

Planning Graph Techniques

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Objectives

Specific Objectives

- Graph-based Planners (GP) techniques

Source

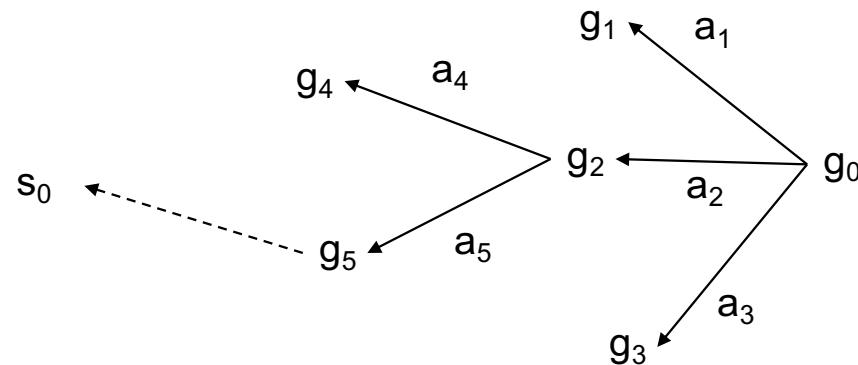
- Stuart Russell & Peter Norvig (2009). Artificial Intelligence: A Modern Approach. Chapter 10. (3rd Edition). Ed. Pearson.
- Dana Nau's slides for Automated Planning. Licensed under License <https://creativecommons.org/licenses/by-nc-sa/2.0/>
- Blum & Furst (1997). Fast planning through planning graph analysis. AI. 90:281-300.

Outline

- Motivation
- Procedure
- GP-based planners
- Baking example
- State reachability
- Comparison with PSP
- GP planners
- Todo example

Motivation (I)

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



Motivation (II)

- Reduce branching factor, how?
- 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

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Procedure: graph expansion

- for $k = 0, 1, 2, \dots$
 - *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

relaxed
problem

Procedure: solution extraction

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

The set of goals we are trying to achieve

The level of the state s_j

A real action or a maintenance action

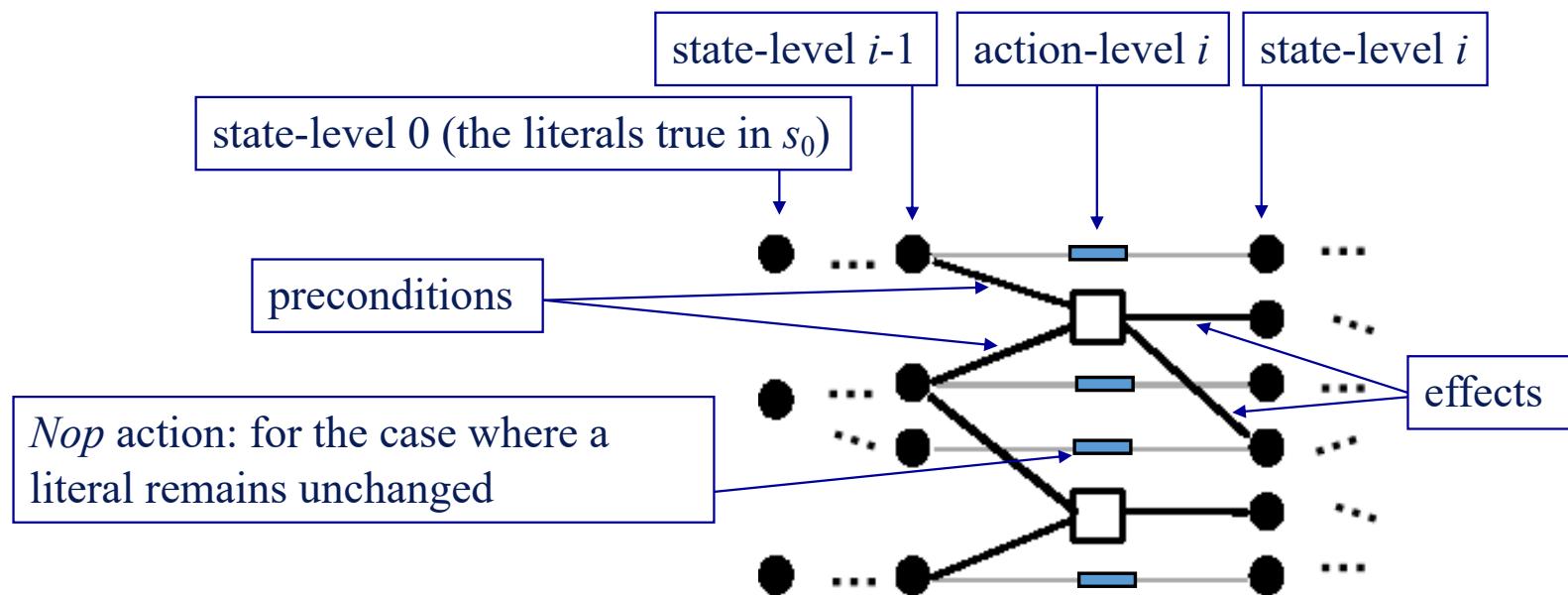
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Graph-based Planners (I)

- The search structure is based on a Planning Graph
- The graph is directed and layered:
 - 2 types of nodes:
 - Proposition nodes: even levels (initial state → o)
 - Action nodes: odd levels
 - 3 types of arcs: represent relationships between actions and propositions:
 - Added
 - Deleted
 - Nop

Graph-based Planners (II)



Graph-based Planners (III)

- GP algorithm works in two alternating phases
 - Expands (add layers) the planning graph until the last proposition layer satisfies the goal condition
 - Try to extract a valid plan (backtracking) from the planning graph
- If unsuccessful continues with the former phase, the planning graph is expanded again

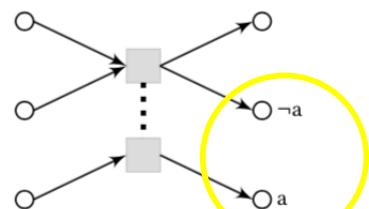
Graph-based Planners (IV)

- It is necessary to develop a reachability analysis to reduce the set of actions that are not supported in each layer
- Compatibility inferring mutual exclusion relations between incompatible **actions** is performed (mutex)
 - Have opposite effects
 - Incompatible preconditions
 - The effect of one action is the opposite of another
- Mutex between incompatible **propositions**: negated literals or all actions that can achieve them are mutex in the previous step

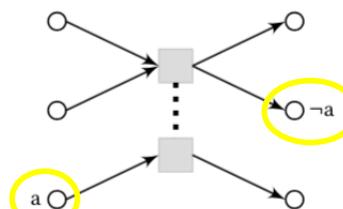
Graph-based Planners (V)

- 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 (may appear in solution)
- Two literals at the same state-level are mutex if
 - *Inconsistent support*: one is the negation of the other (contradiction), or all ways of achieving them are pairwise mutex

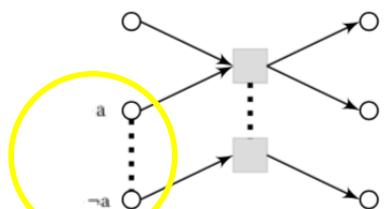
Graph-based Planners (VI)



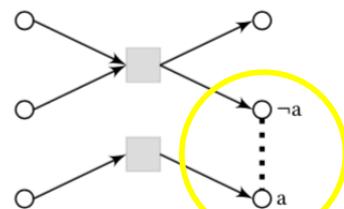
(a) Inconsistent effects



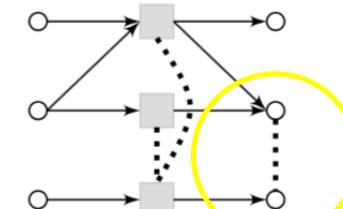
(b) Interference



(c) Competing needs



(d) Contradiction

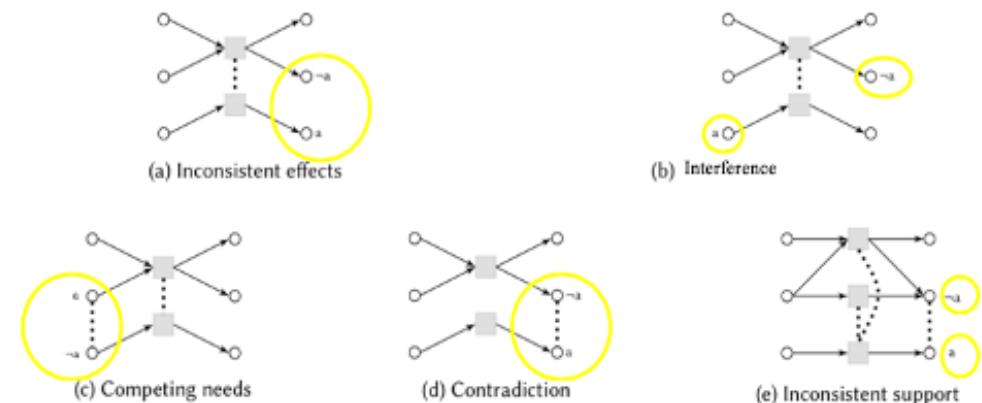
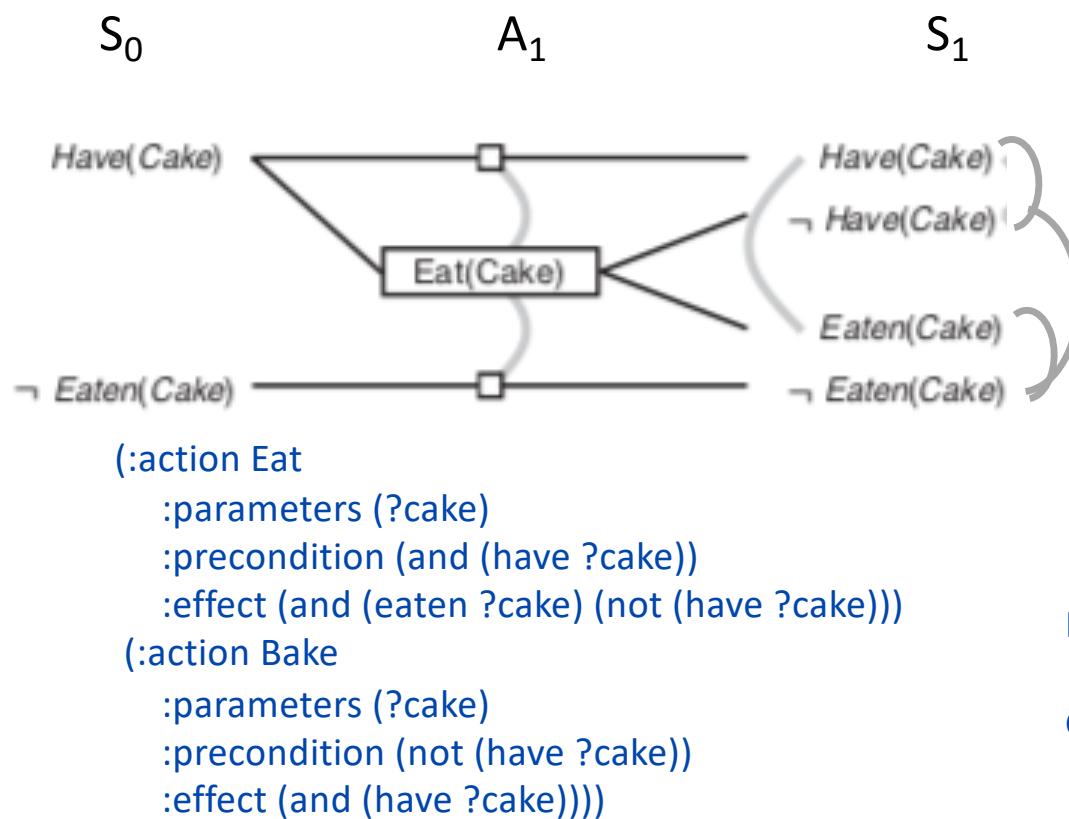


(e) Inconsistent support

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Example



Initial State

Have (cake) & (not (Eaten(cake)))

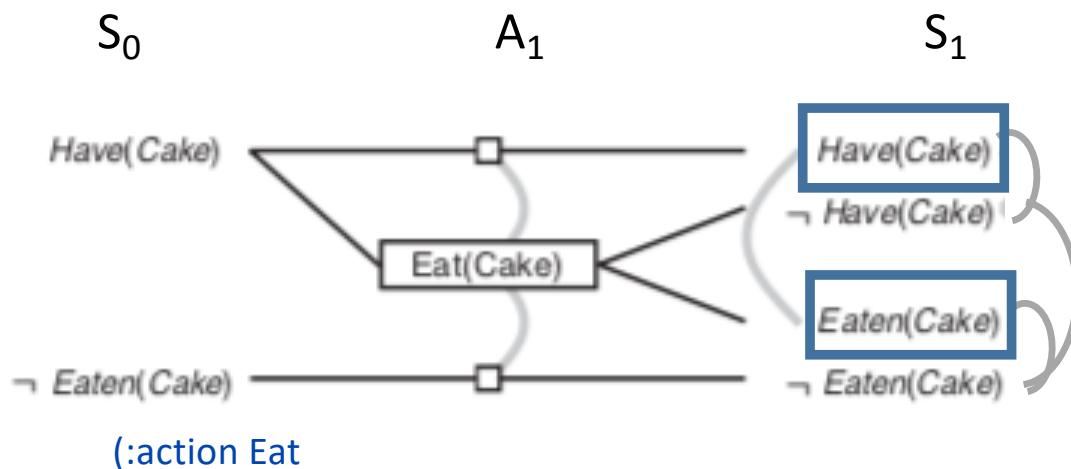
Goal

Eaten (cake) and Have (cake)

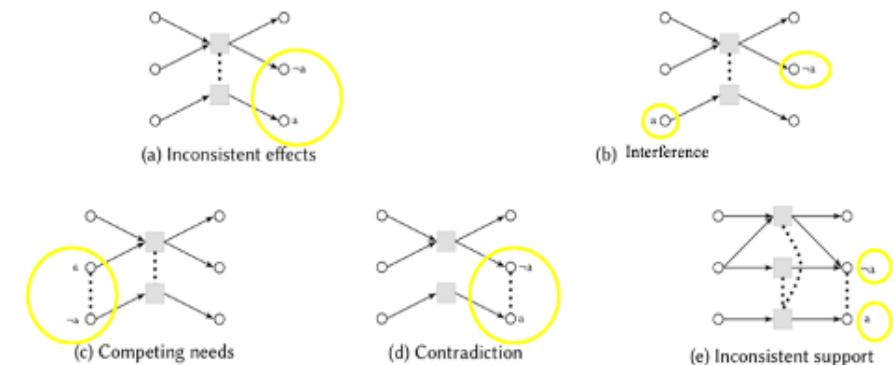
Example: mutex

- *Inconsistent effects:*
 - Eat(C) and no-op Have(C) because they disagree on the effect Have(C)
 - Eat(C) and no-op \neg Eaten(C) because they disagree on the effect \neg Eaten(C)
- *Contradiction:*
 - Have(C) and not Have(C),
 - Eaten(C) and not Eaten(C)
- *Inconsistent support:*
 - Have(C) and Eaten(C) are mutex because the only way of achieving Have(C), the no-op action, is mutex with the only way of achieving Eaten (C).
 - The same between *not Have(C)* and *not Eaten(C)*

Example



```
(:action Eat
  :parameters (?cake)
  :precondition (and (have ?cake))
  :effect (and (eaten ?cake) (not (have ?cake)))
(:action Bake
  :parameters (?cake)
  :precondition (not (have ?cake))
  :effect (and (have ?cake))))
```



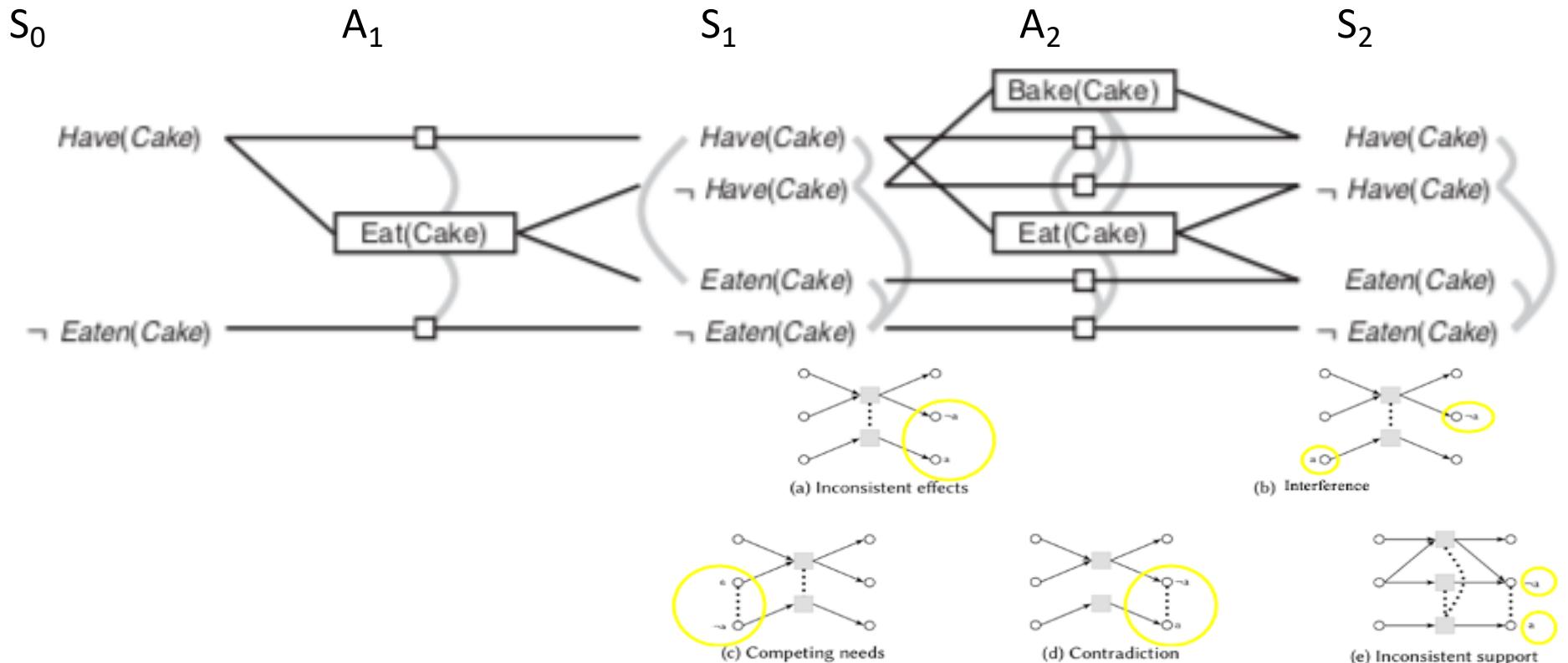
Initial State

Have (cake) & (not (Eaten(cake)))

Goal

Eaten (cake) and Have (cake)

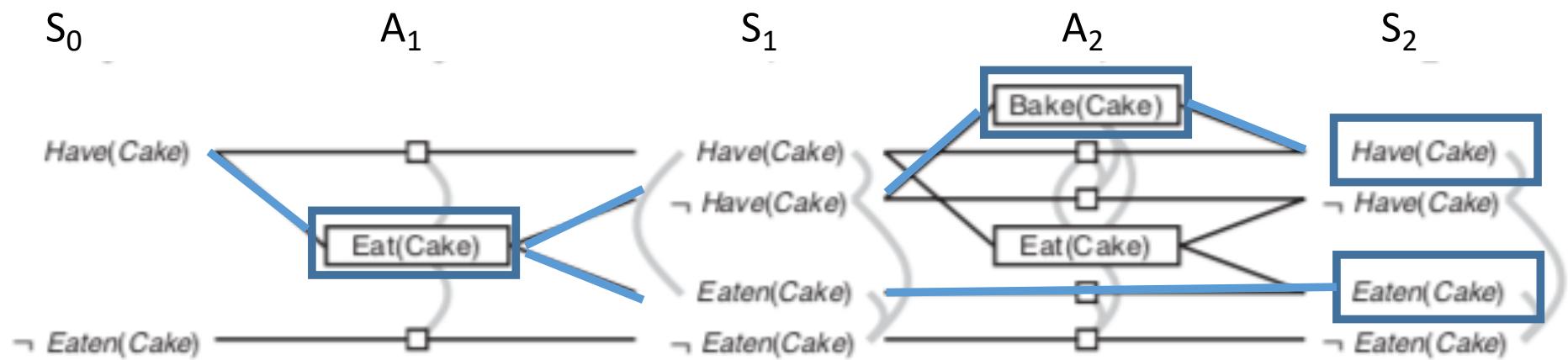
Example



Example: mutex

- *Competing needs:*
 - $\text{Bake}(C)$ and $\text{Eat}(C)$ are mutex because they compete on the value of the $\text{Have}(C)$ precondition
- *Inconsistent effects:*
 - $\text{Eat}(C)$ and no-op $\text{Have}(C)$ because they disagree on the effect $\text{Have}(C)$
 - $\text{Eat}(C)$ and no-op $\neg \text{Eaten}(C)$ because they disagree on the effect $\neg \text{Eaten}(C)$
 - No-op $\neg \text{Eaten}(C)$ and $\text{Eaten}(C)$ (the same with $\text{Hand}(C)$)
 - $\text{Bake}(C)$ and no-op $\neg \text{Have}(C)$ because they disagree on the effect $\text{Have}(C)$
- *Contradiction:* $\text{Have}(C)$ and not $\text{Have}(C)$, $\text{Eaten}(C)$ and not $\text{Eaten}(C)$
- Note that in S2 $\text{Have}(C)$ and $\text{Eaten}(C)$ are not mutex since we can achieve $\text{Have}(C)$ with Bake

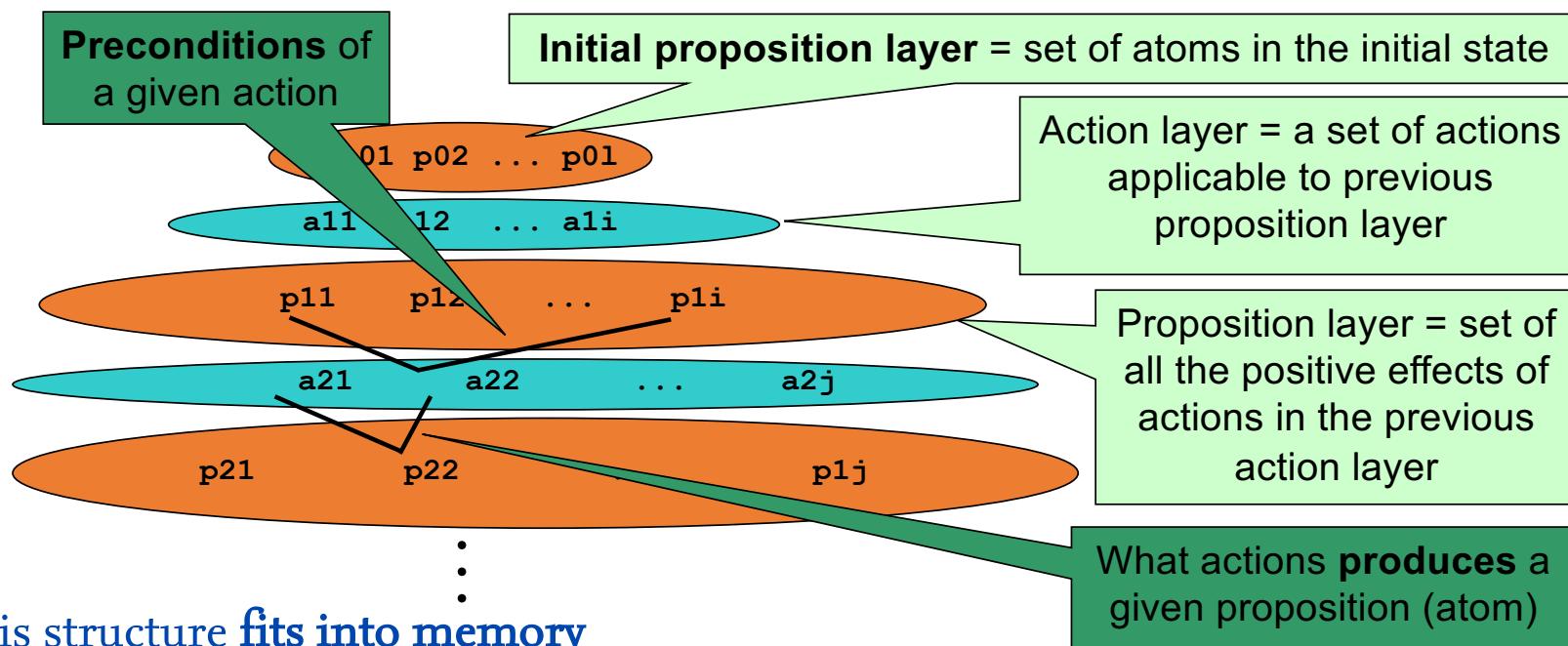
Example: Solution Extraction



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State reachability



- this structure **fits into memory**
 - every **proposition** knows its origin in the previous action layer
 - every **action** knows its precondition in the previous proposition layer

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Comparison with Plan-Space Planning

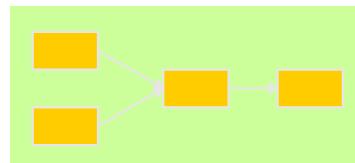
- Advantage:
 - The backward-search part of GP—which is the hard part—will only look at the actions in the planning graph
 - Smaller search space than PSP; thus faster
- Disadvantage:
 - To generate the planning graph, GP creates a huge number of ground atoms
 - Many of them may be irrelevant
 - Can 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
 - GP solves classical planning problems much faster than PSP

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GP Planners

- A big number of descendent
 - SGP: contingent planner
 - TGP: includes temporal reasoning
 - IPP: allows resource reasoning
 - TPSYS: combines GP & TGP
 - SAPA: uses a set of heuristics based on distances to control the search
 - STAN: extracts admissible heuristics from a domain analysis tool called TIM
 - LPG: combines GP & SAT
 - ...
- Output



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Example II

- Suppose you want to prepare dinner

$s_o = \{\text{garbage}, \text{cleanHands}, \text{quiet}\}$

$g = \{\text{dinner}, \text{present}, \neg\text{garbage}\}$

Action	Preconditions	Effects
cook()	cleanHands	dinner
wrap()	quiet	present
carry()	<i>none</i>	$\neg\text{garbage}, \neg\text{cleanHands}$
dolly()	<i>none</i>	$\neg\text{garbage}, \neg\text{quiet}$

- Specify one case of mutex and the level when it occurs:
 - Interference
 - Inconsistent support

Example II

- Suppose you want to prepare dinner

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Let's do a Socrative!!!

- Specify one case of mutex and the level when it occurs:
 - Interference
 - Inconsistent support