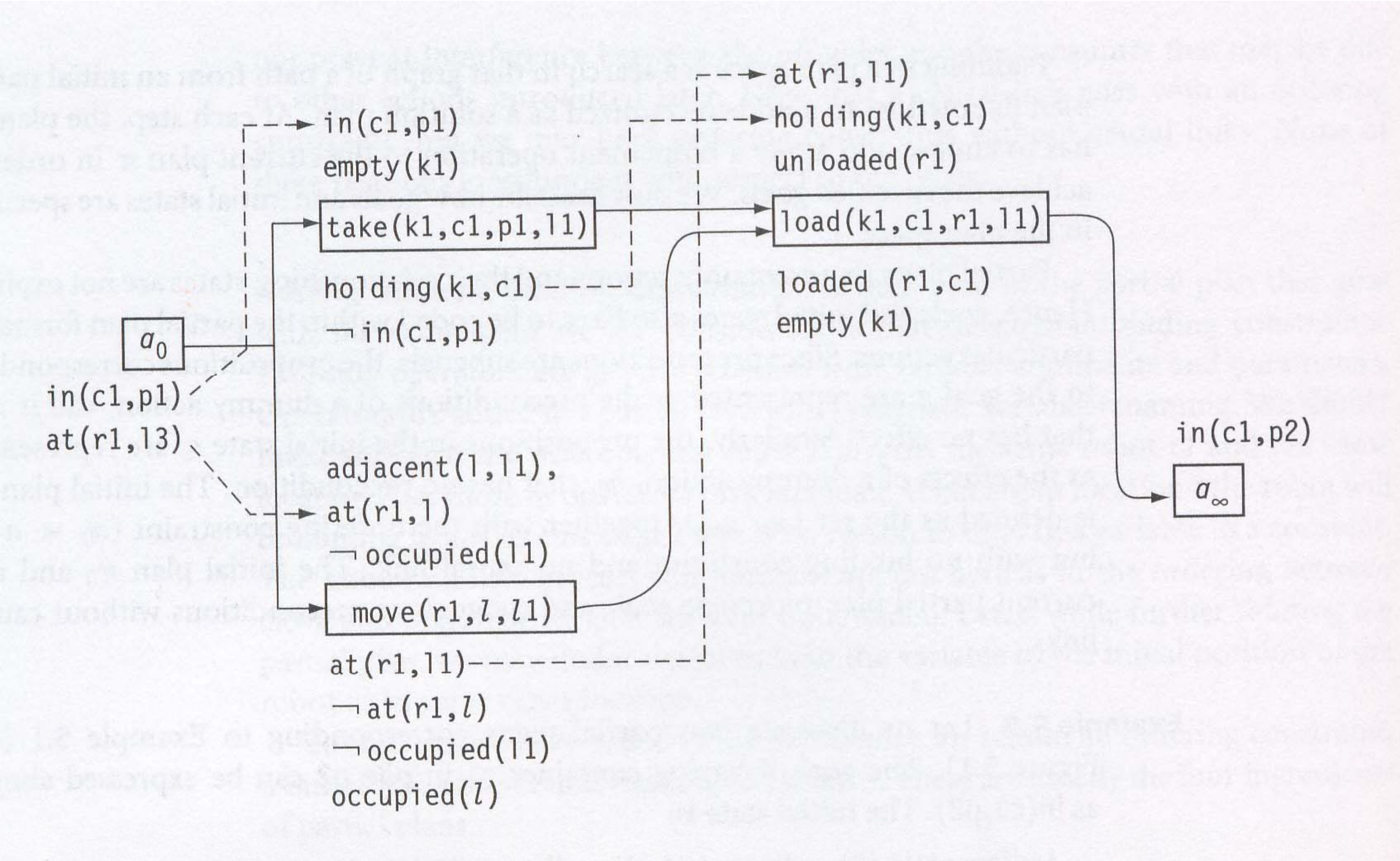
- Basic idea
- Open goals
- Threats
- The PSP algorithm
- Long example
- Comments

Plan-Space Planning - Basic Idea

- Backward search from the goal
- Each node of the search space is a *partial plan*
  - » A set of partially-instantiated actions
  - » A set of constraints
  - ◆ Make more and more refinements, until we have a solution
- Types of constraints:
  - ◆ *precedence constraint*: a must precede b
  - ◆ *binding constraints*:
    - » inequality constraints, e.g., $v_1 \neq v_2$ or $v \neq c$
    - » equality constraints (e.g., $v_1 = v_2$ or $v = c$) or substitutions
  - ◆ *causal link*:
    - » use action a to establish the precondition p needed by action b
- How to tell we have a solution: no more *flaws* in the plan
  - ◆ Will discuss flaws and how to resolve them

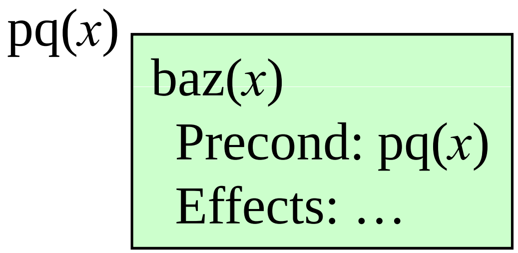


An Example of Partial Plan

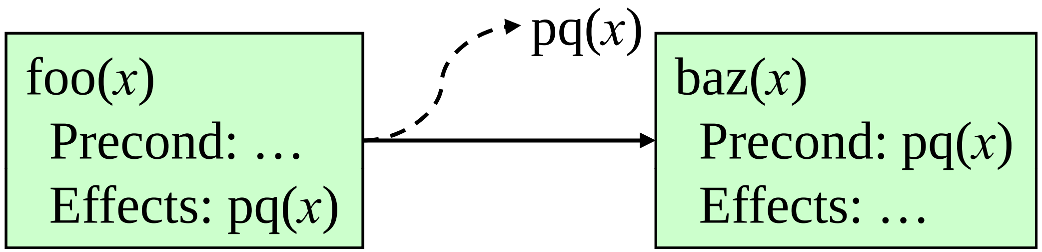


Flaws: 1. Open Goals

- Open goal:
  - An action a has a precondition p that we haven't decided how to establish

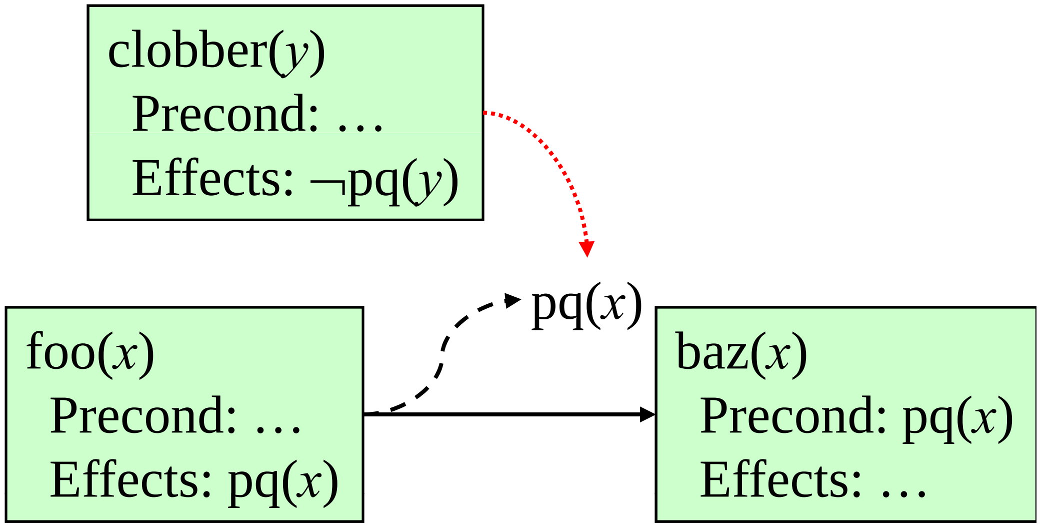


- Resolving the flaw:
  - Find an action b
    - (either already in the plan, or insert it)
  - that can be used to establish p
    - can precede a and produce p
  - Instantiate variables
  - Create a causal link



Flaws: 2. Threats

- Threat: a deleted-condition interaction
  - Action *a* establishes a precondition (e.g., pq(*x*)) of action *b*
  - Another action *c* is capable of deleting *p*
- Resolving the flaw:
  - impose a constraint to prevent *c* from deleting *p*
- Three possibilities:
  - Make *b* precede *c*
  - Make *c* precede *a*
  - Constrain variable(s) to prevent *c* from deleting *p*



The PSP Procedure

$$
\begin{array}{l}
\mathsf{PSP}(\pi) \\
\quad flaws \leftarrow \mathsf{OpenGoals}(\pi) \cup \mathsf{Threats}(\pi) \\
\quad \text{if } flaws = \emptyset \text{ then return}(\pi) \\
\quad \text{select any flaw } \phi \in flaws \\
\quad resolvers \leftarrow \mathsf{Resolve}(\phi, \pi) \\
\quad \text{if } resolvers = \emptyset \text{ then return(failure)} \\
\quad \text{nondeterministically choose a resolver } \rho \in resolvers \\
\quad \pi' \leftarrow \mathsf{Refine}(\rho, \pi) \\
\quad \text{return}(\mathsf{PSP}(\pi')) \\
\text{end}
\end{array}
$$

- PSP is both sound and complete

Example

- Similar (but not identical) to an example in Russell and Norvig's *Artificial Intelligence: A Modern Approach* (1st edition)
- Operators:
  - **Start**

    Precond: none

    Effects: At(Home), sells(HWS,Drill), Sells(SM,Milk), Sells(SM,Banana)
  - **Finish**

    Precond: Have(Drill), Have(Milk), Have(Banana), At(Home)
  - **Go(*l*,*m*)**

    Precond: At(*l*)

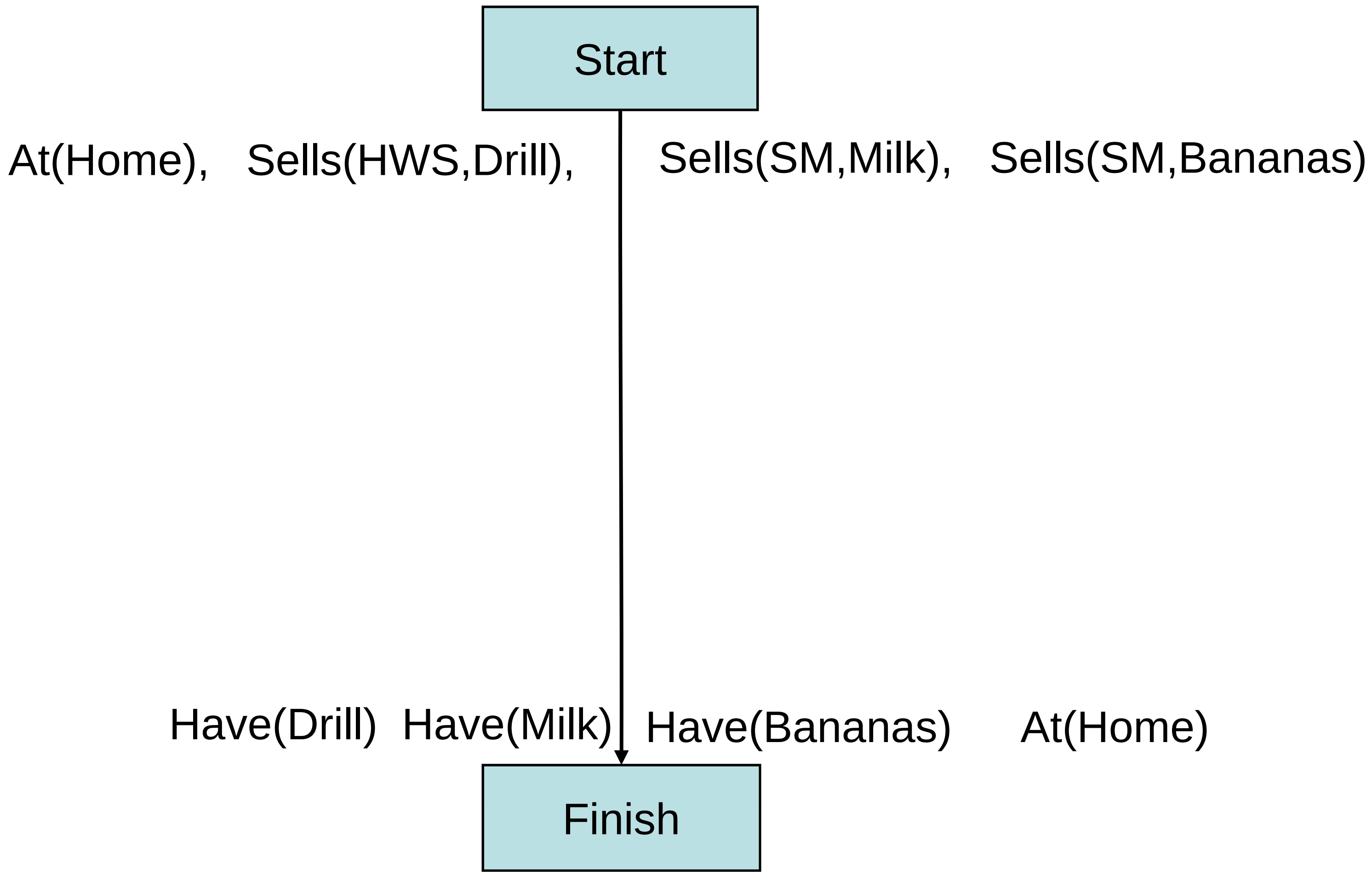
    Effects: At(*m*), ¬At(*l*)
  - **Buy(*p*,*s*)**

    Precond: At(*s*), Sells(*s*,*p*)

    Effects: Have(*p*)

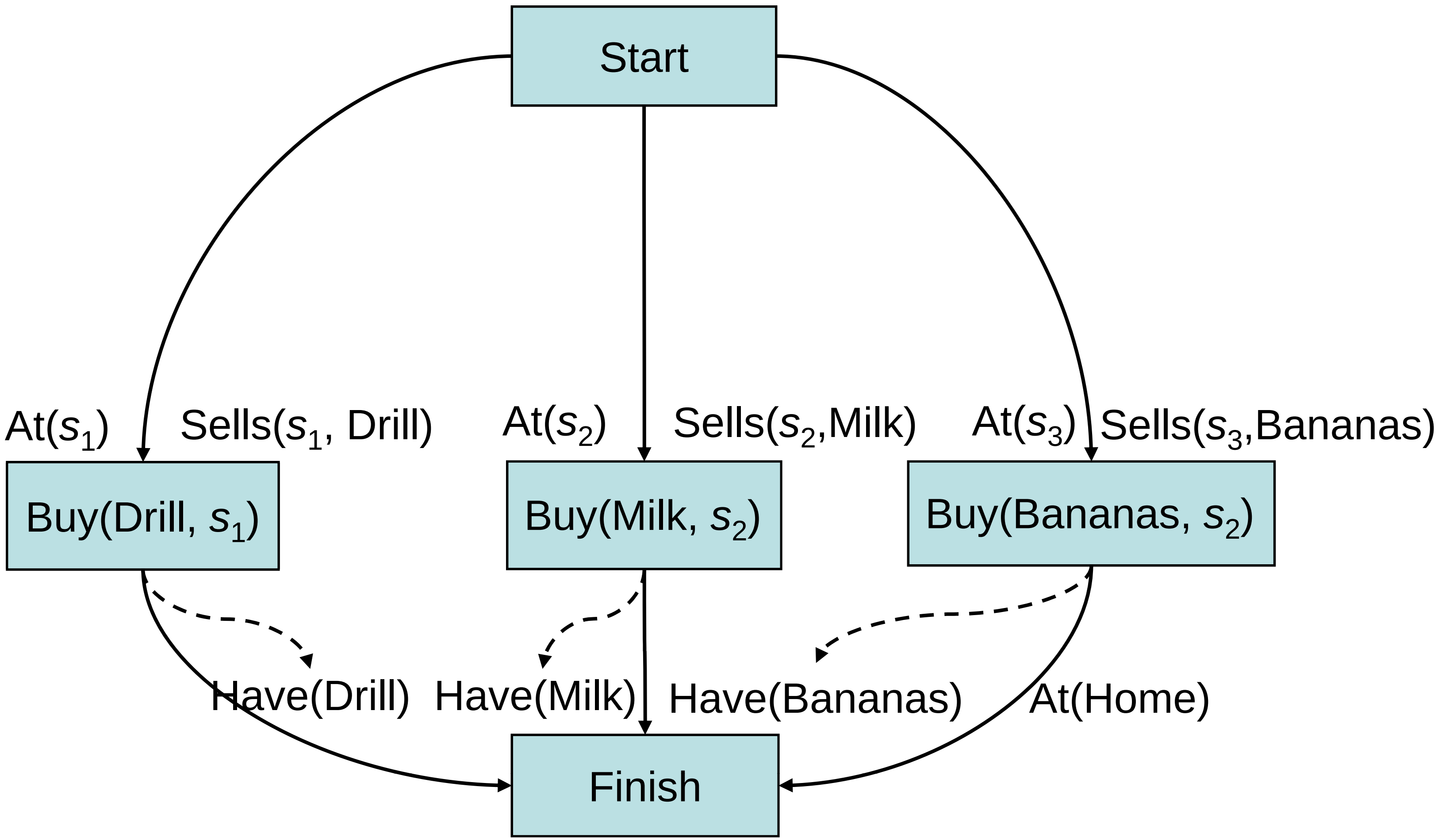
Example (continued)

- Initial plan



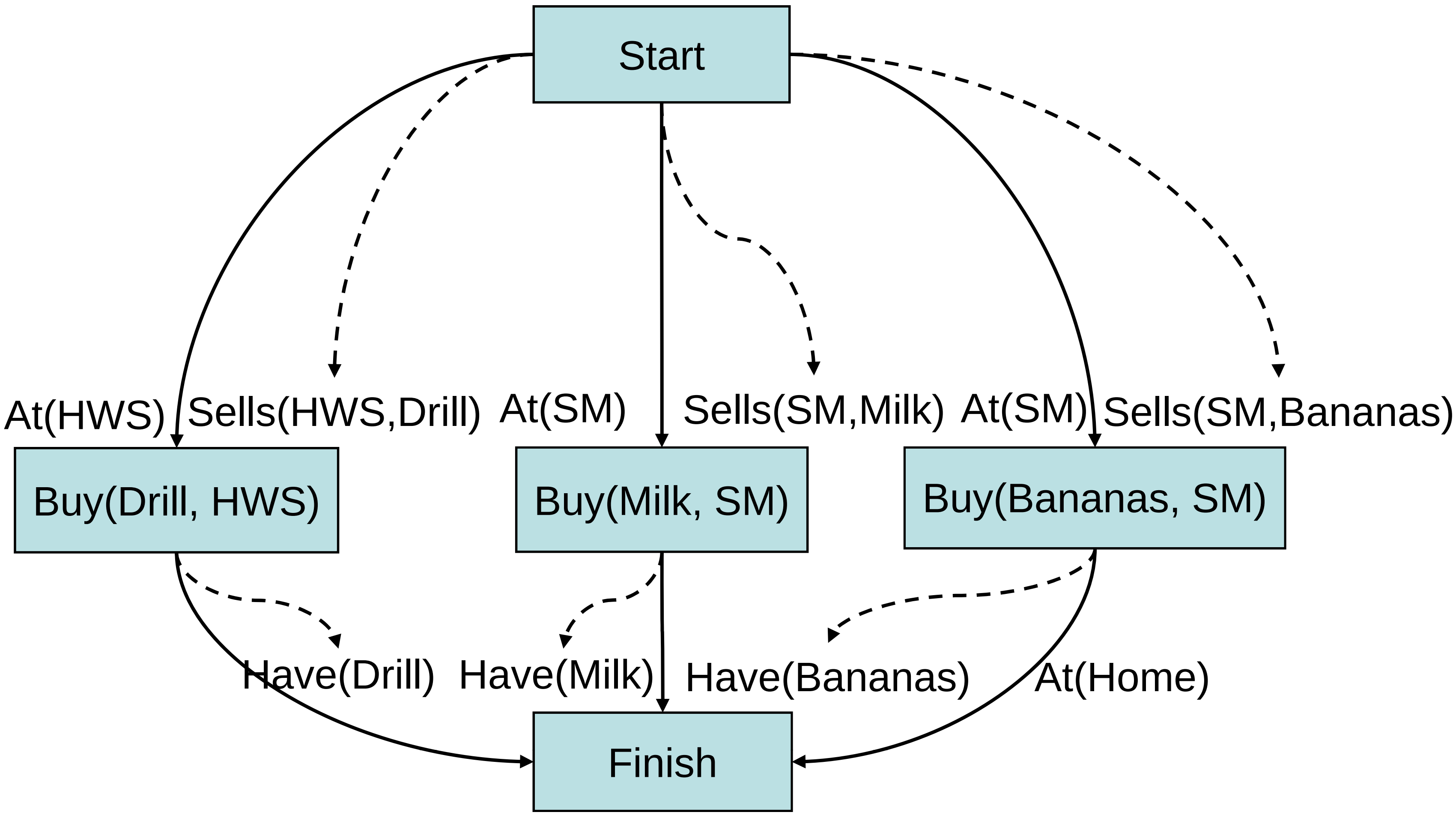
Example (continued)

- The only possible ways to establish the Have preconditions



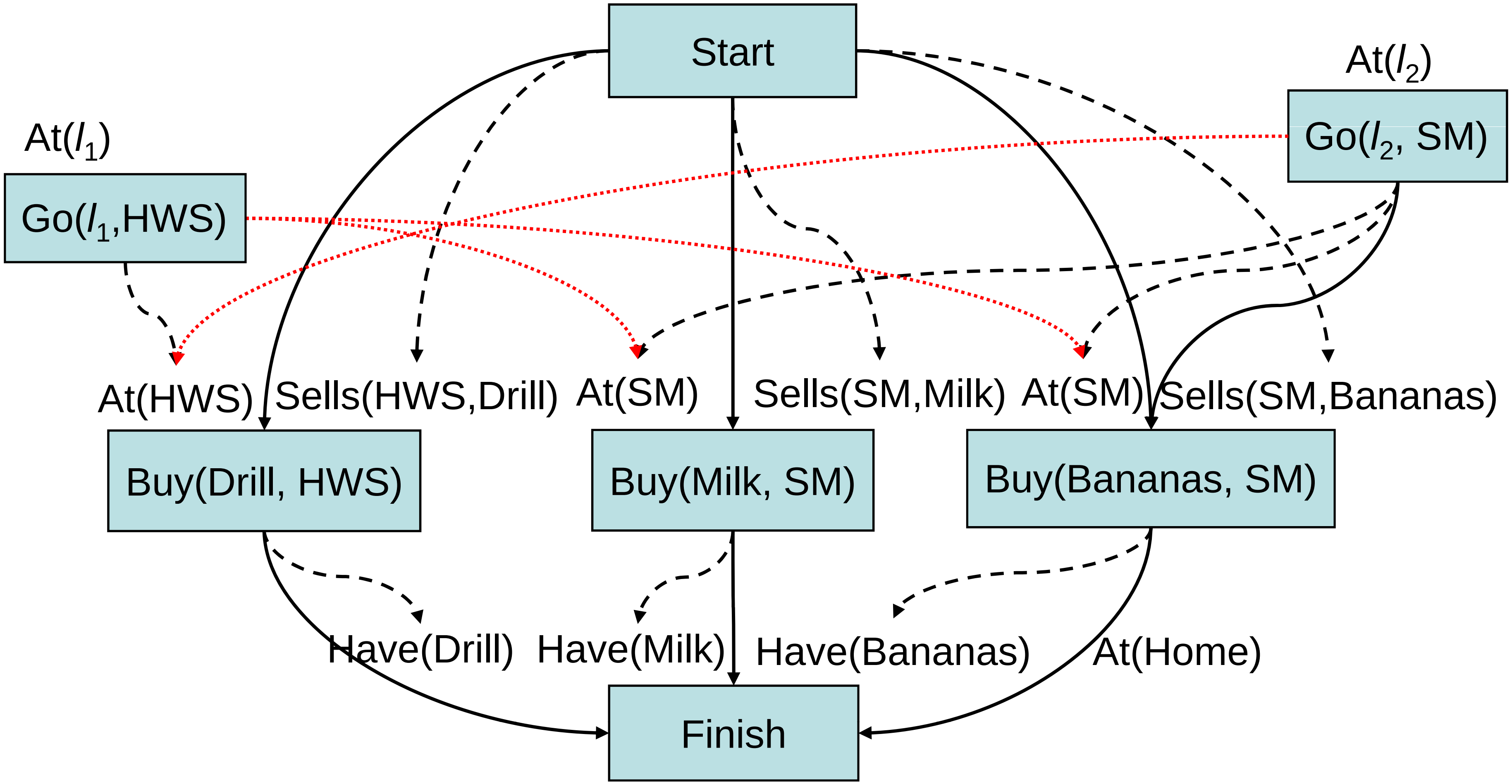
Example (continued)

- The only possible ways to establish the Sells preconditions



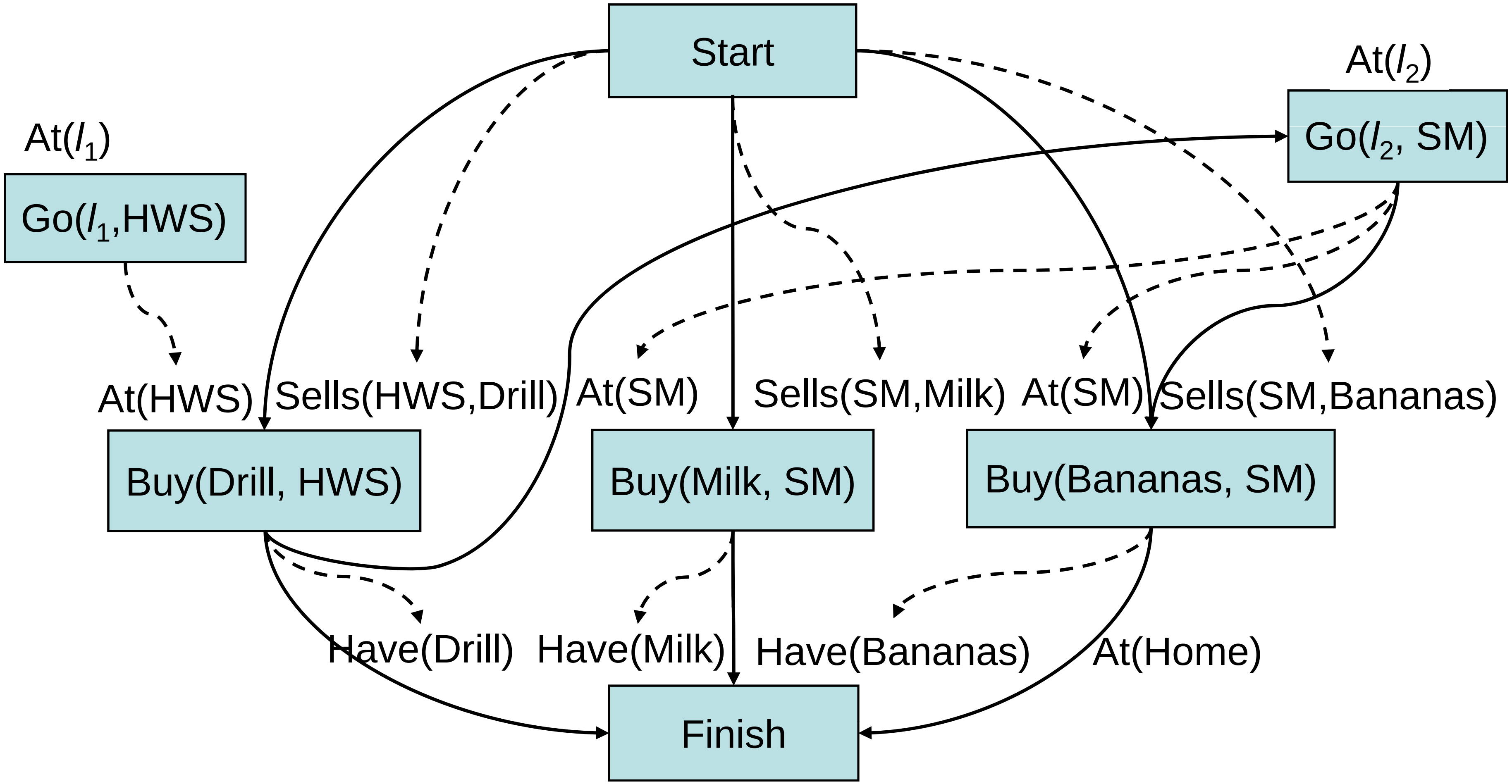
Example (continued)

- The only ways to establish At(HWS) and At(SM)
  - Note the threats



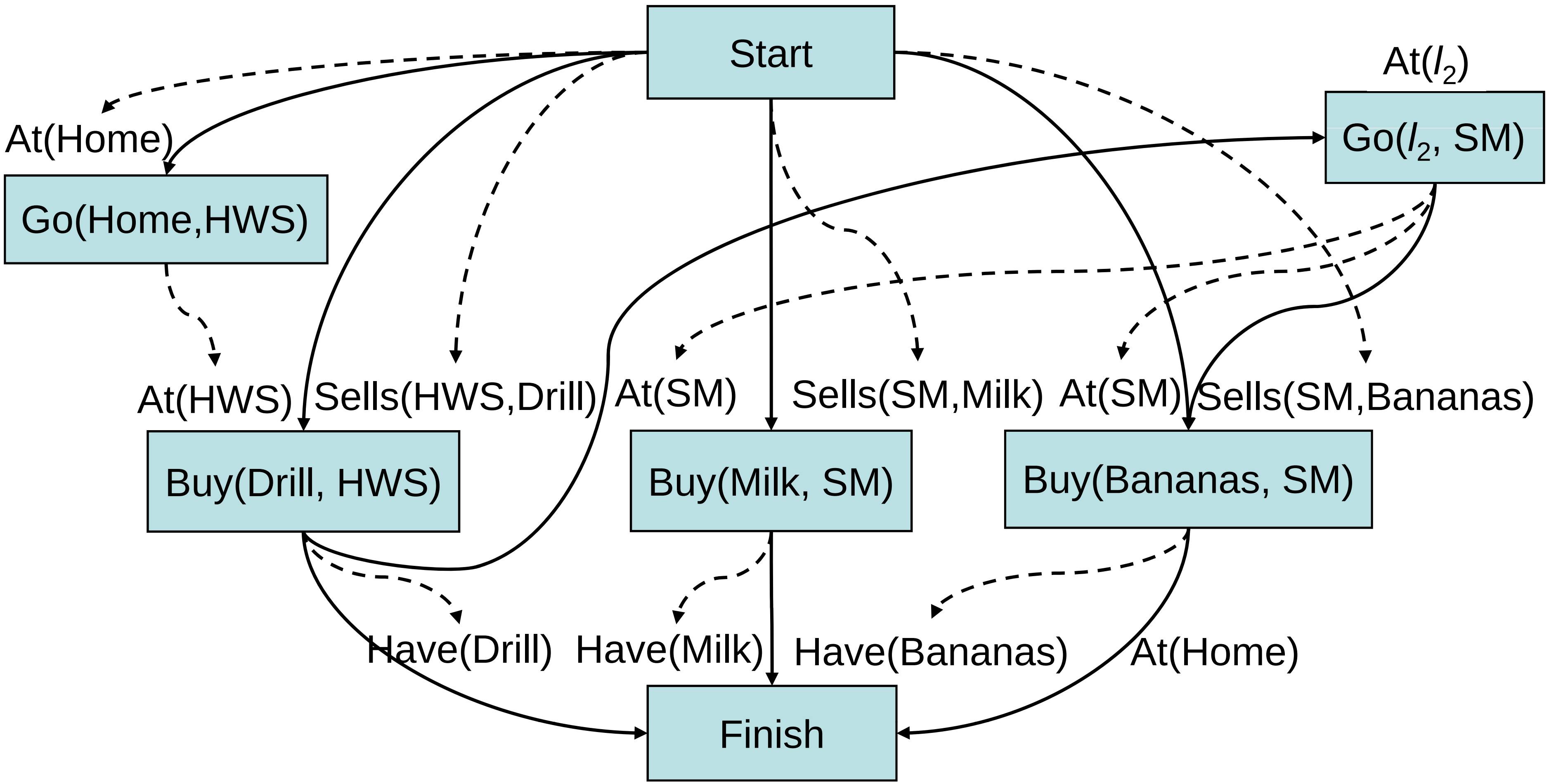
Example (continued)

- To resolve the threat to At(s_1), make Buy(Drill) precede Go(SM)
    - This resolves all three threats



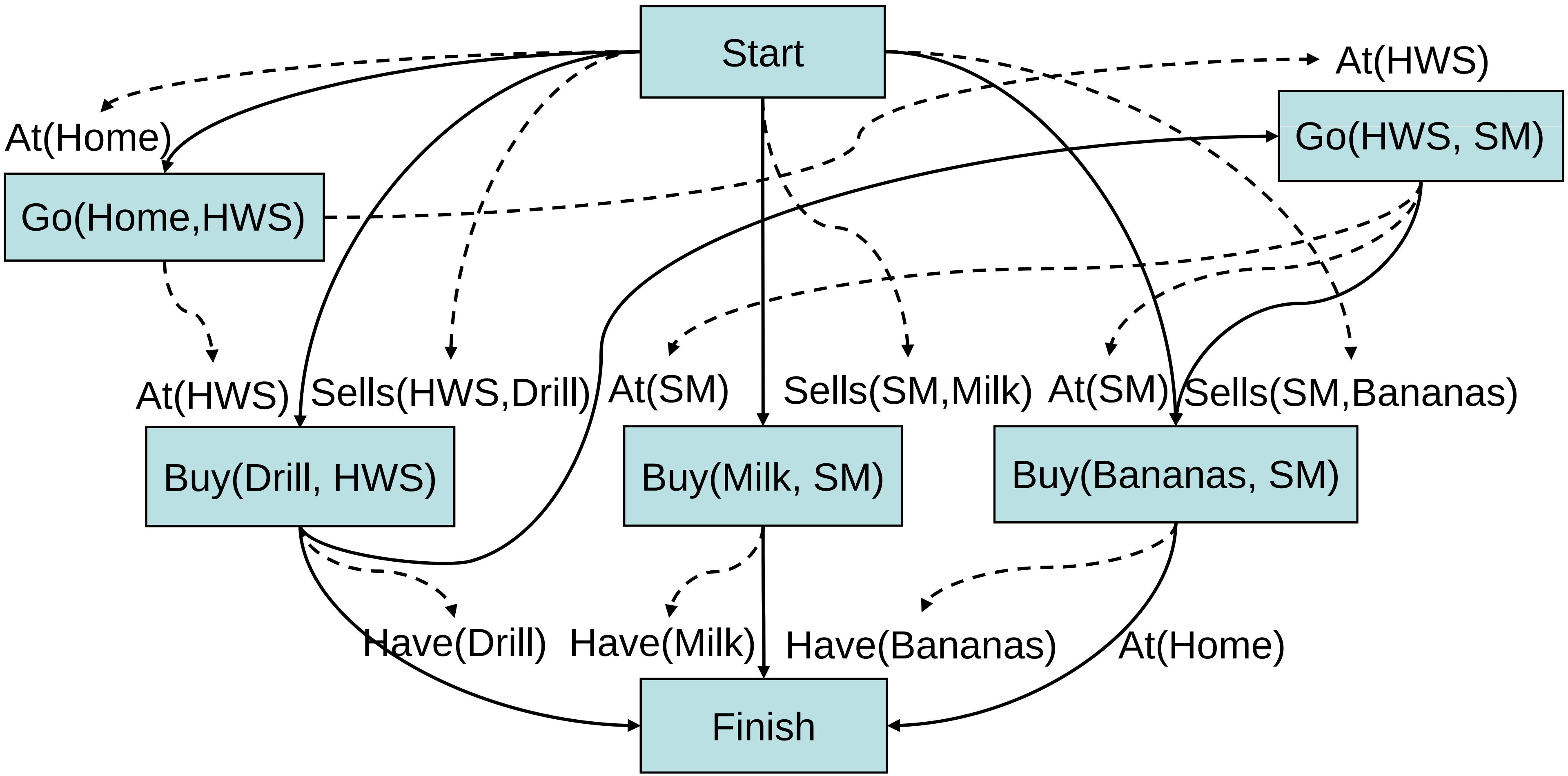
Example (continued)

- Establish At(l_1) with l_1=Home



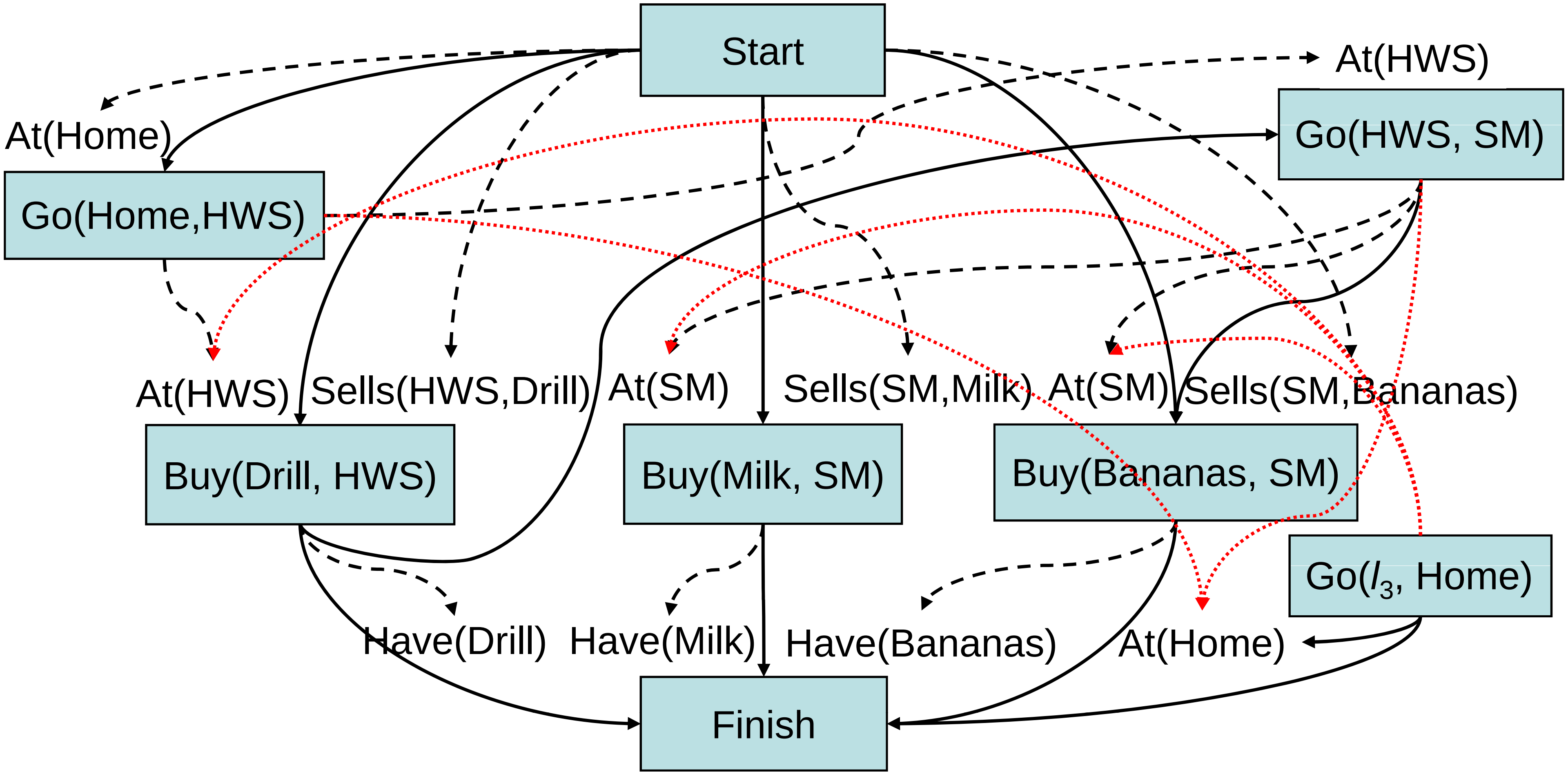
Example (continued)

- Establish At(l_2) with l_2= HWS



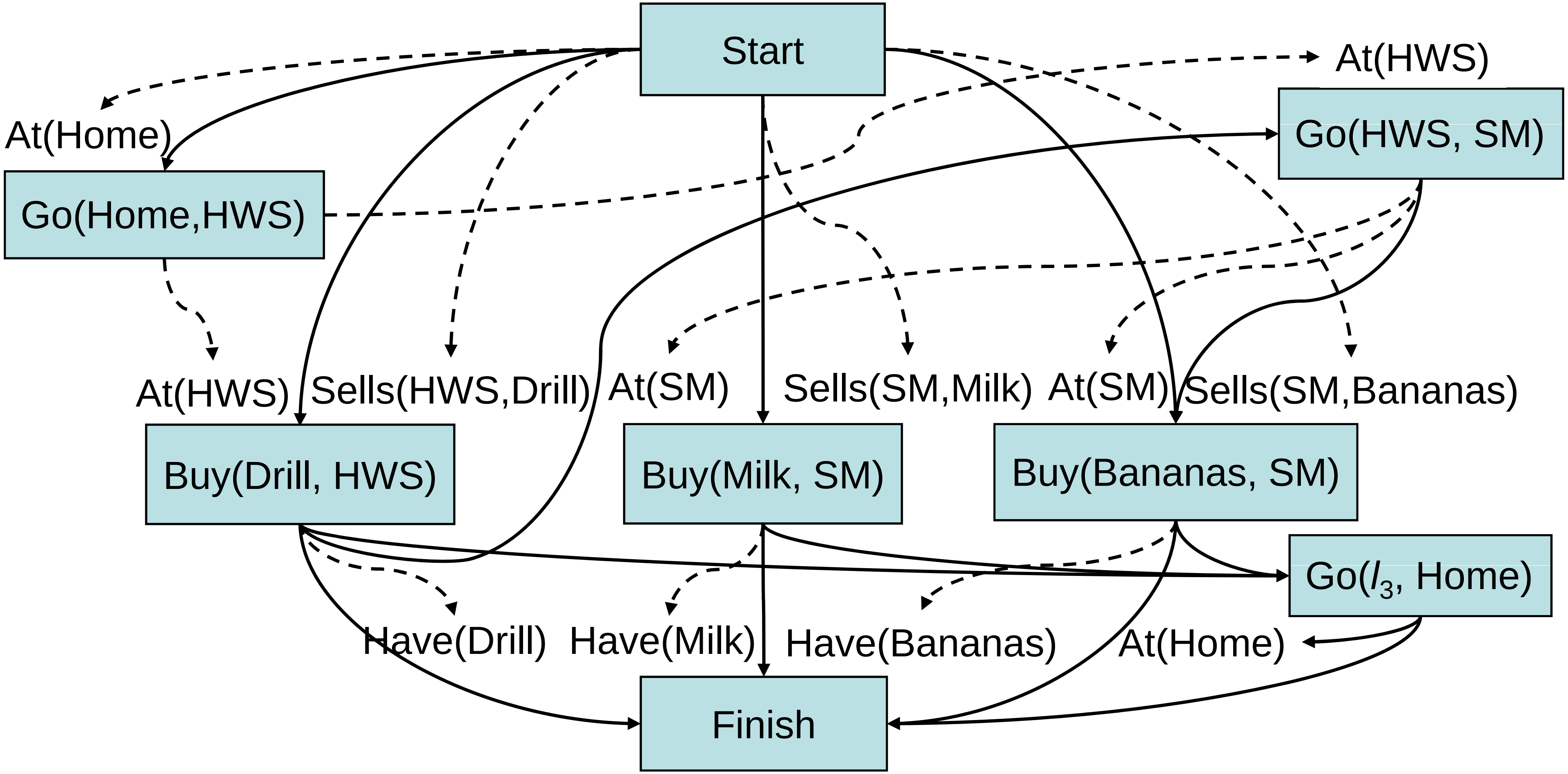
Example (continued)

- Establish At(Home) for Finish
  - This creates a bunch of threats



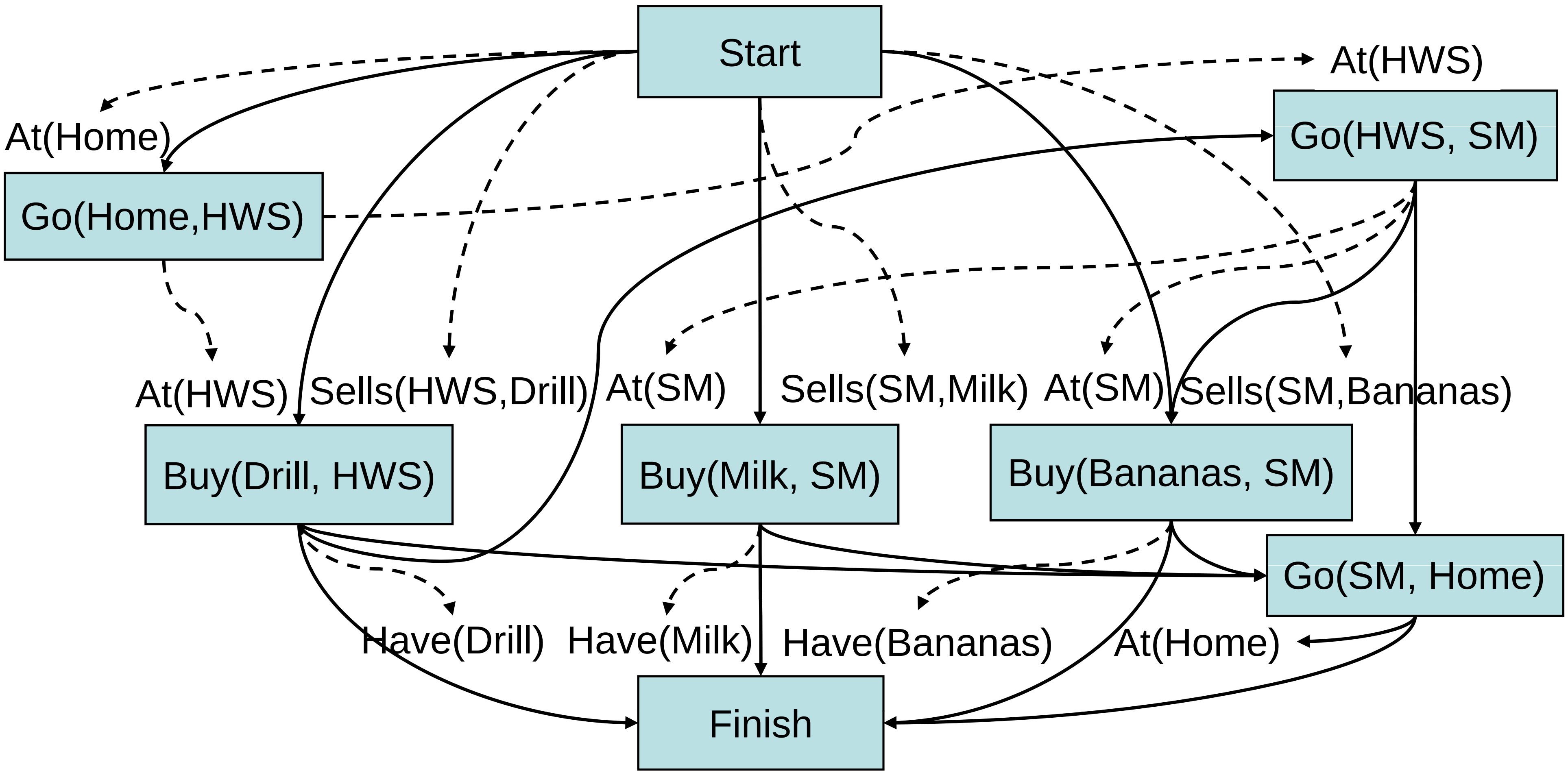
Example (continued)

- Constrain Go(l_3,Home) to remove threats to At(SM)
  - This also removes the other threats

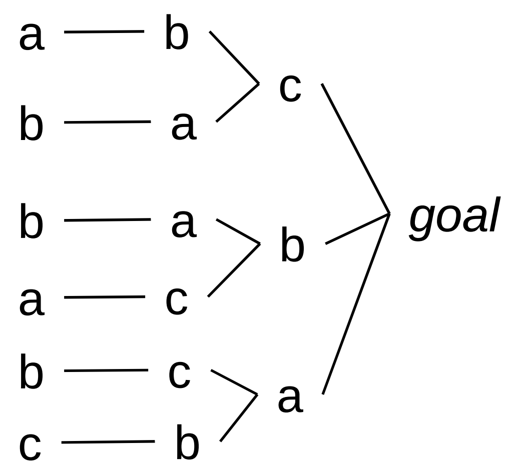


Final Plan

- Establish At(l_3) with l_3=SM



Comments



- PSP doesn’t commit to orderings and instantiations until necessary
  - Avoids generating search trees like this one:
- Problem: how to prune infinitely long paths?
  - Loop detection is based on recognizing states we’ve seen before
  - In a partially ordered plan, we don’t know the states
- Can we prune if we see the same *action* more than once?

  … — go(b,a) — go(a,b) – go(b,a) — at(a)

No. Sometimes we might need the same action several times in different states of the world (see next slide)

Example

- 3-digit binary counter starts at 000, want to get to 110

  s_0 = {d3=0, d2=0, d1=0}

  g = {d3=1, d2=1, d1=0}

- Operators to increment the counter by 1:

  incr0

  Precond: d_1=0

  Effects: d_1=1

  incr01

  Precond: d_2=0, d_1=1

  Effects: d_2=1, d_1=0

  incr011

  Precond: d_3=0, d_2=1, d_1=1

  Effects: d_3=1, d_2=0, d_1=0

A Weak Pruning Technique

- Can prune all paths of length > n, where n = |{all possible states}|
  - This doesn’t help very much

- I’m not sure whether there’s a good pruning technique for plan-space planning