Lecture slides for

Automated Planning: Theory and Practice

Chapter 6
Planning-Graph Techniques

Dana S. Nau

University of Maryland

3:04 PM February 8, 2012

History

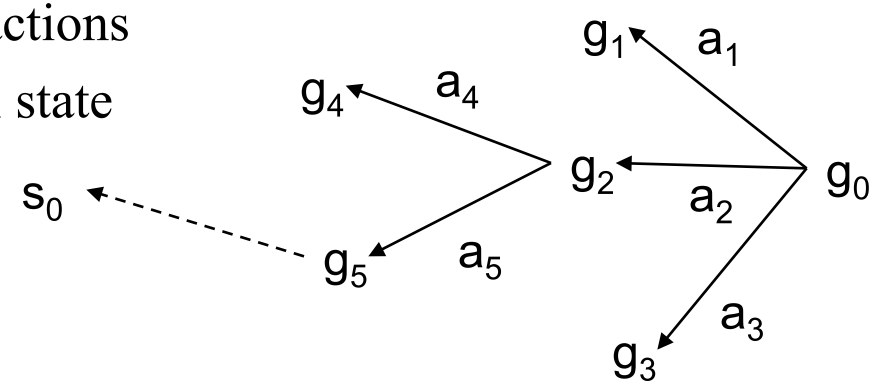
- Before Graphplan came out, most planning researchers were working on PSP-like planners
  - POP, SNLP, UCPOP, etc.
- Graphplan caused a sensation because it was so much faster
- Many subsequent planning systems have used ideas from it
  - IPP, STAN, GraphHTN, SGP, Blackbox, Medic, TGP, LPG
  - Many of them are much faster than the original Graphplan

Outline

- Motivation
- The Graphplan algorithm
- Constructing planning graphs
  - example
- Mutual exclusion
  - example (continued)
- Doing solution extraction
  - example (continued)
- Discussion

Motivation

- A big source of inefficiency in search algorithms is the *branching factor*
  - the number of children of each node
- e.g., a backward search may try lots of actions that can't be reached from the initial state



- One way to reduce branching factor:
- First create a *relaxed problem*
  - Remove some restrictions of the original problem
    - » Want the relaxed problem to be easy to solve (polynomial time)
  - The solutions to the relaxed problem will include all solutions to the original problem
- Then do a modified version of the original search
  - Restrict its search space to include only those actions that occur in solutions to the relaxed problem

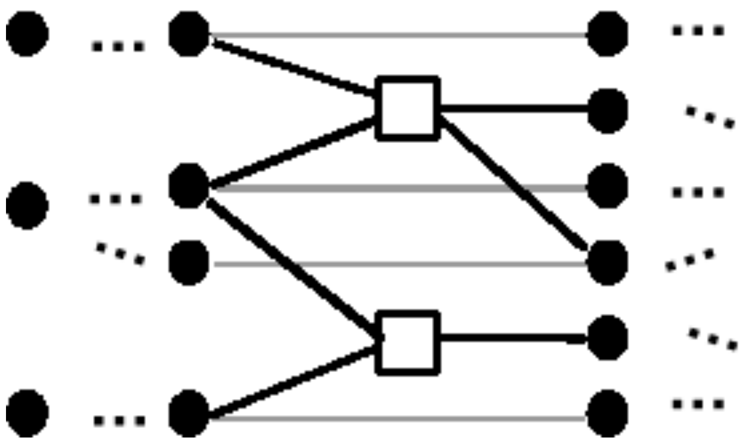
Graphplan

procedure Graphplan:

- for $k = 0, 1, 2, \ldots$
  - *Graph expansion:*
    - » create a "planning graph" that contains k "levels"
  - Check whether the planning graph satisfies a necessary (but insufficient) condition for plan existence

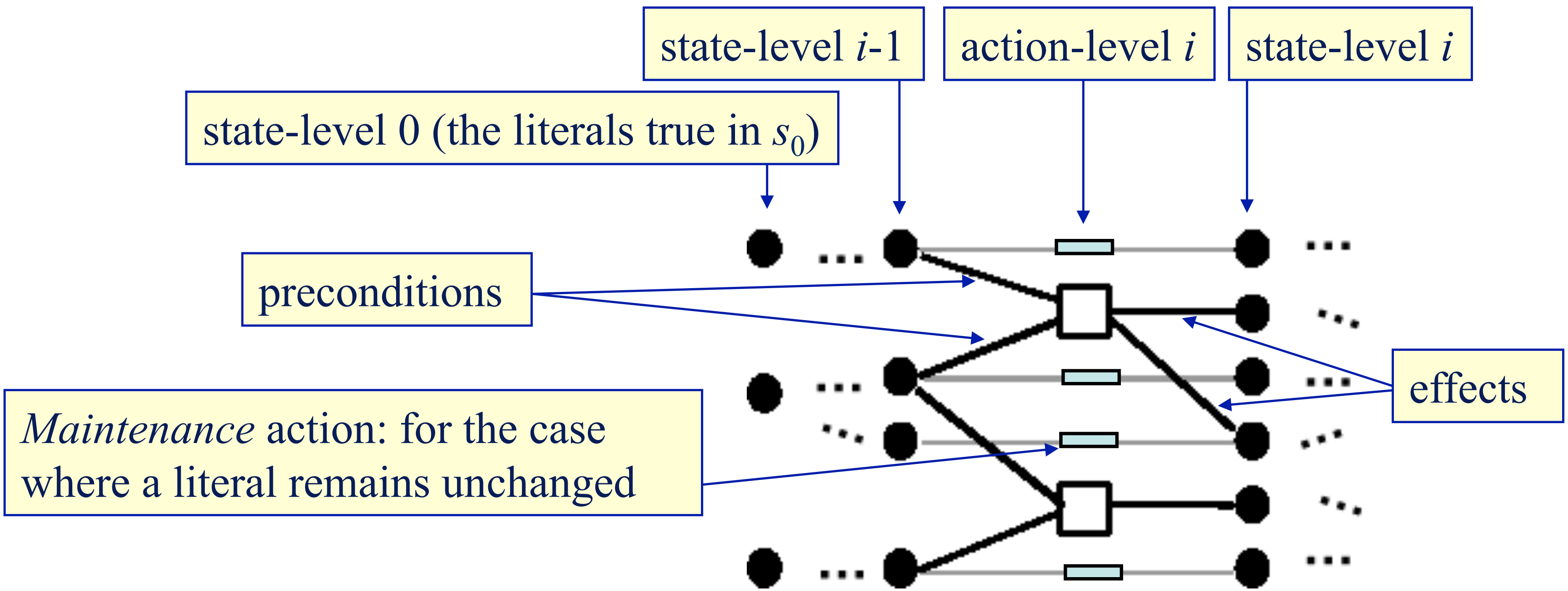
relaxed problem

  - If it does, then
    - » do *solution extraction:*
      - backward search, modified to consider only the actions in the planning graph
      - if we find a solution, then return it



The Planning Graph

- Search space for a relaxed version of the planning problem
- Alternating layers of ground literals and actions
  - Nodes at action-level *i*: actions that might be possible to execute at time *i*
  - Nodes at state-level *i:* literals that might possibly be true at time *i*
  - Edges: preconditions and effects



Example

- Due to Dan Weld (U. of Washington)

- Suppose you want to prepare dinner as a surprise for your sweetheart (who is asleep)

  s_0 = {garbage, cleanHands, quiet}

  g = {dinner, present, ¬garbage}

Action	Preconditions	Effects
cook()	cleanHands	dinner
wrap()	quiet	present
carry()	*none*	¬garbage, ¬cleanHands
dolly()	*none*	¬garbage, ¬quiet

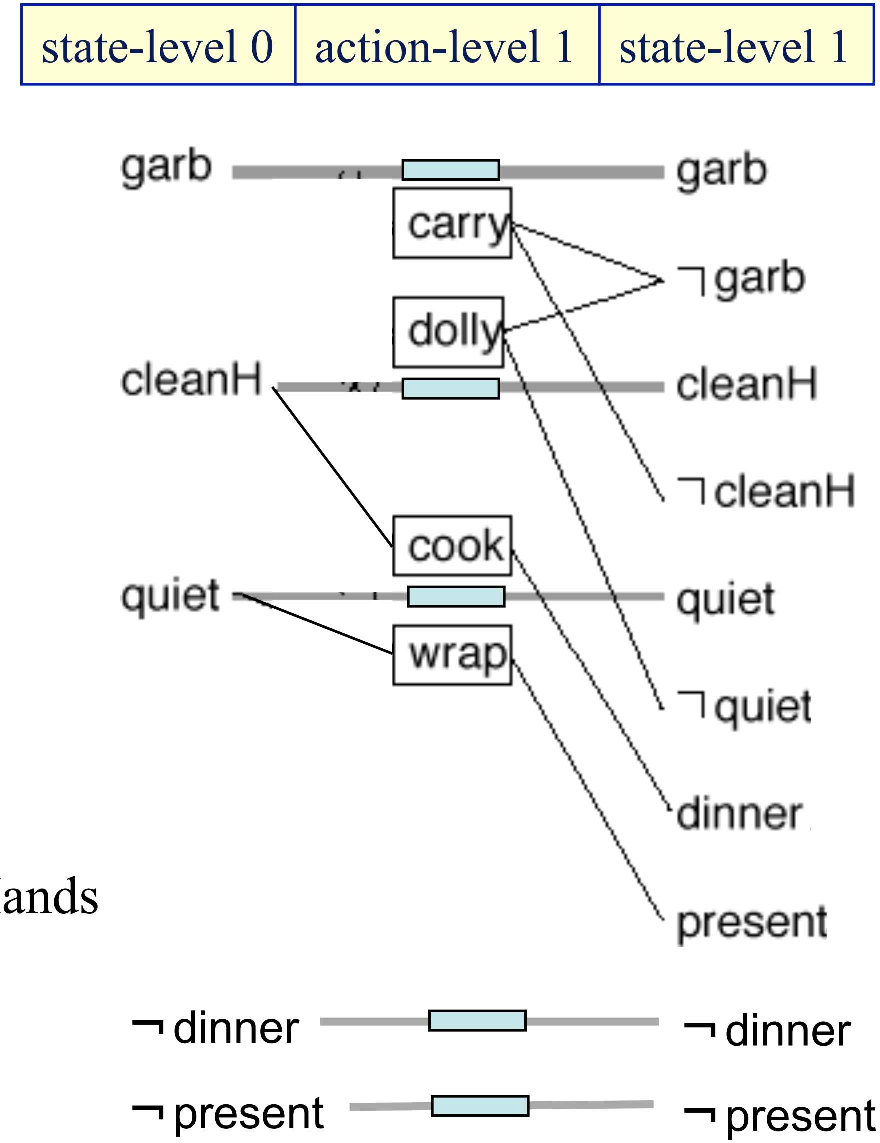
Also have the maintenance actions: one for each literal

Example (continued)

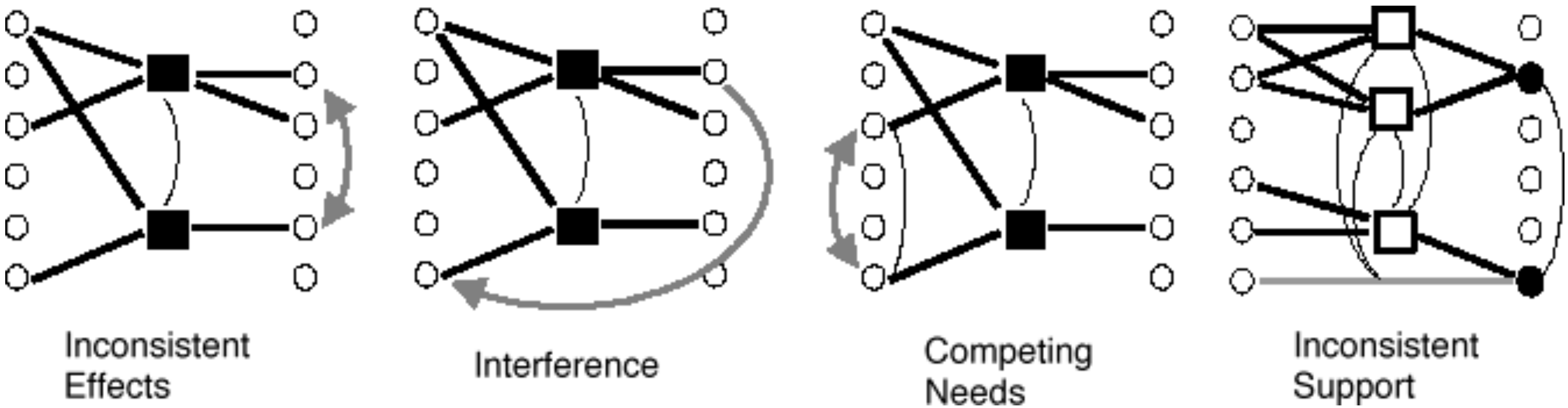
- state-level 0:
  {all atoms in s_0} ∪
  {negations of all atoms not in s_0}
- action-level 1:
  {all actions whose preconditions
  are satisfied and non-mutex in s_0}
- state-level 1:
  {all effects of all of the
  actions in action-level 1}

Action	Preconditions	Effects
cook()	cleanHands	dinner
wrap()	quiet	present
carry()	*none*	¬garbage, ¬cleanHands
dolly()	*none*	¬garbage, ¬quiet

Also have the maintenance actions



Mutual Exclusion



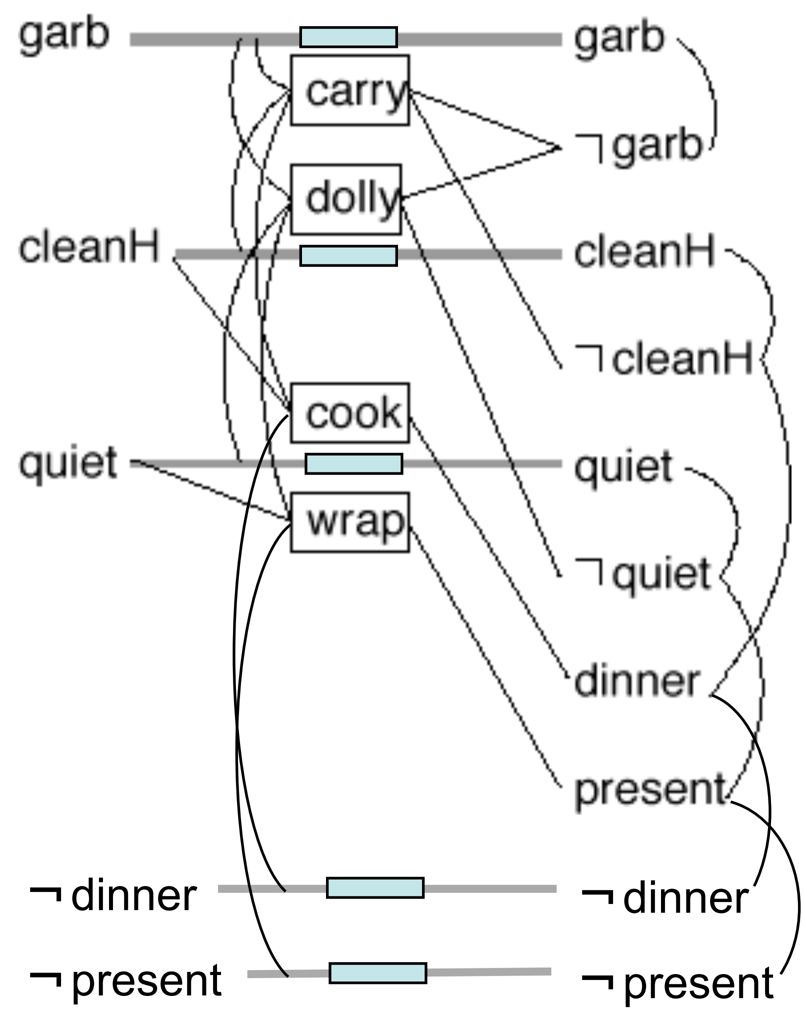
- Two actions at the same action-level are mutex if
  - *Inconsistent effects:* an effect of one negates an effect of the other
  - *Interference:* one deletes a precondition of the other
  - *Competing needs:* **they have mutually exclusive preconditions**
- Otherwise they don't interfere with each other
  - Both may appear in a solution plan
- Two literals at the same state-level are mutex if
  - *Inconsistent support:* one is the negation of the other, **or all ways of achieving them are pairwise mutex**

Recursive propagation of mutexes

Example (continued)

- Augment the graph to indicate mutexes
- *carry* is mutex with the maintenance action for *garbage* (inconsistent effects)
- *dolly* is mutex with *wrap*
  - interference
- ~*quiet* is mutex with *present*
  - inconsistent support
- each of *cook* and *wrap* is mutex with a maintenance operation

state-level 0	action-level 1	state-level 1

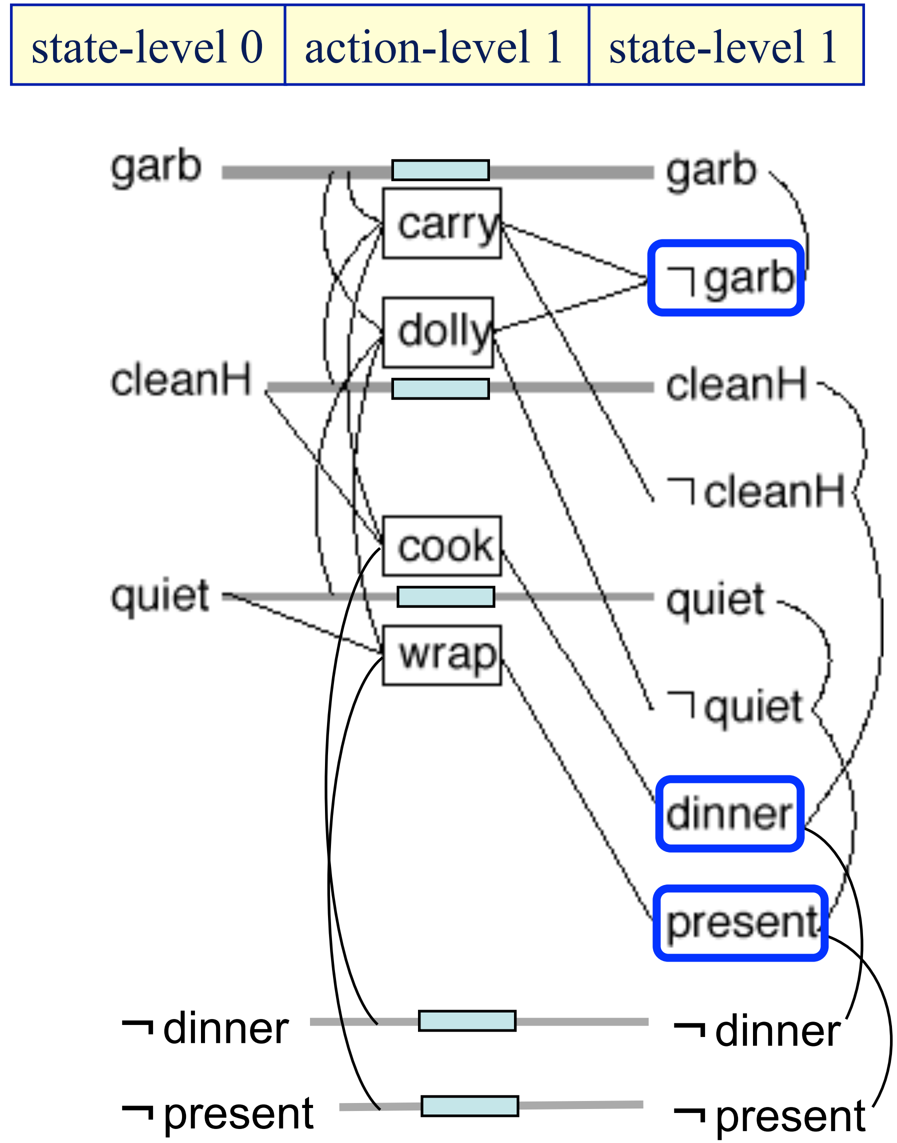


Action	**Preconditions**	**Effects**
cook()	cleanHands	dinner
wrap()	quiet	present
carry()	*none*	¬garbage, ¬cleanHands
dolly()	*none*	¬garbage, ¬quiet

Also have the maintenance actions

Example (continued)

- Check to see whether there's a possible solution
- Recall that the goal is
  - {¬*garbage, dinner, present*}
- Note that in state-level 1,
  - All of them are there
  - None are mutex with each other
- Thus, there's a chance that a plan exists
- Try to find it
  - Solution extraction



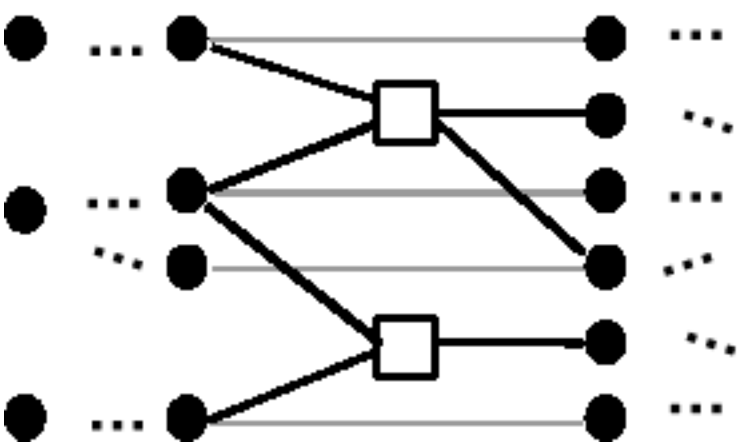
Solution Extraction

The set of goals we are trying to achieve

The level of the state s_j

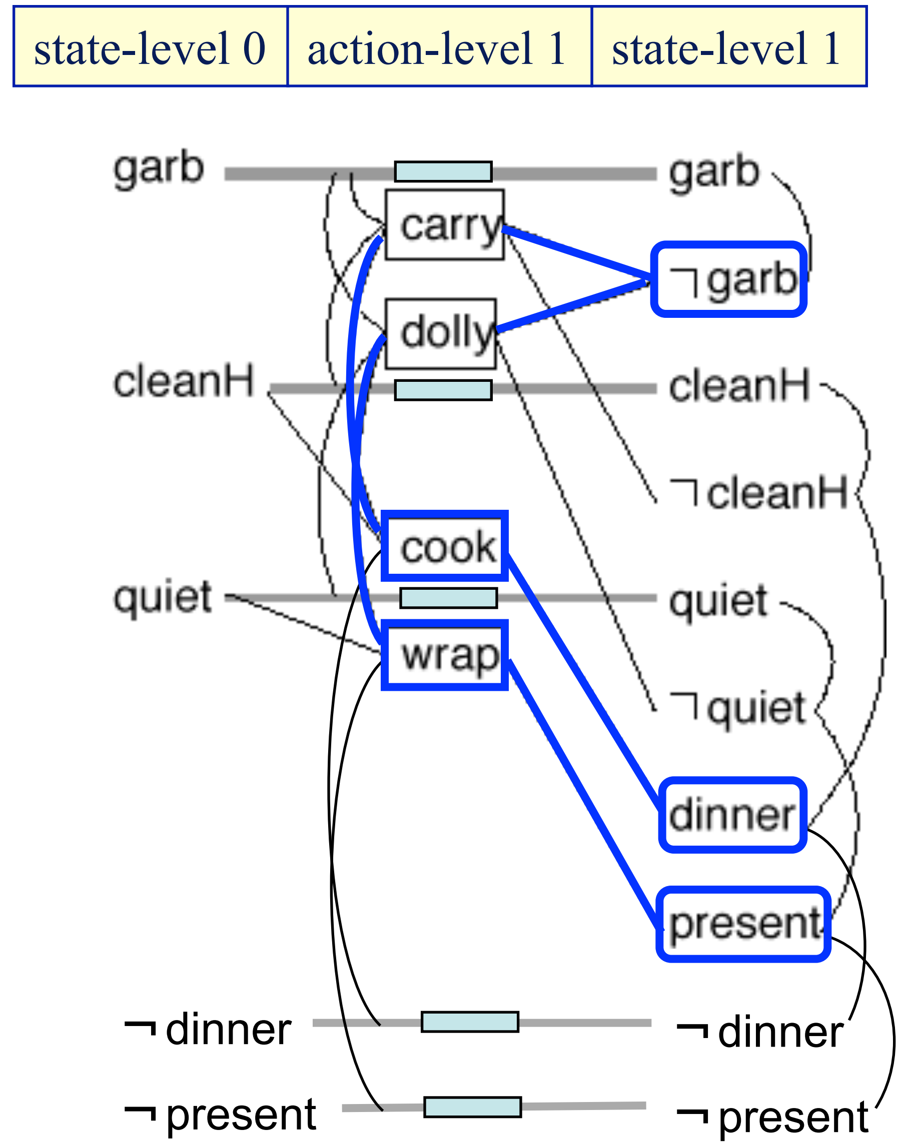
A real action or a maintenance action

procedure Solution-extraction(g,j)
  if j=0 then return the solution
  for each literal l in g
    nondeterministically choose an action to use in state s_{j-1} to achieve l
  if any pair of chosen actions are mutex
    then backtrack
  g' := {the preconditions of the chosen actions}
  Solution-extraction(g', j–1)
end Solution-extraction



Example (continued)

- Two sets of actions for the goals at state-level 1
- Neither of them works
  - Both sets contain actions that are mutex



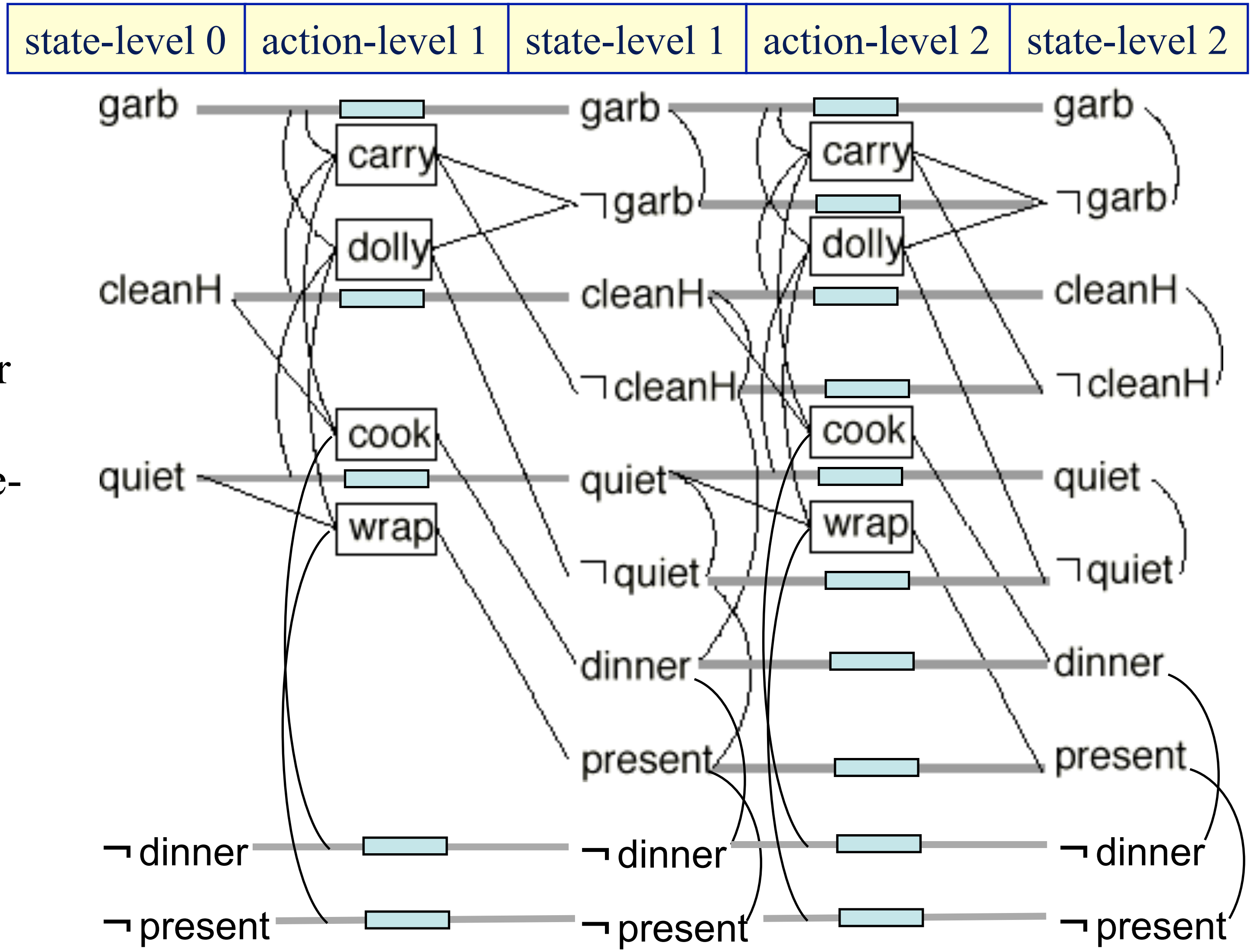
Recall what the algorithm does

procedure Graphplan:

- for $k = 0, 1, 2, \ldots$
  - *Graph expansion:*
    - create a "planning graph" that contains k "levels"
  - Check whether the planning graph satisfies a necessary (but insufficient) condition for plan existence
  - If it does, then
    - do *solution extraction:*
      - backward search, modified to consider only the actions in the planning graph
      - if we find a solution, then return it

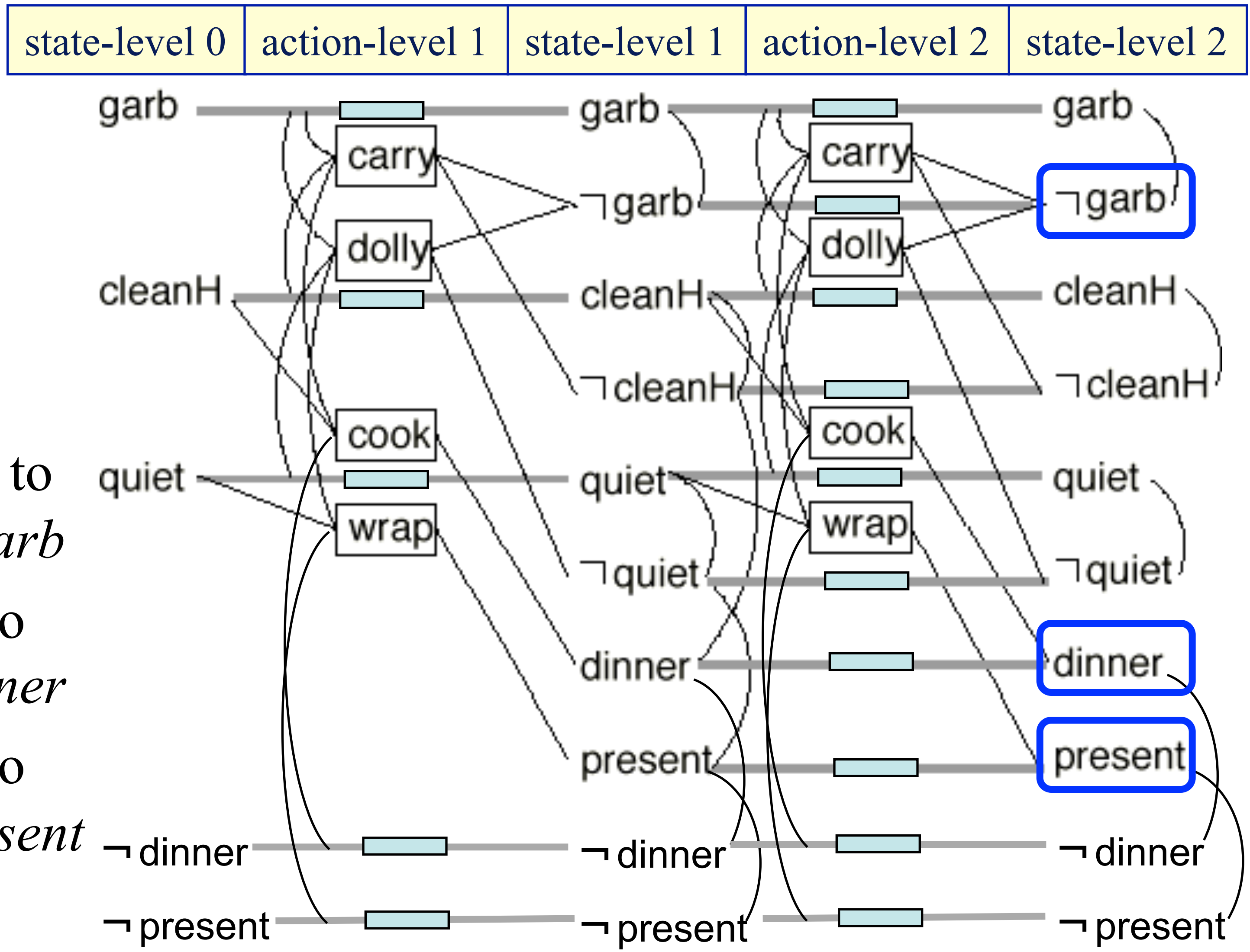
Example (continued)

- Go back and do more graph expansion
- Generate another action-level and another state-level



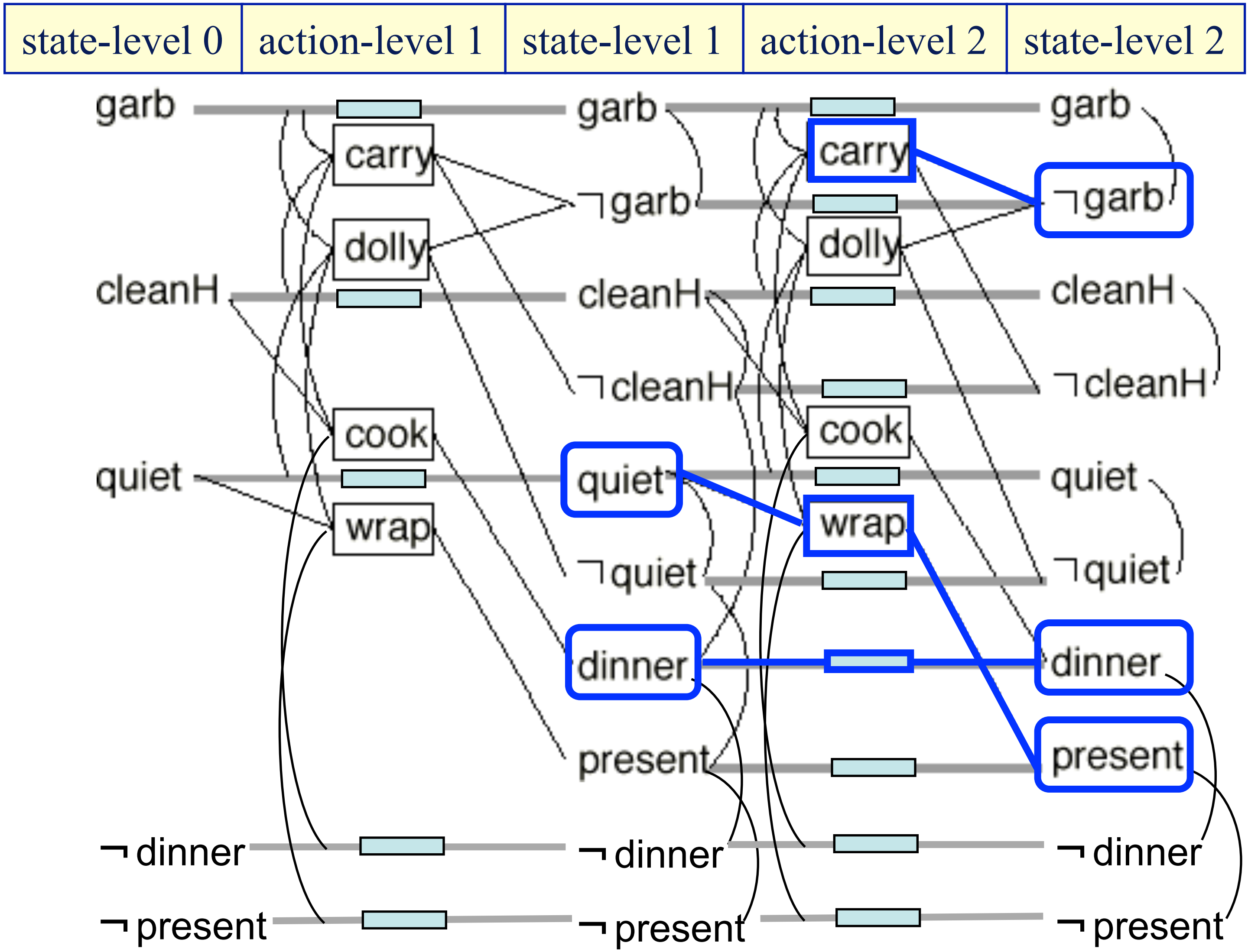
Example (continued)

- Solution extraction
- Twelve combinations at level 4
  - Three ways to achieve ¬*garb*
  - Two ways to achieve *dinner*
  - Two ways to achieve *present*



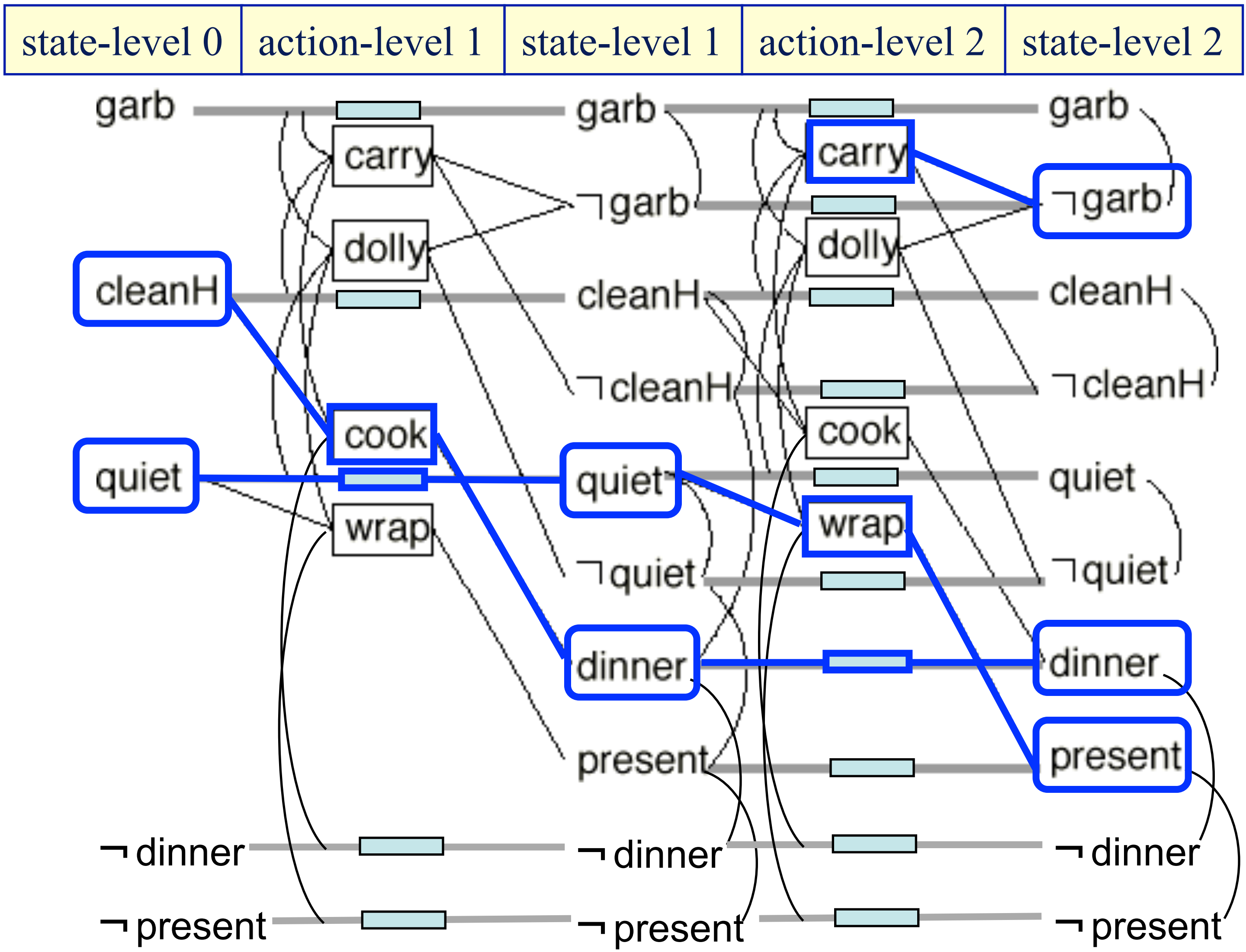
Example (continued)

- Several of the combinations look OK at level 2
- Here's one of them



Example (continued)

- Call Solution-Extraction recursively at level 2
- It succeeds
- Solution whose *parallel length* is 2



Comparison with Plan-Space Planning

- Advantage:
  - The backward-search part of Graphplan—which is the hard part—will only look at the actions in the planning graph
  - smaller search space than PSP; thus faster
- Disadvantage:
  - To generate the planning graph, Graphplan creates a huge number of ground atoms
  - Many of them may be irrelevant
- Can alleviate (but not eliminate) this problem by assigning data types to the variables and constants
  - Only instantiate variables to terms of the same data type
- For classical planning, the advantage outweighs the disadvantage
  - GraphPlan solves classical planning problems much faster than PSP