COMP9414: Artificial Intelligence

Lecture 3b: Planning

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This Lecture

- Reasoning About Action
- STRIPS Planner
- GraphPlan
- Planning as Constraint Satisfaction

Planning Agent

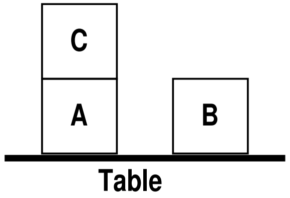
- Environment changes due to the performance of actions
- Planning scenario
  - Agent can control its environment
  - Only atomic actions, not processes with duration
  - Only single agent in the environment (no interference)
  - Only changes due to agent executing actions (no evolution)
- More complex examples
  - Robocup dog
  - Delivery robot
  - Self-driving car

Reasoning About Action

- Semantics: Divide the world into a sequence of (notional) time points
  - Situation is a (complete) state of world at a time point
  - Action is a transition between situations
  - Nothing (of relevance) happens between situations
- Planner: Maintain an incomplete description of situations
  - Confusingly, also called a state of the world
  - Search for path from initial state to a goal state
  - State transitions correspond to actions
  - Major problem is to specify actions

The Blocks World

- Blocks can be placed on the table and can be stacked on one another
- All blocks the same size and table large enough to hold all blocks



State: $on(C, A)$, $on(A, Table)$, $on(B, Table)$ $clear(B)$, $clear(C)$

Specifying Actions (STRIPS)

- Action Description — name of action
- Preconditions — action can be performed in a situation only if precondition holds in situation prior to action being performed
- Delete List — literals to be deleted from the state (description) after action is performed
- Add List — literals to be added to the state (description) after action is performed
- STRIPS Assumption — any literals in the state (description) not contained in the delete list remain the same after the action is performed (c.f. frame problem)

Assumes actions are executed perfectly (reasonable for planning?)

Blocks World Actions (STRIPS)

- Action Description: $move(x, y, z)$ $(x \neq y \neq z?)$
- Preconditions: $on(x, y)$, $clear(x)$, $clear(z)$
- Delete List: $clear(z)$, $on(x, y)$
- Add List: $on(x, z)$, $clear(y)$, $clear(Table)$
  - Add $clear(Table)$ to ensure table is always clear

Problems in Reasoning About Action

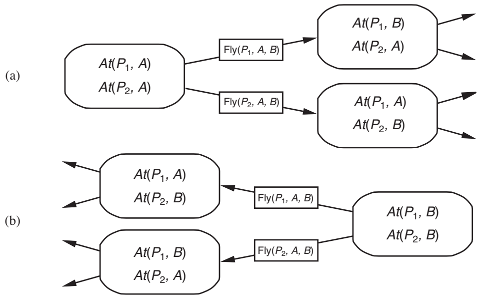
- Frame Problem
  - How to chartacterize literals of the state that are not changed by performing an action?
    - Problem is there are a lot of such literals
    - Both “epistemological” and “computational” problem
- Ramification Problem
  - What are the direct and indirect effects of performing an action?
    - Problem is that indirect effects depend on initial situation
- Qualification Problem
  - What preconditions are required in a specification of an action?
    - Problem is that qualifications depend on context

Planning

- Plan — sequence (or ordered set) of actions to achieve some goal
- Planner — problem solver that produces plans
- Goal – typically a conjunction of literals
- Initial State – typically a conjunction of literals
- Blocks World Example for goal $on(B, C) \wedge on(C, Table)$
  - $move(C, A, Table), move(B, Table, C)$

Simple Planning Algorithms

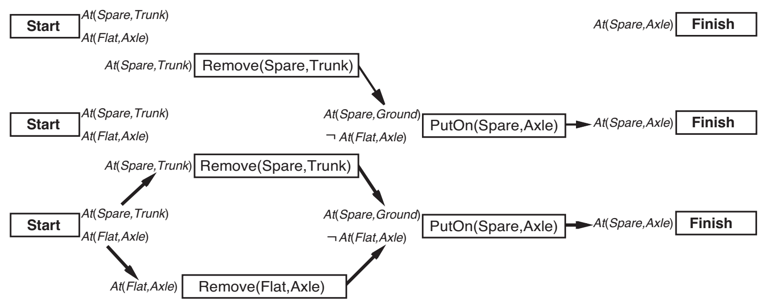
- Forward search and goal regression



- Problem with forward search is state space can be very large
- Problem with regression is that it is hard and doesn't always work

Nonlinear Planning

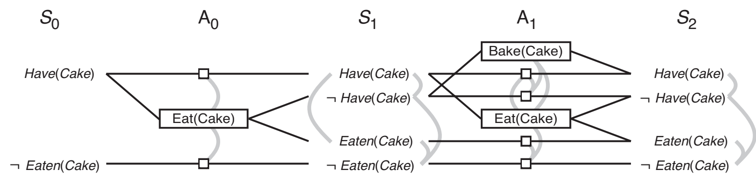
- Start with goal regression and try to fix "flaws" in the plan



- Least commitment: execution can be in any permissible order

Forward Search with Plan Graphs

- Only consider "propositional" plans
- S_i contains all literals that *could* hold at time i
- A_i contains all actions that *could* have preconditions satisfied at time i
- Actions linked to preconditions
- Literals that persist from time i to time $i+1$ linked via actions
- Mutual exclusion (mutex) links between actions/literals at same time



Mutual Exclusion

- Actions
  - Inconsistent effects: One action negates an effect of the other
  - Interference: Effect of one action is the negation of a precondition of the other
  - Competing needs: Precondition of one action is mutually exclusive with a precondition of the other
- Literals
  - One literal is the negation of the other
  - Inconsistent support: Each possible pair of actions that could achieve the two literals is mutually exclusive

GraphPlan Expansion Step

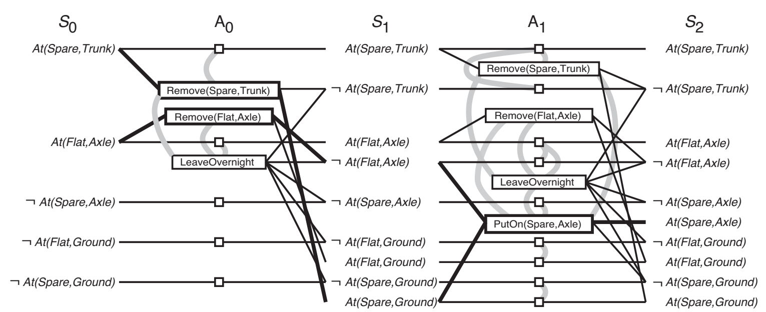
- Add actions to A_i whose preconditions are at S_i
- Add "persistence actions" to A_i for literals from S_i
- Add mutex links to A_i for actions that cannot occur together
- Add effects of all actions in A_i to S_{i+1}
- Add literals to S_{i+1} for persistence actions from A_i
- Add mutex links to S_{i+1} for literals that cannot occur together

GraphPlan Algorithm

- Graph = Initial plan graph with initial state S_0
- nogoods = empty set
- For $t = 0, \cdots$
  - If all goals are non-mutex in S_t
    - Extract solution from graph
      - Graph as CSP with variables T/F for when action in the plan
      - Or heuristically guided regression from S_t to S_0
    - If valid solution, return solution
  - If graph and nogoods didn't change then return failure
  - Expand graph to next level

GraphPlan Example

- After expansion to Level 2



Planning as Constraint Satisfaction

CSP for each planning horizon k (vary k as needed)

- Variables
  - Create a variable for each literal and time $0, \cdots, k$
  - Create a variable for each action and time $0, \cdots, k-1$
- Constraints
  - State constraints: literals at time t
  - Precondition constraints: actions and states at time t
  - Effect constraints: actions at time t, literals at times t and $t+1$
  - Action constraints: actions at time t (mutual exclusion)
  - Initial state constraints: literals at time 0
  - Goal constraints: literals at time k

Conclusion

- Reasoning about action interesting from philosophical point of view
- Recent advances in planning give great improvements in efficiency
- Planning makes use of CSP framework with heuristics
- Multi-agent systems, dynamic worlds much more complex