Informatics 2D – Reasoning and Agents

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Lecture 16 – Introduction to Planning
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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

What is planning?

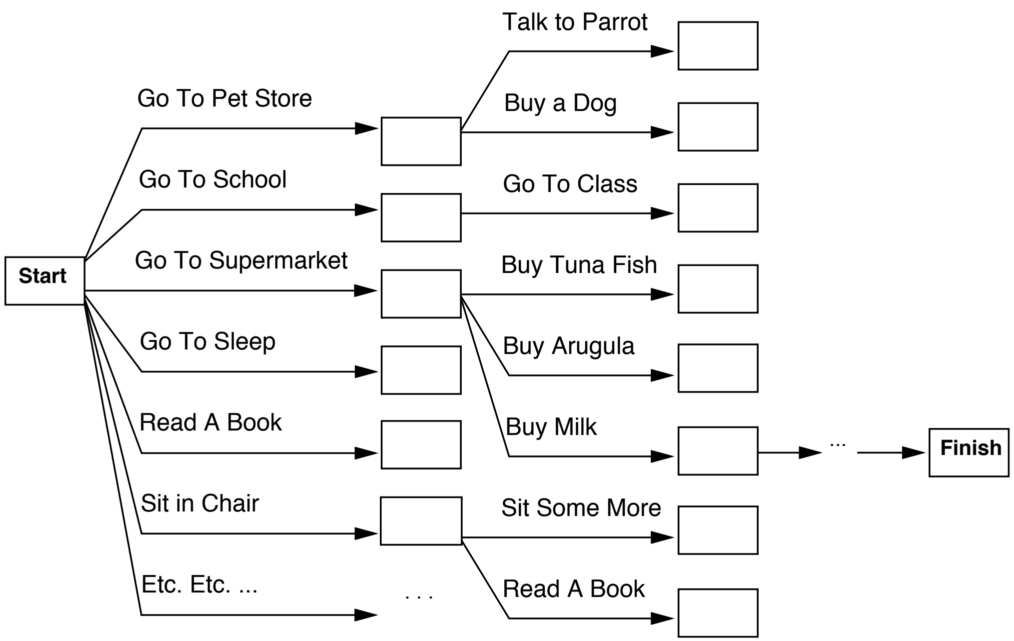
- **Planning** is the task of coming up with a sequence of actions that will achieve a goal
- We are only considering **classical planning** in which environments are
  - fully observable (accessible),
  - deterministic,
  - finite,
  - static (up to agents' actions),
  - discrete (in actions, states, 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), high complexity
  2. If p is a sequence that achieves the goal, then so is $[a, a^{-1}|p]$!
- Solutions: We need
  1. To reduce comlpexity to allow scaling up.
  2. To allow reasoning to be guided by plan 'quality'/efficiency.
- Do 1. today; 2. next time.

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:
  - $Happy \wedge Sunshine$, $At(Plane_1, Melbourne) \wedge At(Plane_2, Sydney)$
- So these aren't states:
  - $At(x, y)$ (no variables allowed),
    $Love(Father(Fred), Fred)$ (no function symbols allowed)
    $\neg Happy$ (no negtion 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

$$\begin{array}{l} \mathit{Action}(\mathit{Fly}(p, \mathit{from}, \mathit{to}), \\ \quad \textsc{Precond}: \mathit{At}(p, \mathit{from}) \wedge \mathit{Plane}(p) \wedge \mathit{Airport}(\mathit{from}) \wedge \mathit{Airport}(\mathit{to}) \\ \quad \textsc{Effect}: \neg \mathit{At}(p, \mathit{from}) \wedge \mathit{At}(p, \mathit{to})) \end{array}$$

- 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** and **delete 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 $\textsc{Effects}$ added to the state and every negative literal $\neg P$ removed from it (under the given substitution) .
- In our example s' would be

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

- "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: nothing must be stacked on x: $Clear(x)$.

Blocks world example

- Action schema:

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

- Problem: when $x = Table$ or $y = Table$ 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

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

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