Informatics 2D: Reasoning and Agents

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Lecture 16: Introduction to Planning

Where are we?

The first two blocks of the course dealt with ...

- Basic notions of agency
- Intelligent problem-solving
- Heuristic search, constraints
- Logic & logical reasoning
- Reasoning about actions and time

In the remainder of the course we will talk about ...

- Planning
- Uncertainty

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What is planning?

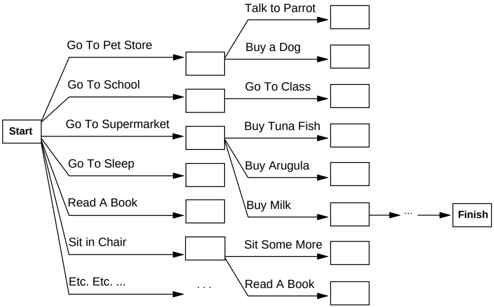
- **Planning** is the task of coming up with a sequence of actions that will achieve a goal
- We are only considering **classical planning** in which environments are
  - fully observable (accessible),
  - deterministic,
  - finite,
  - static (up to agents' actions),
  - discrete (in actions, states, objects and events).
- (Lifting some of these assumptions will be the subject of the "uncertainty" part of the course)

Why planning?

- So far we have dealt with two types of agents:
  1. Search-based problem-solving agents
  2. Logical planning agents
- Do these techniques work for solving planning problems?

Why planning?

- Consider a search-based problem-solving agent in a robot shopping world
- Task: Go to the supermarket and get milk, bananas and a cordless drill
- What would a search-based agent do?



Problems with search

- No goal-directedness.
- No problem decomposition into sub-goals that build on each other
  - May undo past achievements
  - May go to the store 3 times!
- Simple goal test doesn't allow for the identification of milestones
- How do we find a good heuristic function?
  How do we model the way humans perceive complex goals and the quality of a plan?

How about logic & deductive inference?

- Generally a good idea, allows for “opening up” representations of states, actions, goals and plans
- If $Goal = Have(Bananas) \wedge Have(Milk)$ this allows achievement of sub-goals (if independent)
- Current state can be described by properties in a compact way (e.g. $Have(Drill)$ stands for hundreds of states)
- Allows for compact description of actions, for example

$$Object(x) \Rightarrow Can(a, Grab(x))$$

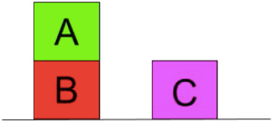
- Allows for representing a plan hierarchically, e.g. $GoTo(Supermarket) = Leave(House) \wedge ReachLocationOf(Supermarket) \wedge Enter(Supermarket)$ then decompose further into sub-plans

How about logic & deductive inference?

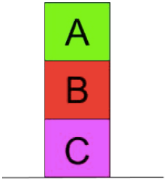
Problems:

1. In its general form either awkward (propositional logic) or tractability problems (first-order logic)
2. If p is a sequence that achieves the goal, then so is $[a, a^{-1}|p]$!
3. (Logically independent) subgoals may need to be undone to achieve other goals.

Goal: $on(A, B) \wedge on(B, C)$



Initial State



Goal

What next?

Solutions: We need

1. To reduce complexity to allow scaling up.
2. To allow reasoning to be guided by plan 'quality'/efficiency.

Do 1. next, and 2. after that.

Representing planning problems

- Need a language expressive enough to cover interesting problems, restrictive enough to allow efficient algorithms.
- Planning Domain Definition Language or PDDL
- PDDL will allow you to express:
  1. states
  2. actions: a description of transitions between states
  3. and goals: a (partial) description of a state.

Representing States and Goals in PDDL

- **States** represented as conjunctions of propositional or function-free first order positive literals:
  - $Happy \land Sunshine$,
    $At(Plane_1, Melbourne) \land At(Plane_2, Sydney)$
- So these aren't states:
  - $At(x, y)$ (no variables allowed),
    $Love(Father(Fred), Fred)$ (no function symbols allowed)
    $\neg Happy$ (no negation allowed).

  Closed-world assumption!
- A **goal** is a partial description of a state, and you can use negation, variables etc. to express that description.
  - $\neg Happy$, $At(x, SFO)$, $Love(Father(Fred), Fred)$ ...

Actions in PDDL

$Action(Fly(p, from, to),$

$\quad \text{Precond:} At(p, from) \wedge Plane(p) \wedge Airport(from) \wedge Airport(to)$

$\quad \text{Effect:} \neg At(p, from) \wedge At(p, to))$

- Actually **action schemata**, as they may contain variables
- Action name and parameter list serves to identify the action
- **Precondition**: defines states in which action is **executable**:
  - Conjunction of positive and negative literals, where all variables must occur in action name.
- **Effect**: defines how literals in the input state get changed (anything not mentioned stays the same).
  - Conjunction of positive and negative literals, with all its variables also in the preconditions.
  - Often positive and negative effects are divided into **add list**

The semantics of PDDL: States and their Descriptions

- $s \models At(P_1, SFO)$ iff $At(P_1, SFO) \in s$
  $s \models \neg At(P_1, SFO)$ iff $At(P_1, SFO) \notin s$
  $s \models \phi(x)$ iff there is a ground term d such that $s \models \phi[x/d]$.
  $s \models \phi \wedge \psi$ iff $s \models \phi$ and $s \models \psi$

The Semantics of PDDL: Applicable Actions

- Any action is **applicable** in any state that satisfies the precondition with an appropriate substitution for parameters.
- Example: State

$$At(P_1, Melbourne) \wedge At(P_2, Sydney) \wedge Plane(P_1) \wedge Plane(P_2) \wedge Airport(Sydney) \wedge Airport(Melbourne) \wedge Airport(Heathrow)$$

satisfies

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

with substitution (among others)

$$\{p/P_2, from/Sydney, to/Heathrow\}$$

The semantics of PDDL: The Result of an Action

- **Result** of executing action a in state s is state s' with any positive literal P in a's Effects added to the state and every negative literal $\neg P$ removed from it (under the given substitution) .
- In our example s' would be

$$At(P_1, Melbourne) \wedge At(P_2, Heathrow) \wedge Plane(P_1) \wedge Plane(P_2)$$
$$\wedge Airport(Sydney) \wedge Airport(Melbourne) \wedge Airport(Heathrow)$$

- "PDDL assumption": every literal not mentioned in the effect remains unchanged (cf. frame problem)
- **Solution** = action sequence that leads from the initial state to a state that satisfies the goal.

Blocks world example

- Given: A set of cube-shaped blocks sitting on a table
- Can be stacked, but only one on top of the other
- Robot arm can move around blocks (one at a time)
- Goal: to stack blocks in a certain way
- Formalisation in PDDL:
  - $On(b,x)$ to denote that block b is on x (block/table)
  - $Move(b,x,y)$ to indicate action of moving b from x to y
  - Precondition for this action requires $Clear(z)$: nothing stacked on z.

Blocks world example

- Action schema:

$$
\begin{aligned}
&\mathit{Action}(\mathit{Move}(b,x,y),\\
&\quad \text{Precond:}\mathit{On}(b,x)\land \mathit{Clear}(b)\land \mathit{Clear}(y)\\
&\quad \text{Effect:}\mathit{On}(b,y)\land \mathit{Clear}(x)\land \neg \mathit{On}(b,x)\land \neg \mathit{Clear}(y))
\end{aligned}
$$

- Problem: when $x = \mathit{Table}$ or $y = \mathit{Table}$ we infer that the table is clear when we have moved a block from it (not true) and require that table is clear to move something on it (not true)
- Solution: introduce another action

$$
\begin{aligned}
&\mathit{Action}(\mathit{MoveToTable}(b,x),\\
&\quad \text{Precond:}\mathit{On}(b,x)\land \mathit{Clear}(b)\\
&\quad \text{Effect:}\mathit{On}(b,\mathit{Table})\land \mathit{Clear}(x)\land \neg \mathit{On}(b,x))
\end{aligned}
$$

Does this Work?

- Interpret *Clear*(b) as "there is space on b to hold a block" (thus *Clear*(*Table*) is always true)
- But without further modification, planner can still use *Move*(b, x, *Table*):
  - Needlessly increases search space (not a big problem here, but can be)
- So part of solution is to also add *Block*(b) $\wedge$ *Block*(y) to precondition of *Move*

Summary

- Defined the planning problem
- Discussed problems with search/logic
- Introduced PDDL: a special representation language for planning
- Blocks world example as a famous application domain
- Next time: Algorithms for planning!
  State-Space Search and Partial-Order Planning