Planning

COMP3431 Robot Software Architectures

Planning

A planner finds sequences of actions that will cause transitions from an initial state through intermediates states to a goal state

Actions

- Transitions from one state to the next are achieved by *actions*.
- Must specify how actions work
- Must work out correct sequence of actions to reach goal

Action Models

- Action action(<parameters>)
  - PRECOND: <conditions that must be true to apply this actions>
  - EFFECTS: <conditions that become true or false after executing the action>

Action Example

Action Fly(p, from, to)

PRECOND: Plane(p) $\wedge$ At(p, from) $\wedge$ Airport(from) $\wedge$ Airport(to)

EFFECT: $\neg$At(p, from) $\wedge$ At(p, to))

- positive and negative literals in effects can be separated into an *add list* and and *delete list*

Example

Init: $Airport(MEL) \wedge Airport(SYD) \wedge Plane(P_1) \wedge Plane(P_2) \wedge Cargo(C_1) \wedge Cargo(C_2) \wedge$
$At(C_1, SYD) \wedge At(C_2, MEL) \wedge At(P_1, SYD) \wedge At(P_2, MEL)$

Goal: $At(C_1, MEL) \wedge At(C_2, SYD)$

Action Load(c, p, a)

PRECOND: $At(c, a) \wedge At(p, a) \wedge Cargo(c) \wedge Plane(p) \wedge Airport(a)$

EFFECT: $\neg At(c, a) \wedge In(c, p)$

Action Unload(c, p, a)

PRECOND: $In(c, p) \wedge At(p, a) \wedge Cargo(c) \wedge Plane(p) \wedge Airport(a)$

EFFECT: $At(c, a) \wedge \neg In(c, p)$

Action Fly(p, from, to)

PRECOND: $At(p, from) \wedge Plane(p) \wedge Airport(from) \wedge Airport(to)$

EFFECT: $\neg At(p, from) \wedge At(p, to)$

$Load(C_1, P_1, SYD)$

$Fly(P_1, SYD, MEL)$

$Unload(C_1, P_1, MEL)$

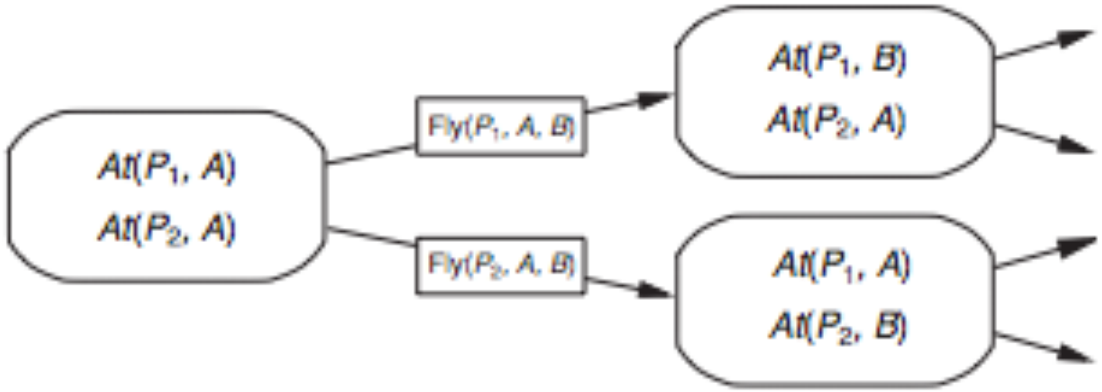
$Load(C_2, P_2, MEL)$

$Fly(P_2, MEL, SYD)$

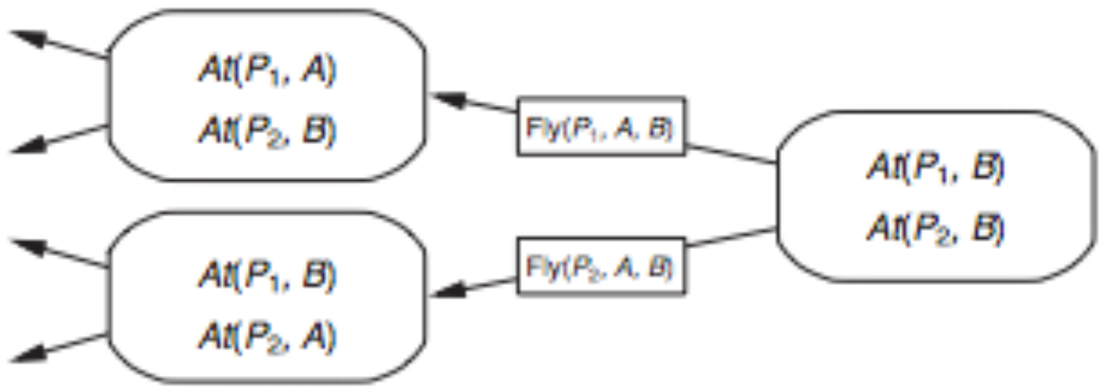
$Unload(C_2, P_2, SYD)$

Progression and Regression

- Forward Search



- Backward Search



Backward Regression

$$g' = (g - Add(a)) \cup Precond(a)$$

- g' is the regression from goal g over action a
- I.e. going backwards from g, we look for an action, a, that has preconditions and effects that satisfy g'

Planning and TR Programs

Action :-

goal → do_nothing

precond → action

....

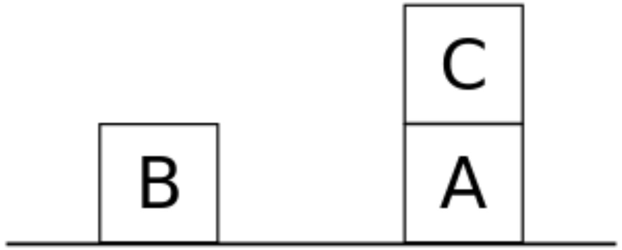
start → action

- TR Programs list actions from a plan, keeping preconditions
- Each rule below should be the regression of the rule above

Sussman's Anomaly

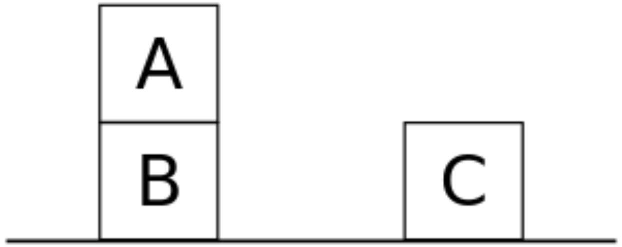
- Goal: On(A, B) ∧ On(B, C)

- Try achieving On(A, B) first



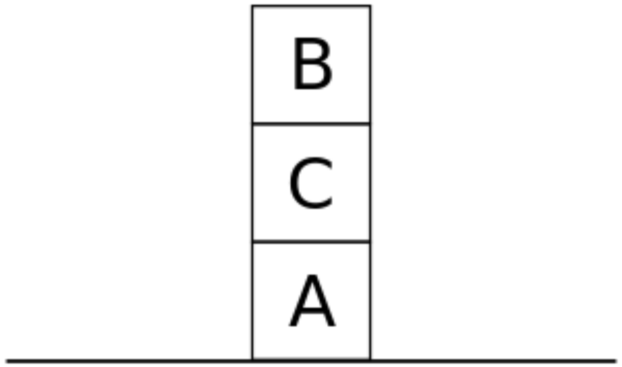
[move(c,a,floor), move(a,floor,b), **move(a,b,floor)**, move(b,floor,c)]

- Trying On(B, C) first



[move(b,floor,c), **move(b,c,floor)**, move(c,a,floor), move(a,floor,b)]

- Should be:



[move(c,a,floor), move(b,floor,c), move(a,floor,b)]

WARPLAN

Warren, D. H. D. (1974). *Warplan: A system for generating plans.* Memo No. 76, Department of Computational Logic, University of Edinburgh.

- WARPLAN tries to interleave actions by protecting goals.
  - Achieve on(A,B): [move(c,a,floor), move(a,floor,b)]
  - Protect on(A,B)
  - Now try on(B,C) by appending actions to end of plan
    - If it tries to undo a protected goal, move backwards through plan and try to slot new plan in.

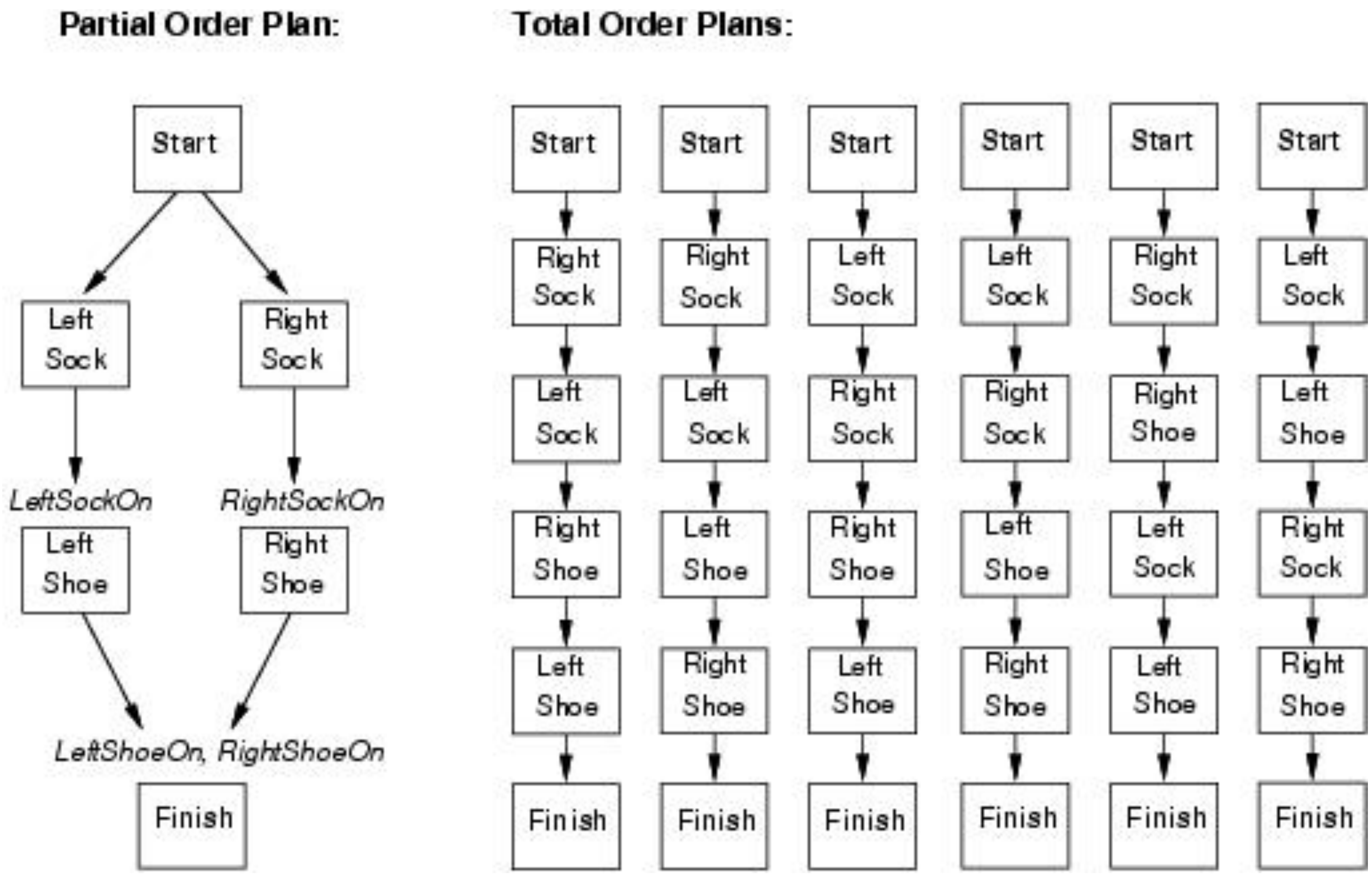
Warplan

- [move(c,a,floor), move(a,floor,b), **move(a,b,floor)**, ..]
- [move(c,a,floor), .., move(a,floor,b)]

Try inserting plan for on(B,C) here

- check that goals before and after are preserved

Partially Ordered Plans



Partial-Order Planning

Init: Tire(Flat) ∧ Tire(Spare) ∧ At(Flat, Axle) ∧ At(Spare, Boot)

Goal: At (Spare, Axle)

Action Remove(obj, loc)

PRECOND: At(obj, loc)

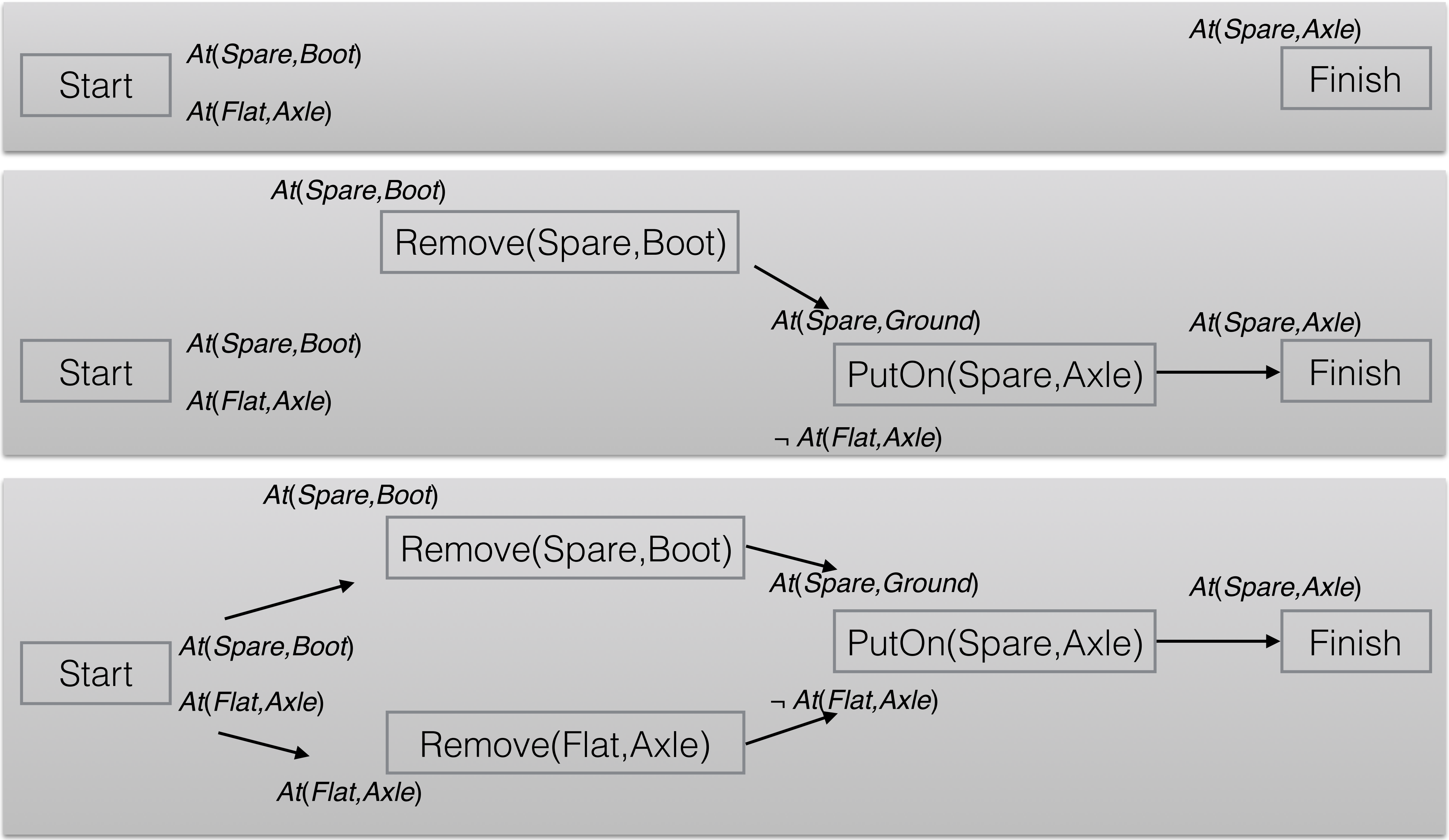
EFFECT: ¬ At(obj, loc) ∧ At(obj, Ground)

Action PutOn(t, Axle)

PRECOND: Tire(t) ∧ At(t, Ground) ∧ ¬ At(Flat, Axle)

EFFECT: ¬ At(t, Ground) ∧ At(t, Axle)

Partial-Order Planning



Forward Planning

- Forward planners are now among the best.
- Use heuristics to estimate costs
- Possible to use heuristic search, like A*, to reduce branching factor.

Planning graphs

- Used to achieve better heuristic estimates.
  - A solution can also directly extracted using GRAPHPLAN.
- Consists of a sequence of levels that correspond to time steps in the plan.
  - Level 0 is the initial state.
  - Each level consists of a set of literals and a set of actions.
    - Literals = all those that could be true at that time step, depending upon the actions executed at the preceding time step.
    - Actions = all those actions that could have their preconditions satisfied at that time step, depending on which of the literals actually hold.

Planning graphs

- Records only a restricted subset of possible negative interactions among actions
- They work only for propositional problems.

Example

Init: Have (Cake)

Goal: Have(Cake) $\wedge$ Eaten(Cake)

Action: Eat (Cake)

PRECOND: Have(Cake)

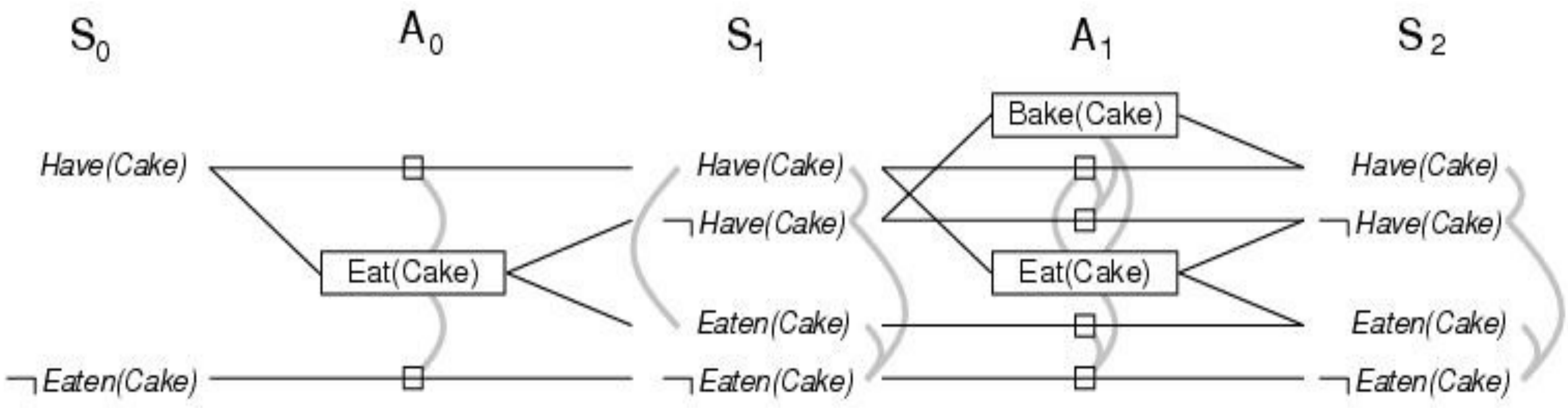
EFFECT: $\neg$ Have(Cake) $\wedge$ Eaten(Cake)

Action: Bake (Cake)

PRECOND: $\neg$ Have(Cake)

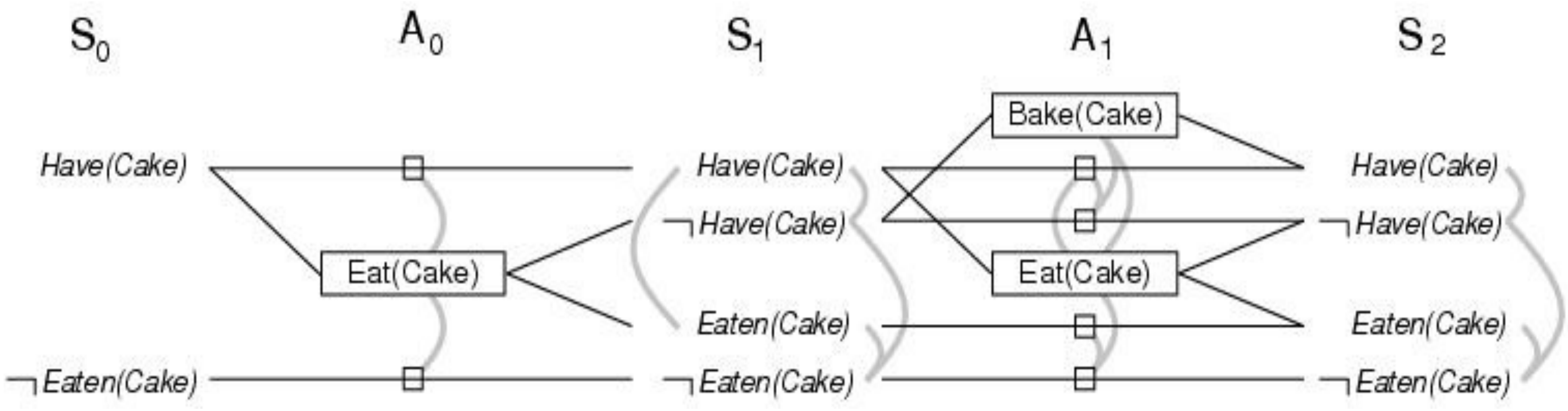
EFFECT: Have(Cake)

Cake example



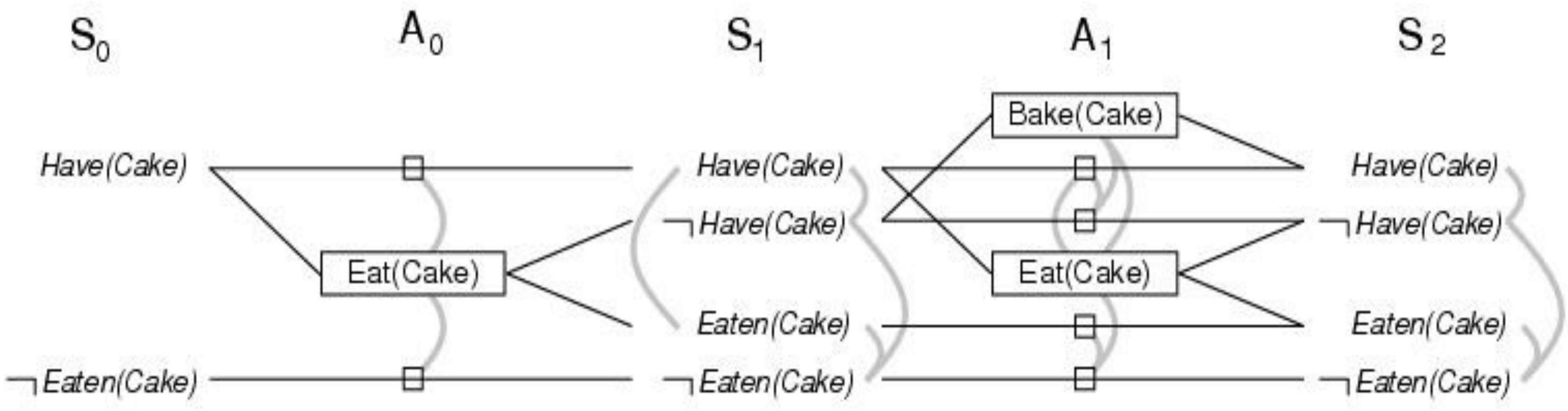
- Start at level S0 and determine action level A0 and next level S1.
  - A0 >> all actions whose preconditions are satisfied in the previous level.
  - Connect precond and effect of actions S0 --> S1
  - Inaction is represented by persistence actions.
- Level A0 contains the actions that could occur
  - Conflicts between actions are represented by mutex links

Cake example



- Level S1 contains all literals that could result from picking any subset of actions in A0
  - Conflicts between literals that can not occur together (as a consequence of the selection action) are represented by mutex links.
  - S1 defines multiple states and the mutex links are the constraints that define this set of states.
- Continue until two consecutive levels are identical: leveled off
  - Or contain the same amount of literals (explanation follows later)

Cake example



- A mutex relation holds between **two actions** when:
  - Inconsistent effects: one action negates the effect of another.
  - Interference: one of the effects of one action is the negation of a precondition of the other.
  - Competing needs: one of the preconditions of one action is mutually exclusive with the precondition of the other.
- A mutex relation holds between **two literals** when (inconsistent support):
  - If one is the negation of the other OR
  - if each possible action pair that could achieve the literals is mutex.

PG and heuristic estimation

- PG's provide information about the problem
  - A literal that does not appear in the final level of the graph cannot be achieved by any plan.
    - Useful for backward search (cost = inf).
  - Level of appearance can be used as cost estimate of achieving any goal literals = level cost.
  - Small problem: several actions can occur
    - Restrict to one action using serial PG (add mutex links between every pair of actions, except persistence actions).
  - Cost of a conjunction of goals? Max-level, sum-level and set-level heuristics.
- PG is a relaxed problem.

The GRAPHPLAN Algorithm

How to extract a solution directly from the PG

```
function GRAPHPLAN(problem) return solution or failure
    graph ← INITIAL-PLANNING-GRAPH(problem)
    goals ← GOALS[problem]
    loop
     if goals all non-mutex in last level of graph then
        solution ← EXTRACT-SOLUTION(graph, goals, LENGTH(graph))
        if solution ≠failure then return solution
        else if NO-SOLUTION-POSSIBLE(graph) then return failure
     graph ← EXPAND-GRAPH(graph, problem)
```

Example: Spare tire problem

Init(At(Flat, Axle) ∧ At(Spare,Trunk))

Goal(At(Spare,Axle))

Action(Remove(Spare,Trunk)

PRECOND: At(Spare,Trunk)

EFFECT: ¬At(Spare,Trunk) ∧ At(Spare,Ground))

Action(Remove(Flat,Axle)

PRECOND: At(Flat,Axle)

EFFECT: ¬At(Flat,Axle) ∧ At(Flat,Ground))

Action(PutOn(Spare,Axle)

PRECOND: At(Spare,Groundp) ∧ ¬At(Flat,Axle)

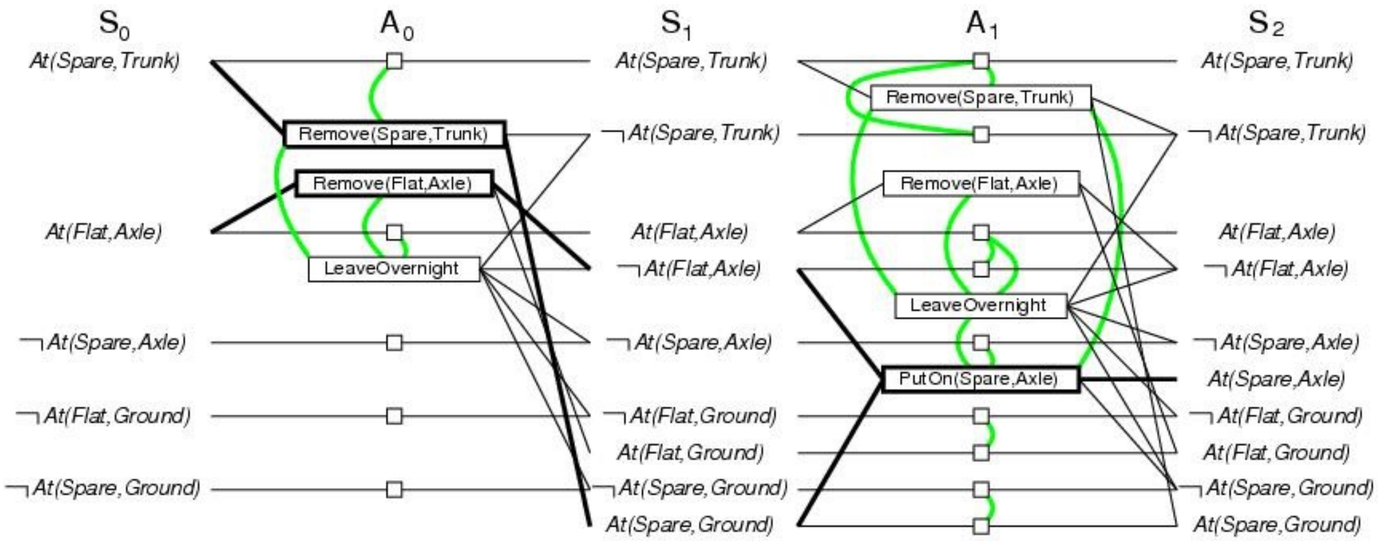
EFFECT: At(Spare,Axle) ∧ ¬At(Spare,Ground))

Action(LeaveOvernight

PRECOND:

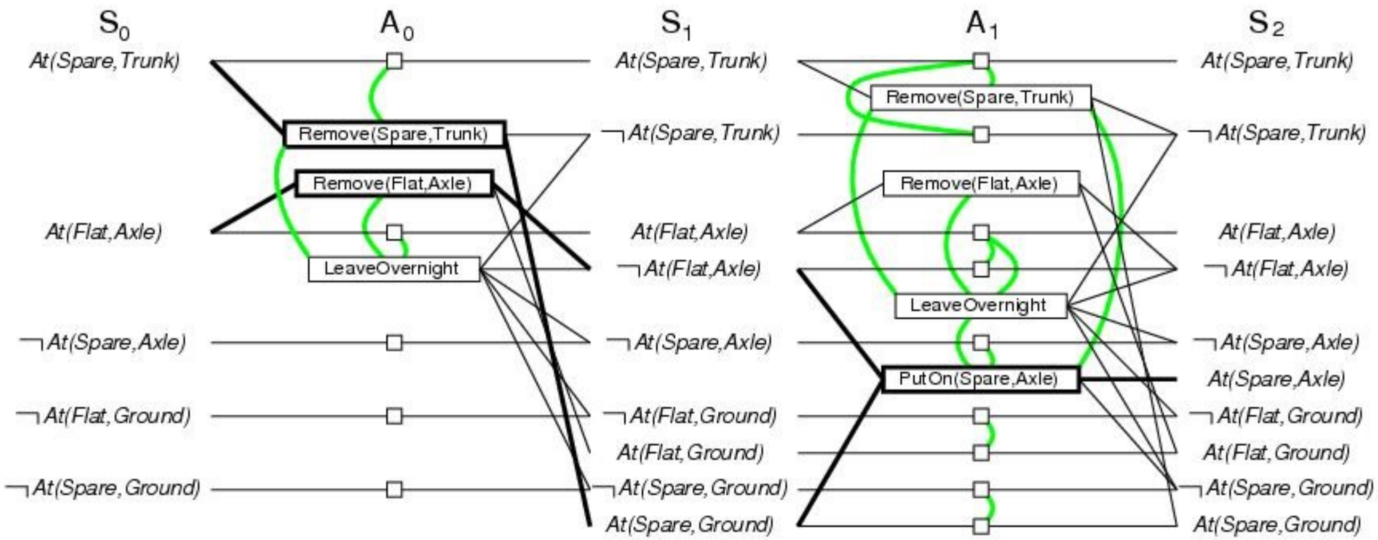
EFFECT: ¬ At(Spare,Ground) ∧ ¬ At(Spare,Axle) ∧ ¬ At(Spare,trunk) ∧ ¬ At(Flat,Ground) ∧ ¬ At(Flat,Axle))

GRAPHPLAN example



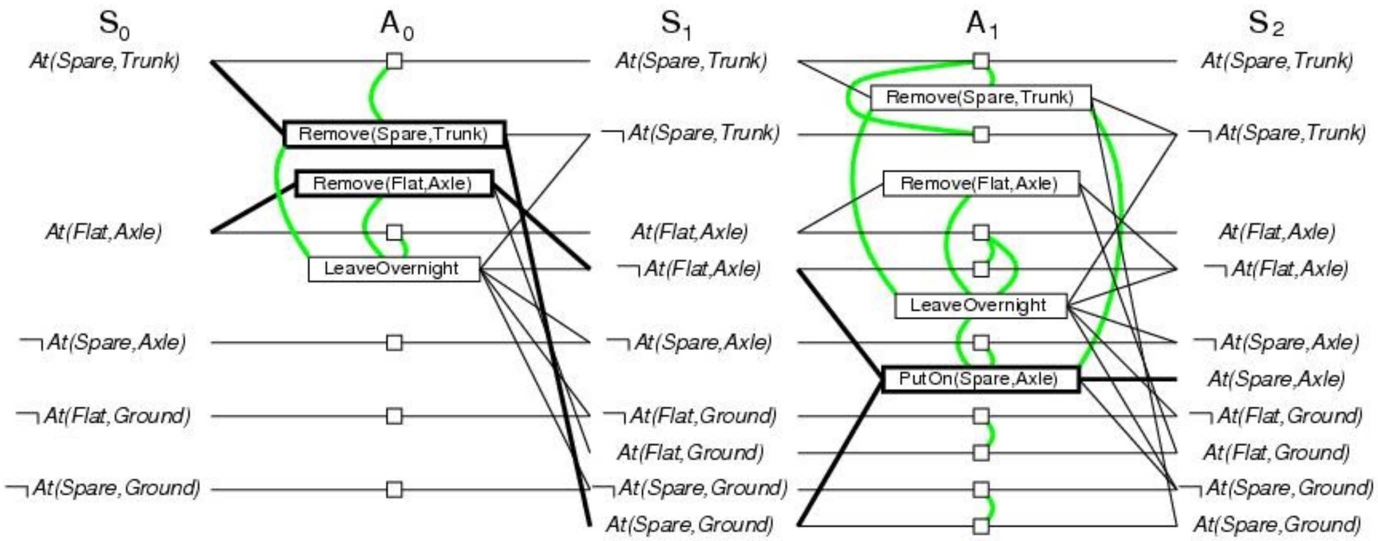
- Initially the plan consist of literals from the initial state and literals from the closed world assumption (S0).
- Add actions whose preconditions are satisfied by EXPAND-GRAPH (A0)
- Also add persistence actions and mutex relations.
- Add the effects at level S1
- Repeat until goal is in level Si

GRAPHPLAN example



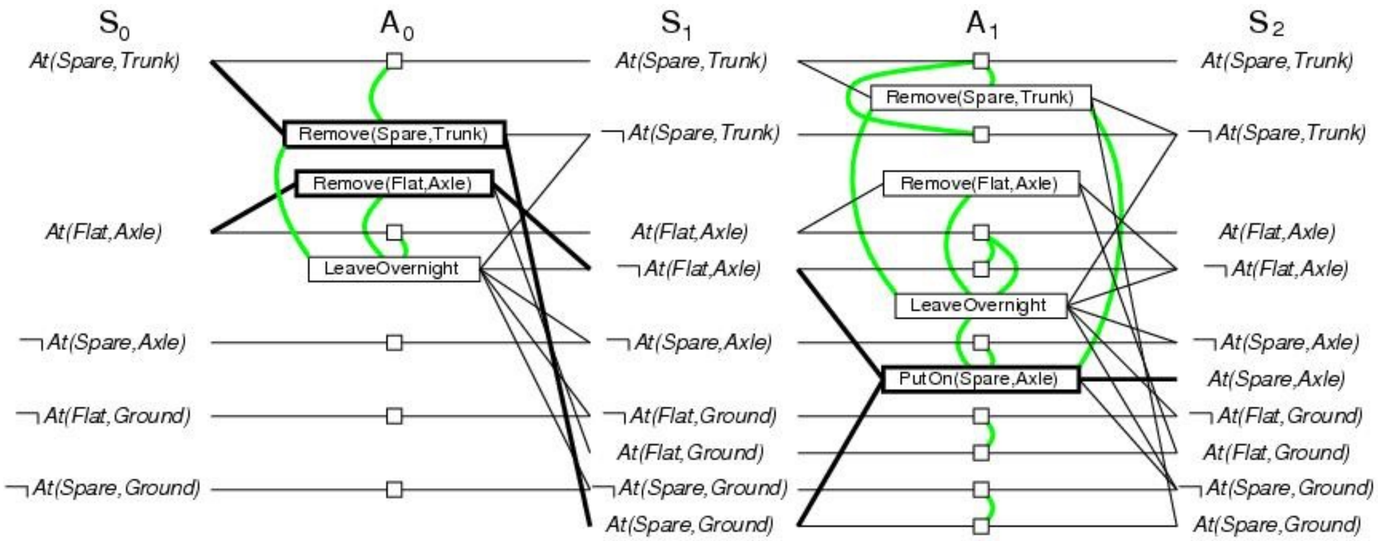
- EXPAND-GRAPH also looks for mutex relations
  - Inconsistent effects
    - E.g. Remove(Spare, Trunk) and LeaveOverNight due to At(Spare,Ground) and **not** At(Spare, Ground)
  - Interference
    - E.g. Remove(Flat, Axle) and LeaveOverNight At(Flat, Axle) as PRECOND and **not** At(Flat,Axle) as EFFECT
  - Competing needs
    - E.g. PutOn(Spare,Axle) and Remove(Flat, Axle) due to At(Flat.Axle) and **not** At(Flat, Axle)
  - Inconsistent support
    - E.g. in S2, At(Spare,Axle) and At(Flat,Axle)

GRAPHPLAN example



- In S2, the goal literals exist and are not mutex with any other
  - Solution might exist and EXTRACT-SOLUTION will try to find it
- EXTRACT-SOLUTION can use Boolean CSP to solve the problem or a search process:
  - Initial state = last level of PG and goal goals of planning problem
  - Actions = select any set of non-conflicting actions that cover the goals in the state
  - Goal = reach level S0 such that all goals are satisfied
  - Cost = 1 for each action.

GRAPHPLAN example



- Termination? YES
- PG are monotonically increasing or decreasing:
  - Literals increase monotonically
  - Actions increase monotonically
  - Mutexes decrease monotonically
- Because of these properties and because there is a finite number of actions and literals, every PG will eventually level off !

Extracting the Plan

- Heuristic forward search planners, like Lama, use A* to find path from start to goal
    - Cost is based on level in graph
- Answer Set Programming is a very efficient type of constraint solving that is fast but only works on propositional representations