BLG435E
Artificial Intelligence

Lecture 9: Planning

Outline

- The Planning problem
- Planning with State-space search
- Partial-order planning

What is Planning

- Generate sequences of actions to perform tasks and achieve objectives.
  - States, actions and goals
- Search for solution over abstract space of plans.
- Classical planning environment: fully observable, deterministic, finite, static and discrete.
- Assists humans in practical applications
  - design and manufacturing
  - games
  - space exploration
  - military operations

Difficulty of real-world problems

- Assume a problem-solving agent using some search method …
  - Which actions are relevant?
    - Exhaustive search vs. backward search
  - What is a good heuristic function?
    - Good estimate of the cost of the state?
    - Problem-dependent vs, -independent
  - How to decompose the problem?
    - Most real-world problems are ***nearly*** decomposable.

Planning language

- What is a good language?
  - **Expressive** enough to describe a wide variety of problems.
  - **Restrictive** enough to allow efficient algorithms to operate on it.
  - Planning algorithm should be able to take advantage of the logical structure of the problem.
- STRIPS and ADL

General language features

- Representation of states
  - Decompose the world in logical conditions and represent a state as a *conjunction of positive literals.*
    - Propositional literals: *Poor* $\wedge$ *Unknown*
    - FO-literals (ground and function-free): *At(Plane1, Melbourne)* $\wedge$ *At(Plane2, Sydney)*
  - Closed world assumption
- Representation of goals
  - Partially specified state and represented as a *conjunction of positive ground literals*
    - *Poor* $\wedge$ *Unknown* $\wedge$ *At(P2, Tahiti)*
  - A goal is *satisfied* if the state contains all literals in the goal.

General language features

- Representations of actions
  - Action = PRECOND + EFFECT

    Action(Fly(p,from, to),

    PRECOND: At(p,from) ∧ Plane(p) ∧ Airport(from) ∧ Airport(to)

    EFFECT: ¬AT(p,from) ∧ At(p,to))

  = action schema (p, from, to: need to be instantiated)
    - Action name and parameter list
    - Precondition (conj. of function-free positive literals)
    - Effect (conj of function-free literals and P is True and not P is false)
  - Add-list vs delete-list in Effect

Language semantics?

- How do actions affect states?
  - An action is applicable in any state that satisfies the precondition.
  - FO action schema applicability involves a substitution θ for the variables in the PRECOND.

    At(P1,JFK) ∧ At(P2,SFO) ∧ Plane(P1) ∧ Plane(P2) ∧ Airport(JFK) ∧ Airport(SFO)

    Satisfies : *At(p,from) ∧ Plane(p) ∧ Airport(from) ∧ Airport(to)*
    With θ ={*p/P1,from/JFK,to/SFO*}

    Thus the action *Fly(P1,JFK, SFO)* is applicable.

Language semantics?

- The result of executing action a in state s is the state s'
  - s' is the same as s except
    - Any positive literal *P* in the effect of *a* is added to *s'*
    - Any negative literal ¬*P* is removed from *s'*

    EFFECT: ¬AT(p,from) ∧ At(p,to):

    At(P1,SFO) ∧ At(P2,SFO) ∧ Plane(P1) ∧ Plane(P2) ∧ Airport(JFK) ∧ Airport(SFO)

  - STRIPS assumption: (avoids representational frame problem)

    every literal NOT in the effect remains unchanged

Expressiveness and extensions

- STRIPS is simplified
  - Important limit: function-free literals
    - Allows for propositional representation
    - Function symbols lead to infinitely many states and actions
- Recent extension: Action Description language (ADL)

  Action(Fly(p:Plane, from: Airport, to: Airport),
  PRECOND: At(p,from) ∧ (from ≠ to)
  EFFECT: ¬At(p,from) ∧ At(p,to))

  Standardization : *Planning domain definition language (PDDL)*

Example: air cargo transport

Init(At(C1, SFO) ∧ At(C2,JFK) ∧ At(P1,SFO) ∧ At(P2,JFK) ∧ Cargo(C1) ∧ Cargo(C2) ∧ Plane(P1) ∧ Plane(P2) ∧ Airport(JFK) ∧ Airport(SFO))

Goal(At(C1,JFK) ∧ At(C2,SFO))

Action(Load(c,p,a)
PRECOND: *At(c,a) ∧At(p,a) ∧Cargo(c) ∧Plane(p) ∧Airport(a)*
EFFECT: *¬At(c,a) ∧In(c,p))*

Action(Unload(c,p,a)
PRECOND: *In(c,p) ∧At(p,a) ∧Cargo(c) ∧Plane(p) ∧Airport(a)*
EFFECT: *At(c,a) ∧ ¬In(c,p))*

Action(Fly(p,from,to)
PRECOND: *At(p,from) ∧Plane(p) ∧Airport(from) ∧Airport(to)*
EFFECT: *¬ At(p,from) ∧ At(p,to))*

[Load(C1,P1,SFO), Fly(P1,SFO,JFK), Load(C2,P2,JFK), Fly(P2,JFK,SFO)]

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,Ground) ∧¬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))*

This example goes beyond STRIPS: negative literal in pre-condition (ADL description)

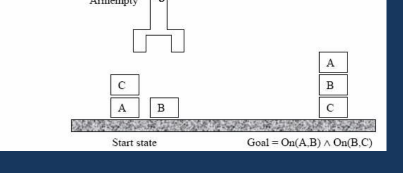
Example Spare tire problem - PDDL

Init(*Tire*(*Flat*) $\wedge$ *Tire*(*Spare*) $\wedge$ *At*(*Flat*, *Axle*) $\wedge$ *At*(*Spare*, *Trunk*))
Goal(*At*(*Spare*, *Axle*))
Action(*Remove*(*obj*, *loc*),
  PRECOND: *At*(*obj*, *loc*)
  EFFECT: $\neg$ *At*(*obj*, *loc*) $\wedge$ *At*(*obj*, *Ground*))
Action(*PutOn*(*t*, *Axle*),
  PRECOND: *Tire*(*t*) $\wedge$ *At*(*t*, *Ground*) $\wedge$ $\neg$ *At*(*Flat*, *Axle*)
  EFFECT: $\neg$ *At*(*t*, *Ground*) $\wedge$ *At*(*t*, *Axle*))
Action(*LeaveOvernight*,
  PRECOND:
  EFFECT: $\neg$ *At*(*Spare*, *Ground*) $\wedge$ $\neg$ *At*(*Spare*, *Axle*) $\wedge$ $\neg$ *At*(*Spare*, *Trunk*)
    $\wedge$ $\neg$ *At*(*Flat*, *Ground*) $\wedge$ $\neg$ *At*(*Flat*, *Axle*) $\wedge$ $\neg$ *At*(*Flat*, *Trunk*))

Example: Blocks world

Init(On(A, Table) ∧ On(B,Table) ∧ On(C,Table) ∧ Block(A) ∧ Block(B) ∧ Block(C) ∧ Clear(A) ∧ Clear(B) ∧ Clear(C))

Goal(On(A,B) ∧ On(B,C))



Action(Move(b,x,y)
  PRECOND: *On(b,x) ∧ Clear(b) ∧ Clear(y) ∧ Block(b) ∧ (b≠x) ∧ (b≠y) ∧ (x≠y)*
  EFFECT: *On(b,y) ∧ Clear(x) ∧ ¬ On(b,x) ∧ ¬ Clear(y))*

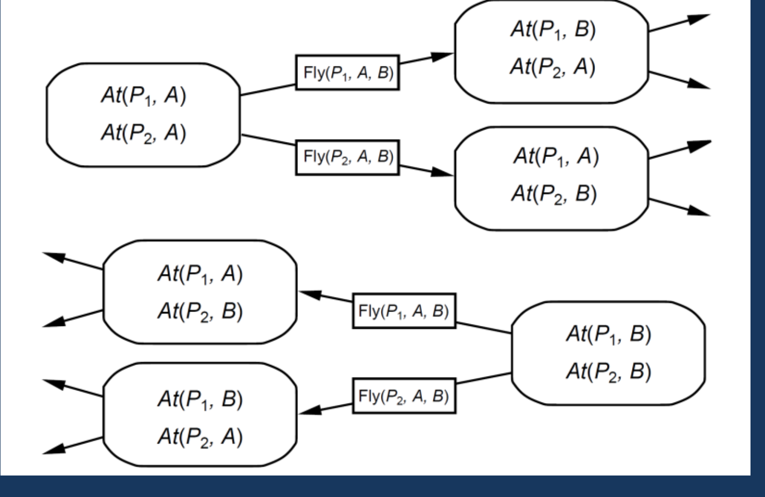
Action(MoveToTable(b,x)
  PRECOND: *On(b,x) ∧ Clear(b) ∧ Block(b) ∧ (b≠x)*
  EFFECT: *On(b,Table) ∧ Clear(x) ∧ ¬ On(b,x))*

Spurious actions are possible: Move(B,C,C)

Planning with state-space search

- Both forward and backward search possible
- Progression planners
  - forward state-space search
  - Consider the effects of all possible actions in a given state
- Regression planners
  - backward state-space search
  - To achieve a goal, what must have been true in the previous state.

Progression and regression



Progression algorithm

- Formulation as state-space search problem:
  - Initial state = initial state of the planning problem
    - Literals not appearing are false
  - Actions = those whose preconditions are satisfied
    - Add positive effects, delete negative
  - Goal test = does the state satisfy the goal
  - Step cost = each action costs 1
- No functions … any graph search that is complete is a complete planning algorithm.
  - e.g. A*
- Inefficient:
  - (1) irrelevant action problem
  - (2) good heuristic is required for efficient search

Regression algorithm

- How to determine predecessors?
  - What are the states from which applying a given action leads to the goal?

    Goal state = *At(C1, B)* ∧ *At(C2, B)* ∧ … ∧ *At(C20, B)*
    Relevant action for the first conjunct*: Unload(C1,p,B)*
    Works only if pre-conditions are satisfied.
    Previous state= *In(C1, p)* ∧ *At(p, B)* ∧ *At(C2, B)* ∧ … ∧ *At(C20, B)*
    Subgoal At(C1,B) should not be present in this state.
- Actions must not undo desired literals (consistent)
- Main advantage: only relevant actions are considered.
  - Often much lower branching factor than forward search.

Regression algorithm

- General process for predecessor construction
  - Give a goal description G
  - Let A be an action that is relevant and consistent
  - The predecessors is as follows:
    - Any positive effects of A that appear in G are deleted.
    - Each precondition literal of A is added , unless it already appears.
- Any standard search algorithm can be used to perform the search.
- Termination when predecessor is satisfied by the initial state.
  - In FO case, satisfaction might require a substitution.

Heuristics for state-space search

- Neither progression nor regression are very efficient without a good heuristic.
  - How many actions are needed to achieve the goal?
  - Exact solution is NP hard, find a good estimate
- Two approaches to find admissible heuristic:
  - The optimal solution to the relaxed problem.
    - Remove all preconditions from actions
  - The subgoal independence assumption:

    The cost of solving a conjunction of subgoals is approximated by the sum of the costs of solving the subproblems independently.

Partial-order planning

- Progression and regression planning are *totally ordered plan search* forms.
  - They cannot take advantage of problem decomposition.
    - Decisions must be made on how to sequence actions on all the subproblems
- Least commitment strategy:
  - Delay choice during search

Shoe example

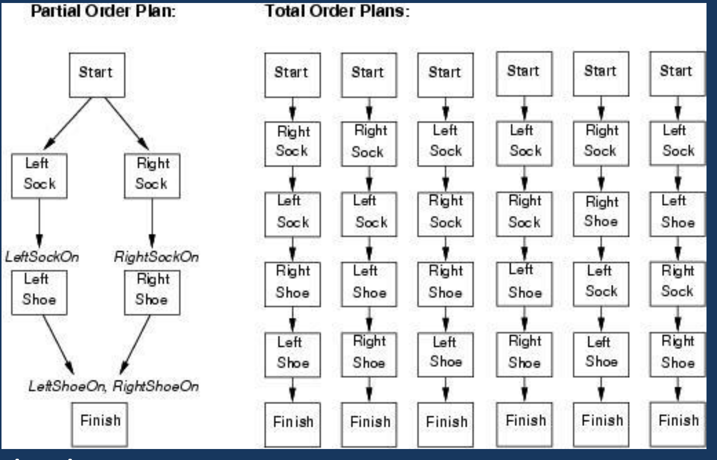
Goal(RightShoeOn $\wedge$ LeftShoeOn)
Init()

Action(RightShoe, PRECOND: RightSockOn
EFFECT: RightShoeOn)
Action(RightSock, PRECOND:
EFFECT: RightSockOn)
Action(LeftShoe, PRECOND: LeftSockOn
EFFECT: LeftShoeOn)
Action(LeftSock, PRECOND:
EFFECT: LeftSockOn)

Planner: combine two action sequences (1)leftsock, leftshoe (2)rightsock, rightshoe

Partial-order planning (POP)

- Any planning algorithm that can place two actions into a plan without specifying the orders is a PO planner.



- linearization

POP as a search problem

- States are (mostly unfinished) plans.
  - The empty plan contains only start and finish actions.
- Each plan has 4 components:
  - A set of actions (steps of the plan)
  - A set of ordering constraints: A < B (A before B)
    - Cycles represent contradictions.
  - A set of causal links
    - The plan may not be extended by adding a new action C that conflicts with the causal link. (if the effect of C is ¬p and if C could come after A and before B)
  - A set of open preconditions.
    - If precondition is not achieved by actions in the plan.

Example of final plan

- Actions={Rightsock, Rightshoe, Leftsock, Leftshoe, Start, Finish}
- Orderings={Rightsock < Rightshoe; Leftsock < Leftshoe}
- Links={Rightsock->Rightsockon -> Rightshoe,
  Leftsock->Leftsockon-> Leftshoe,
  Rightshoe->Rightshoeon->Finish, …}
- Open preconditions={}

POP as a search problem

- A plan is *consistent* iff there are no cycles in the ordering constraints and no conflicts with the causal links.
- A consistent plan with no open preconditions is a *solution*.
- A partial order plan is executed by repeatedly choosing *any* of the possible next actions.

Solving POP

- Assume propositional planning problems:
  - The initial plan contains *Start* and *Finish*, the ordering constraint *Start* < *Finish*, no causal links, all the preconditions in *Finish* are open.
  - Successor function :
    - picks one open precondition *p* on an action *B* and
    - generates a successor plan for every possible consistent way of choosing action *A* that achieves *p*.
  - Test goal

Enforcing consistency

- When generating successor plan:
  - The causal link $A \xrightarrow{p} B$ and the ordering constraint A < B is added to the plan.
    - If A is new, also add start < A and A < B to the plan
  - Resolve conflicts between new causal link and all existing actions
  - Resolve conflicts between action A (if new) and all existing causal links.
  - If a conflict between the casual link and action C
    - either add C < A or B < C

Process summary

- Operators on partial plans
  - Add link from existing plan to open precondition.
  - Add a step to fulfill an open condition.
  - Order one step w.r.t another to remove possible conflicts
- Gradually move from incomplete/vague plans to complete/correct plans
- Backtrack if an open condition is unachievable or if a conflict is irresolvable.

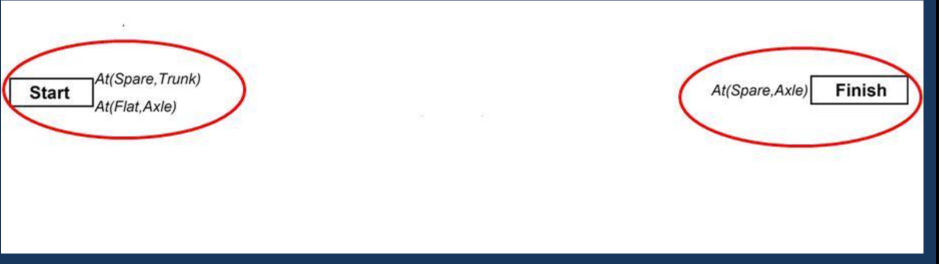
Example: Spare tire problem

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) ∧ ¬Ar(Spare,Ground))*
Action(LeaveOvernight
  PRECOND:
  EFFECT: *¬ At(Spare,Ground) ∧ ¬ At(Spare,Axle) ∧ ¬ At(Spare,trunk) ∧ ¬At(Flat,Ground) ∧ ¬ At(Flat,Axle))*

Solving the problem

- Initial plan: Start with EFFECTS and Finish with PRECOND.



Solving the problem

- Initial plan: Start with EFFECTS and Finish with PRECOND.
- Pick an open precondition: *At(Spare, Axle)*

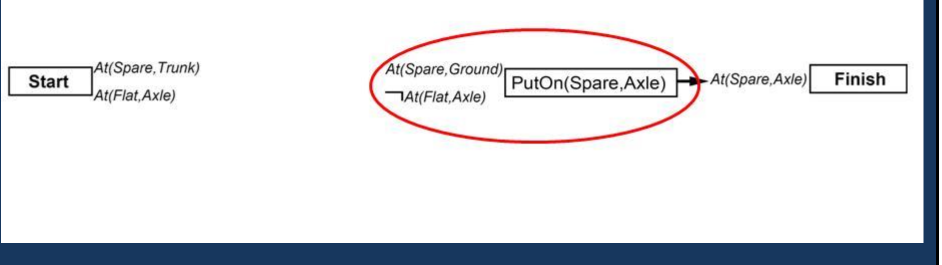
Example: Spare tire problem

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) ∧ ¬Ar(Spare,Ground))*
Action(LeaveOvernight
PRECOND:
EFFECT: *¬ At(Spare,Ground) ∧ ¬ At(Spare,Axle) ∧ ¬ At(Spare,trunk) ∧ ¬At(Flat,Ground) ∧ ¬ At(Flat,Axle))*

Solving the problem

- Pick an open precondition: *At(Spare, Axle)*
- Only *PutOn(Spare, Axle)* is applicable
- Add constraint : *PutOn(Spare, Axle) < Finish*
- Add causal link: $PutOn(Spare,Axle) \xrightarrow{At(Spare,Axle)} Finish$

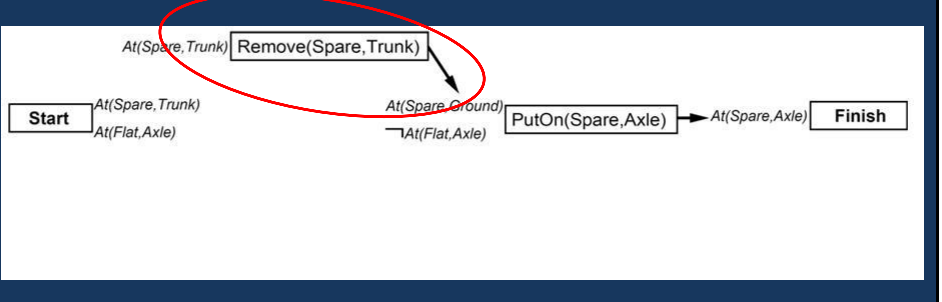


Solving the problem

- Pick an open precondition: *At(Spare, Ground)*

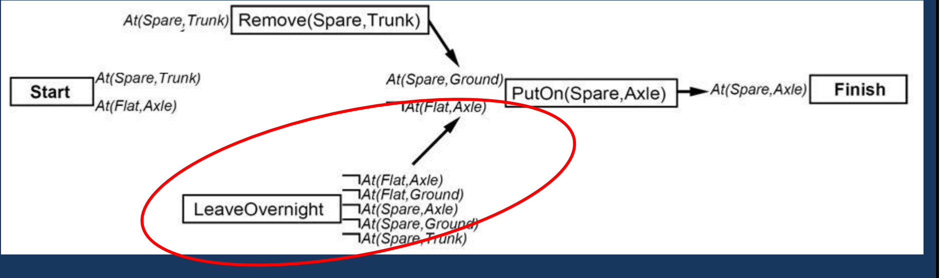
Solving the problem

- Pick an open precondition: *At(Spare, Ground)*
- Only *Remove(Spare, Trunk)* is applicable
- Add causal link: $Remove(Spare,Trunk) \xrightarrow{At(Spare,Ground)} PutOn(Spare,Axle)$
- Add constraint : *Remove(Spare, Trunk) < PutOn(Spare,Axle)*



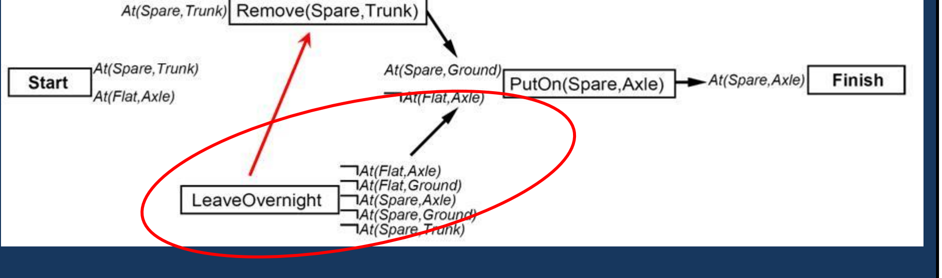
Solving the problem

- Pick an open precondition: ¬*At(Flat, Axle)*
- *LeaveOverNight* is applicable
- Add causal link: $LeaveOverNight \xrightarrow{\neg At(Flat,Axle)} PutOn(Spare, Axle)$
- Is there any conflict?



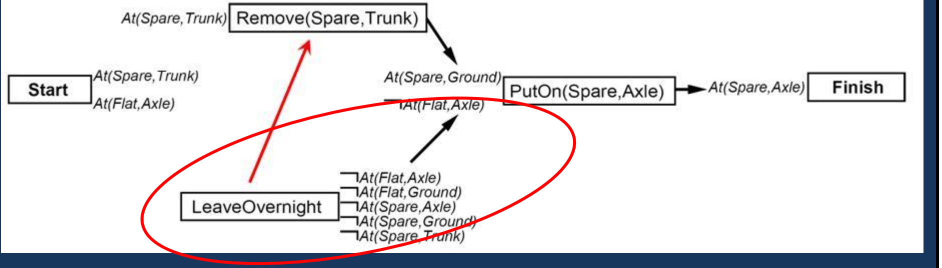
Solving the problem

- *LeaveOverNight* is applicable
- conflict: *LeaveOverNight* also has the effect ¬*At(Spare,Ground)*
- To resolve, add constraint : *LeaveOverNight < Remove(Spare, Trunk)*



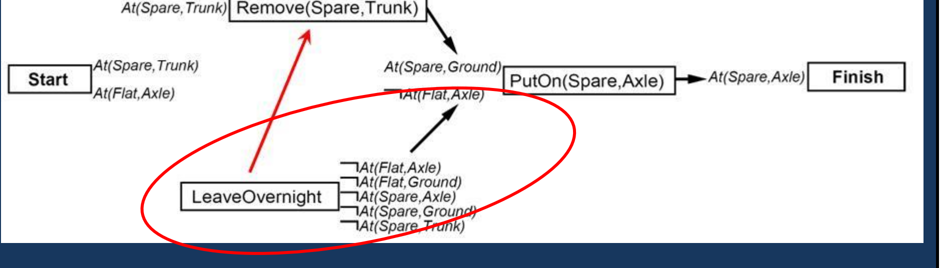
Solving the problem

- To resolve, add constraint : *LeaveOverNight < Remove(Spare, Trunk)*
- Add causal link: $LeaveOverNight \xrightarrow{\neg At(Spare,Ground)} Remove(Spare, Trunk)$



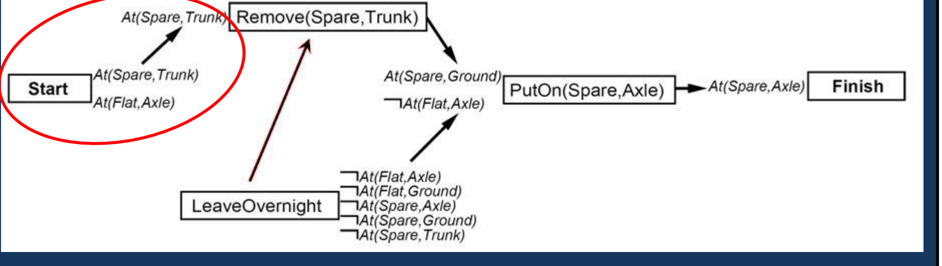
Solving the problem

- Pick an open precondition: *At(Spare, Trunk)*



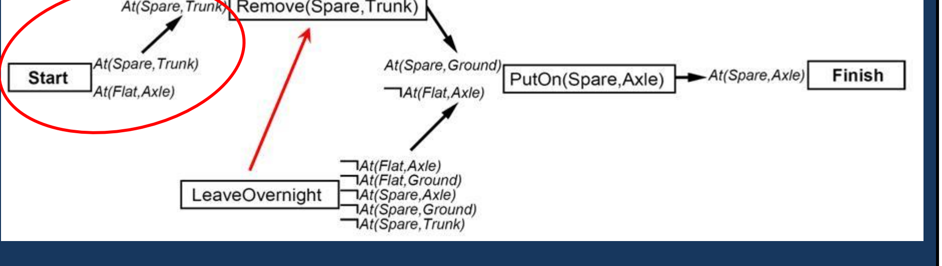
Solving the problem

- Only Start is applicable
- Add causal link: $Start \xrightarrow{At(Spare,Trunk)} Remove(Spare,Trunk)$
- Is there any conflict?



Solving the problem

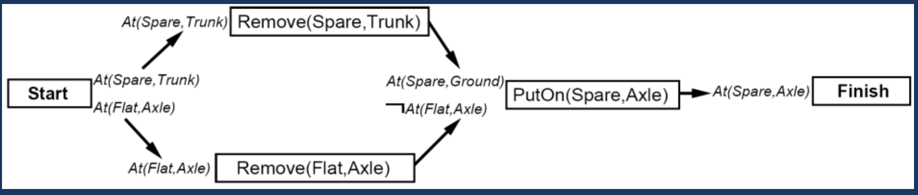
- Only Start is applicable
- Add causal link: $Start \xrightarrow{At(Spare,Trunk)} Remove(Spare,Trunk)$
- Conflict of causal link with effect ¬At(Spare,Trunk) in LeaveOverNight



- No re-ordering solution possible, backtrack

Solving the problem

- Remove *LeaveOverNight*, *Remove(Spare, Trunk)* and causal links
- Repeat step with Remove(Spare,Trunk)
- Add also Remove(Flat,Axle) and finish



Some details …

- What happens when a first-order representation that includes variables is used?
  - Complicates the process of detecting and resolving conflicts.
  - Can be resolved by introducing inequality constraints.
- CSP’s most-constrained-variable constraint can be used for planning algorithms to select a PRECOND.

Planning graphs

- Used to achieve better heuristic estimates.
  - A solution can also be 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

- They work only for propositional problems.
- Example:

Init(Have(Cake))

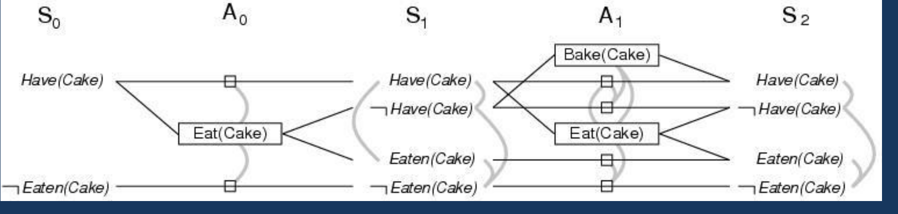
Goal(Have(Cake) $\wedge$ Eaten(Cake))

Action(Eat(Cake), PRECOND: Have(Cake)
  EFFECT: ¬Have(Cake) $\wedge$ Eaten(Cake))

Action(Bake(Cake), PRECOND: ¬ Have(Cake)
  EFFECT: Have(Cake))

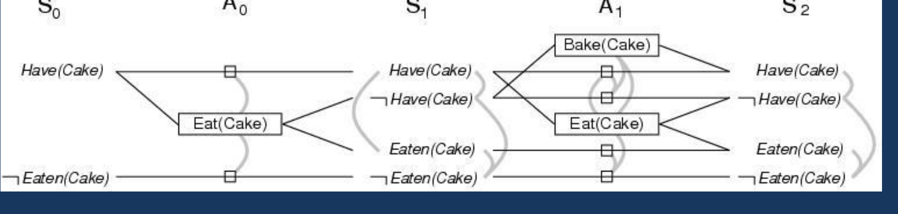
Cake example

- 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 preconditions and effects 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



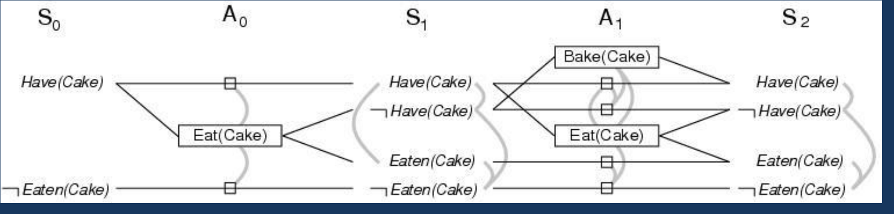
Cake example

- 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 of the 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 number of literals



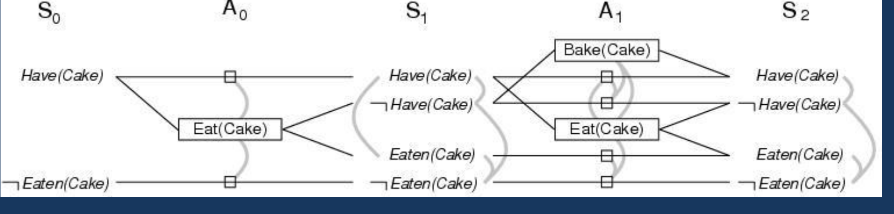
Cake example

- 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.



Cake example

- A mutex relation holds between **two literals** when (inconsistent support):
  - If one is the negation of the other
  - if **each** possible action pair that could achieve the literals is mutex.



PG and heuristic estimation

- PGs 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).
    - Can be used to construct heuristics
  - 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*) **returns** solution or failure

graph ← INITIAL-PLANNING-GRAPH(*problem*)
goals ← CONJUNCTS(*problem*.GOAL)
nogoods ← an empty hash table
for $tl = 0$ **to** ∞ **do**
  if *goals* all non-mutex in S_t of *graph* **then**
    solution ← EXTRACT-SOLUTION(*graph*, *goals*, NUMLEVELS(*graph*), *nogoods*)
    if *solution* $\neq$ *failure* **then return** *solution*
  if *graph* and *nogoods* have both leveled off **then return** *failure*
  graph ← EXPAND-GRAPH(*graph*, *problem*)

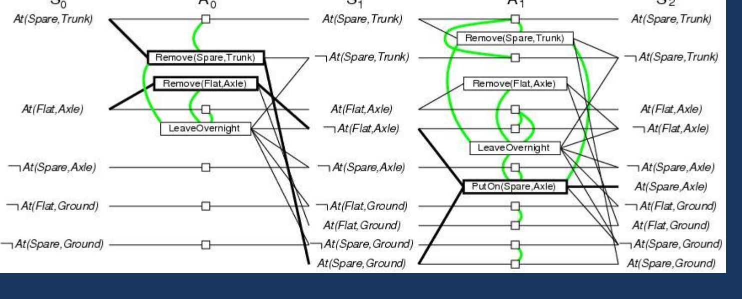
Example: Spare tire problem

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) ∧ ¬Ar(Spare,Ground))*
Action(LeaveOvernight
PRECOND:
EFFECT: *¬ At(Spare,Ground) ∧ ¬ At(Spare,Axle) ∧ ¬ At(Spare,trunk) ∧ ¬At(Flat,Ground) ∧ ¬ At(Flat,Axle))*

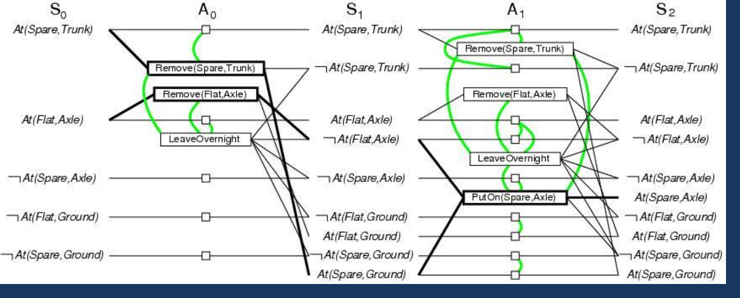
GRAPHPLAN example

- Initially the plan consist of 5 literals from the initial state and the CWA literals (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



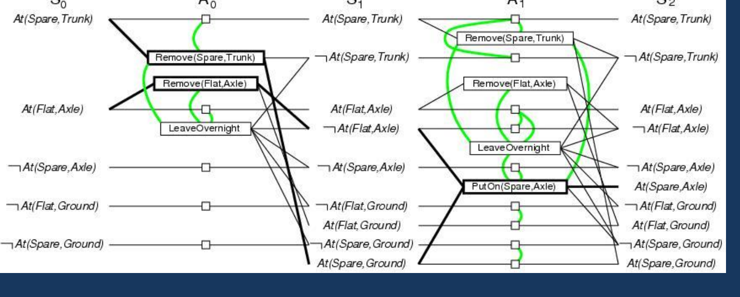
GRAPHPLAN example

- 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 preconditions
  - Inconsistent support
    - E.g. in S2, At(Spare,Axle) and At(Flat,Axle)



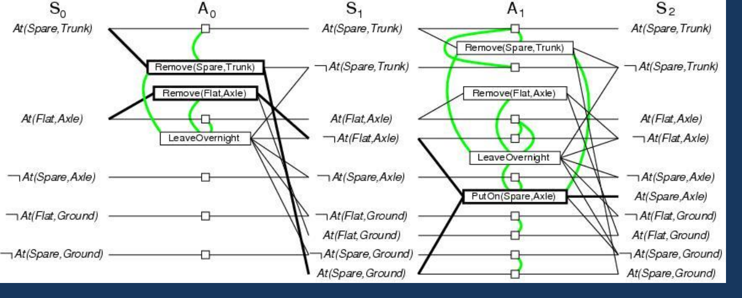
GRAPHPLAN example

- 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 solves a Boolean CSP to solve the problem or a search process:
  - Initial state = last level of PG and the 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.



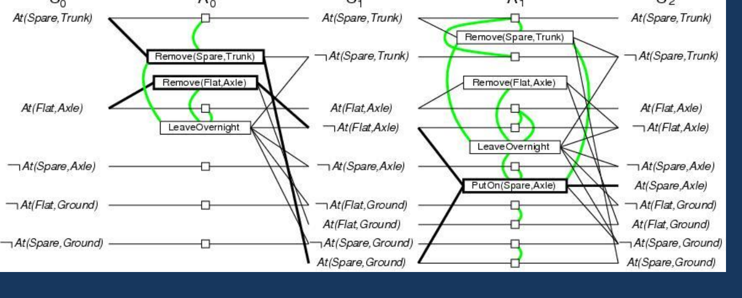
GRAPHPLAN example

- Use heuristics for bakward search
  - Pick first the literal with the highest level cost
  - To achieve it, choose the action with the easiest preconditions first (sum of level costs of preconditions is smallest)



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 !



Analysis of planning approaches

- Planning is an area of great interest within AI
  - Search for solution
  - Constructively prove an existence of solution
- Biggest problem is the combinatorial explosion in states
- Efficient methods are under research
  - e.g. divide-and-conquer