# Classical Planning GraphPlan - SatPlan

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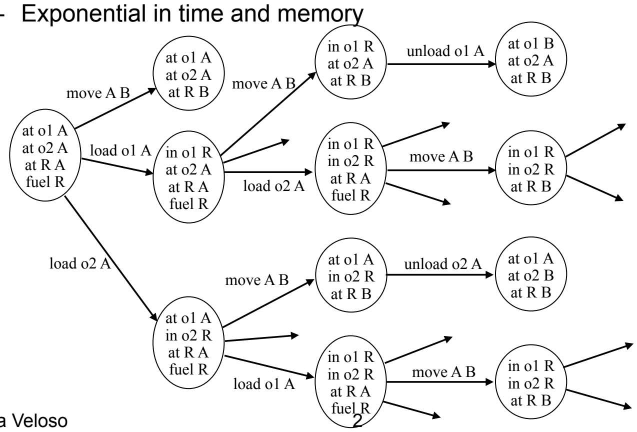
Readings:
- Chapter 10, Russell & Norvig

## Planning Graph – Forward Expansion

- State reachability – "until" goal
  - Can find ***all*** goals reachable from initial state
  - Exponential in time and memory



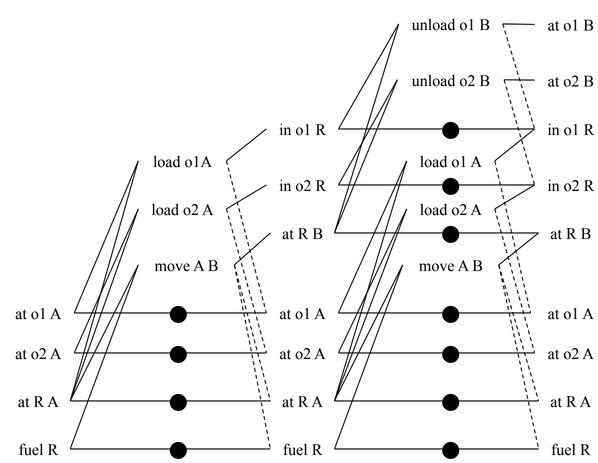
# Graphplan

*Blum & Furst 95*

- Preprocessing before engaging in search.
- Forward search combined with backward search.
- Construct a *planning graph* to reveal constraints
- Two stages:
  – Extend: One time step in the planning graph.
  – Search: Find a valid plan in the planning graph.
- Graphplan finds a plan or proves that no plan has fewer "time steps."



# Plan Graph
## One-Way Rocket Example



## Extending a Planning Graph - Actions

- To create an action-level *i*:
  - Add each instantiated operator, for which all of its preconditions are present at proposition-level *i* AND *no two of its preconditions are exclusive*.
  - Add all the no-op actions.
- Determine the exclusive actions.



## Extending a Planning Graph – Propositions

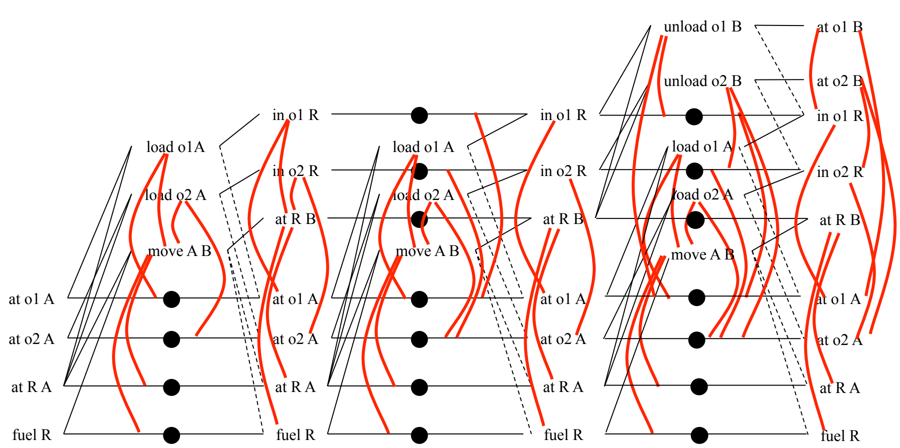
- To create a proposition-level *i* + 1:
  - Add all the effects of the inserted actions at action-level *i* - distinguishing add and delete effects.
- Determine the exclusive actions.

# Planning Graphs

- A literal may exist at level *i* + 1 if it is an Add-Effect of some action in level *i*.
- Two propositions *p* and *q* are *exclusive* in a proposition-level if ALL actions that add *p* are exclusive of ALL actions that add *q*.
- Actions A and B are *exclusive* at action-level *i*, if:
  - Interference: A (or B) deletes a precondition or an Add-Effect of B (or A).
  - Competing Needs: *p* is a precondition of A and *q* is a precondition of B, and *p* and *q* are exclusive in proposition-level *i* - 1.



# Mutex Exclusivity Relations
## One-Way Rocket Example



# Exclusivity Examples

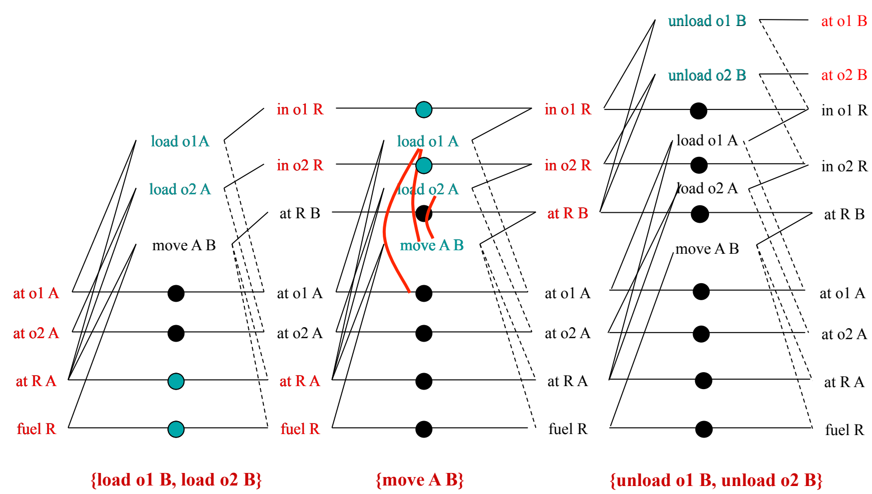
- Exclusive Actions: (Move A B) deletes a precondition of (Load o1 A). Therefore exclusive (existence of threats).
- Exclusive Propositions: (at R A) and (at R B) at time 2 are exclusive. (at R A) is added by a no-op and (at R B) is added by (Move A B) and no-op and (Move A B) are exclusive actions.
- Exclusive Actions: Then (Load o1 A) and (Load o2 B) are exclusive because (at R A) and (at R B) are exclusive.
- Propositions can be exclusive in some time step and not in others: If (at o1 A) and (at R A) at time 1, then (in o1 A) and (at R B) are exclusive at time 2, but not at time 3.



# Searching a Planning Graph

- Level-by-level backward-chaining approach to use the exclusivity constraints.
- Given a set of goals at time *t*, identify all the sets of actions (including no-ops) at time *t* - 1 who add those goals and are not exclusive. The preconditions of these actions are new goals for *t* - 1.

# Searching a Planning Graph






# Recursive Search

- For each goal at time *t* in some arbitrary order:
  - Select some action at time *t* - 1 that achieves that goal and it is not exclusive with any other action already selected.
  - Do this recursively for all the goals at time *t* - do not add new action, but use the ones already selected if they add another goal.
  - If recursion returns failure, then select a different action.
- The new goal set is the set of all the preconditions of the selected actions.

## Enhancements

- Forward-checking - for the goals ahead, check if all the actions that add it are exclusive with the selected action.
- Memoization - when a set of goals is not solvable at some time *t*, then this is recorded and hashed. If back at time *t*, the hash table is checked and search proceeds backing up right away.



## Planning as Satisfiability

- One interpretation: ``first-order deductive theorem-proving does not scale well.' '
- One solution: ``propositional satisfiability' '
- Uniform clausal representation for goals and operators.
- Stochastic local search is a powerful technique for planning.

# SatPlan

- Assume the plan has *n* (time-parallel) steps. *(strong assumption)*
- Initial state: completely specified at time 0.
  $at\text{-}o1\text{-}A_0 \wedge at\text{-}o2\text{-}A_0 \wedge at\text{-}R\text{-}A_0$
- Goal: specified at time 2*n*.
  $at\text{-}o1\text{-}B_6 \wedge at\text{-}o2\text{-}B_6$
- Actions: specified at *odd* times; An action implies its preconditions and effects.
  $(\neg load\text{-}o1\text{-}A_1 \vee at\text{-}o1\text{-}A_0) \wedge (\neg load\text{-}o1\text{-}A_1 \vee at\text{-}R\text{-}A_0) \wedge$
  $(\neg load\text{-}o1\text{-}A_1 \vee in\text{-}R\text{-}A_2) \wedge (\neg load\text{-}o1\text{-}A_1 \vee \neg at\text{-}o1\text{-}A_2)$



# Discussion

- Efficiency
- Optimality
- Comparison