CompSci 366

Introduction to Planning

What’s Happening

- 6 Lectures Covering:
  - Classical Plan Representation
  - Progression Planning
  - Regression Planning
  - Partial Order Planning
- 1 Assignment

Outline

- Why plan?
- Current Status & Future of Planning
- Modeling a Domain
- Plans and Planning

Why Plan?

- We have a problem!
  - We have a goal that isn't currently achieved.

Why Plan?

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  - We have a goal that isn't currently achieved.
- We don't readily know how to solve it!
  - Need to think about how to solve it.

Why Plan?

- We have a problem!
  - We have a goal that isn’t currently achieved.
- We don’t readily know how to solve it!
  - Need to think about how to solve it.
- What we want is a plan!
  - Don’t simply want to know if it is achievable, want a plan that will achieve it.

How Do We Plan?

- We usually do mental simulations of scenarios.
- Not just one scenario, first one rarely succeeds.
- But a search through a space of different scenarios for one that achieves our goal.
- These scenarios describe our *problem space*

Problem Space Hypothesis

- Allen Newell proposed the *Problem Space Hypothesis*: namely that all human problem-solving can be described in terms of:
  - Situations
  - Operators that have preconditions and effects.
  - Search control knowledge.
- Planners are certainly built this way.

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Should We Always Plan?

- In general, planning is very computationally expensive!!!!
- Even in very simplified models of our domains!!
- In everyday life, caching is usually better than planning.

When Should An Agent Plan?

- When it has a problem.

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When Should An Agent Plan?

- When it has a problem.
- That it doesn’t already have a cached solution for.
- But where it has a domain model which will allow it to explore possible solution scenarios.

Examples From NASA

- The Remote Agent Experiment (RAX)

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- The Mars Robotic Outpost

Planning Today

- Experiencing a renaissance.
- Becoming an important component in real-life agents.
- Rapidly changing.

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What We're Going To Study

- Many modern planning approaches are reformulations of classical planning approaches.
- We only have 6 lectures.
- So we're going to study classical planning.

Our First Glimpse of Classical Planning

- Will describe an approach to :
  - Domain modelling *(this lecture)*
  - Search space structure *(next lecture)*
  - Search space traversal *(next lecture)*

Domain Modelling

- Classical assumptions
- Problem representation
- Situation representation
- Goal Representation
- Action representation
- The simulation process
- Plan representation

Classical Assumptions

- Finite propositional domains.
- Omniscience.
- Actions are completely deterministic.
- No exogenous events.

Classical Assumptions

- All actions take unit time to occur.
- Only qualitative resources.
- All actions occur sequentially.

Domain Modelling

- Classical assumptions
- → Problem representation
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Problem Representation

- Problem is described by:
  - A complete description of the initial situation.
  - A description of the desired goals.

Domain Modelling

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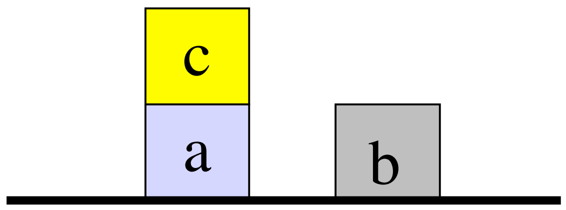
Situation Representation

- Omniscience => must be able to determine the truth/falsity of all propositions for a given situation.
- Generally, situations cannot be represented by vectors.
- Situations are represented by propositional expressions.

Situation Representation cont'd

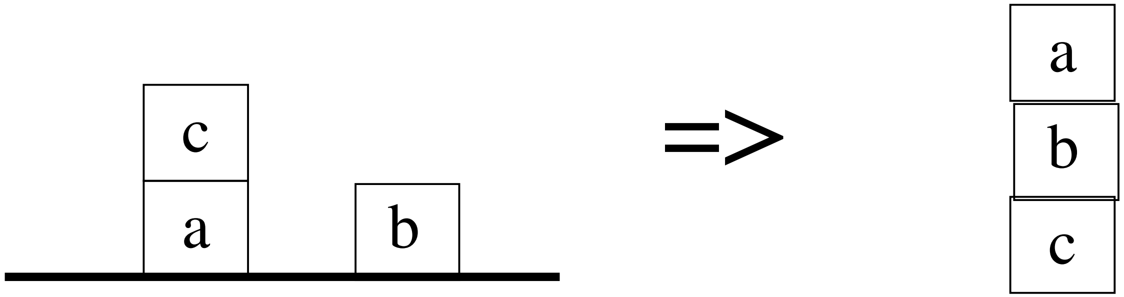
- Given a situation, how do we represent it?



Situation Representation cont'd

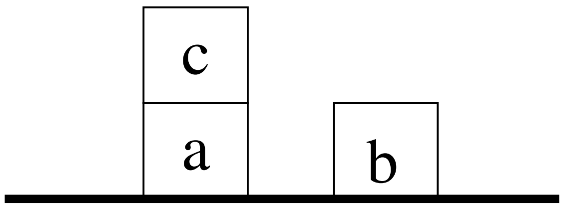
- Need to do some domain ontology engineering
  - What aspects are important?
  - What do we want to capture?
- In general, very difficult to get right.

Sample Problem



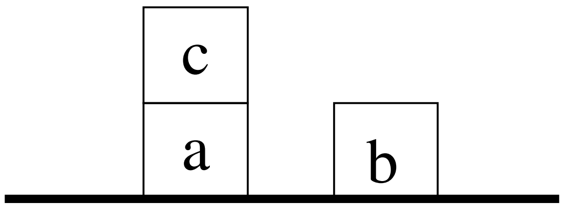
- What's important and needs to be represented?
- Assume we only need the following predicates:
  - **on(Block1, Thing1)**
  - **clear(Block)**

Situation Representation cont'd



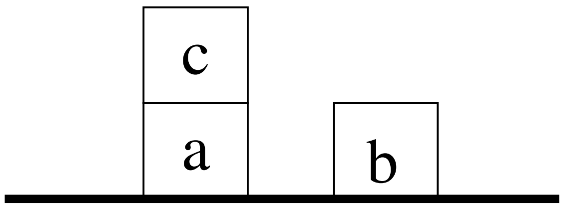
- Given our ontology, how would we describe this situation?
- Need to know everything about situation.

Situation Representation cont'd



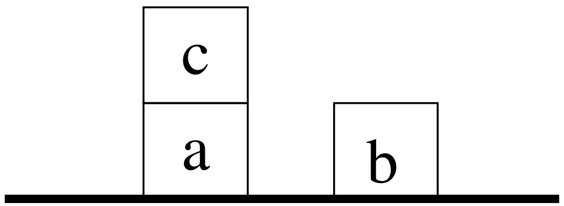
- What about : **on(c,a), on(a,table), clear(c), on(b, table), clear(b), ~on(c,b), ~on(c,table), on(c,a) ^ on(a,table), on(c,a) v on(a,b), …**

Situation Representation cont'd



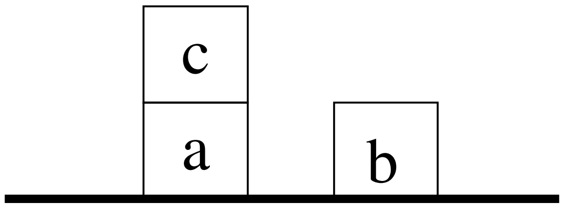
- Negated literals: an infinite number of things that aren't true in a given situations.
- Logical expressions: an infinite number of true expressions can be built up from logical combinations of literals.

Situation Representation cont'd



- Negated literals: use closed world assumption (CWA) [similar to negation by failure in Prolog].
- Logical expressions: use deduction to evaluate.

Situation Representation cont'd



- Situation = {**on(c,a), on(a,table), clear(c), on(b, table), clear(b)**}
- Want to be able to infer **~on(c,b)**, etc., and **on(c,a) ^ on(a,table)**, etc., from this representation.

Domain Modelling

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Goal Representation

- In situations, the fact that **on(b,c)** is *not true* is presented by not having them in the list of true literals.

- How would we represent the goal of wanting **on(b,c)** to be *false*?

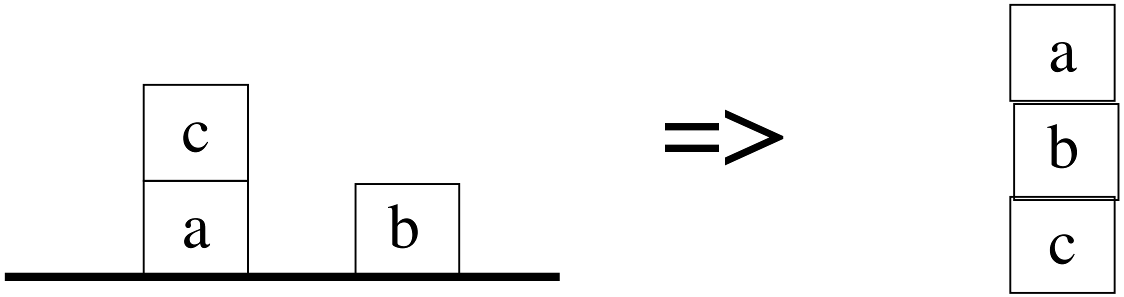
Goal Representation

- For states, there are only 2 options a literal is either true or it is false.
- For goals, there are 3 options, a literal is desired to be true, desired to be false, or we don’t care.
- With goals we need to distinguish between what we want to be false and what we don’t care about.

Goal Representation

- How would we represent the goal of wanting **on(b,c)** to be *false* versus not caring about it?
- For us, we represent it as **not(on(b,c))**.
- Literals we don't care about are not mentioned in the goal description.

Problem Representation Revisited



- Initial situation = **{on(c,a), on(a,table), clear(c), on(b, table), clear(b)}**
- Goal situation = **{on(a,b), on(b,c)}**, note haven't said what, if anything, is on top of **a** nor what **c** is on top of, it's a "don't care".

Domain Modelling

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Action Representation

- Propositionally based.
- Use action schema rather than concrete actions (i.e., parameterised actions).
- Need to describe:
  - When action is legal.
  - What are the effects of executing the action.
  - Perhaps, when the action makes sense.

Action Representation cont'd

- Action schema represents actions that will take place in our simulations and reflect what happens in our domain.
- Action representation includes:
  - Action schema name.
  - Action schema parameters.
  - Action preconditions.
  - Action effects.

Action Representation cont'd

- Example action schema:
  - Move block from location to location.
  - op(move, [Block, FromLoc, ToLoc], [on(Block,FromLoc), clear(Block), clear(ToLoc)], [not(on(Block,FromLoc)), clear(FromLoc), not(clear(ToLoc)), on(Block, ToLoc)] *)*
- What's wrong with this schema?

Action Representation cont'd

- What happens when **ToLoc** is the table?

Action Representation cont'd

- What happens when **ToLoc** is the table?
  - Can only move blocks to the table at certain times.
  - Moving a block to the table makes the table no longer clear (whatever that means, what does "clear" mean anyway?).
  - Then can't move anything to it until it's made clear again.
- How could we fix this?

Action Representation cont'd

- One way: extend domain language by introducing new action for moving blocks to table: **newStack(Block, FromLoc)**
- Also**,** check that **move**'s **ToLoc** is a block: add block type check to preconditions and add block type info to situation descriptions.

Action Representation cont'd

- **move** action schema revisited:
  – op(move, [Block, FromLoc, ToBlock], [on(Block,FromLoc), clear(Block), block(ToBlock), clear(ToBlock)], [not(on(Block,FromLoc)), clear(FromLoc), not(clear(ToBlock)), on(Block, ToBlock)] *)*
- What else is wrong with this schema?

Action Representation cont'd

- What happens if **Block = ToBlock**?
  - **move**'s preconditions are satisfied.
  - But end up with a block being on top of itself.
- How do we fix this?

Action Representation cont'd

- One way would be to add the constraint that **Block** and **ToBlock** can't be the same block to **move**'s preconditions: [on(Block,FromLoc), ..., clear(ToBlock)] => [on(Block,FromLoc), …, clear(ToBlock), *neq(Block,ToBlock)*]

Action Representation cont'd

- Note that *neq(Block,ToBlock)* is a different kind of test from **clear(ToBlock)**.
- The latter tests a situation, while the former tests a planner choice.
- The latter is called an *object-level test* and the former is called a *meta-level test*.

Action Representation cont'd

- Is our description of the **move** action good enough now? How can we tell?

Action Representation cont'd

- Is our description of the **move** action good enough now? How can we tell?
- *It's good enough if the plans our planner creates using these descriptions usually (almost always, …) succeed when we execute them in the "real world".*
- How might it fail?

Action Representation cont’d

- It could fail if our preconditions don’t capture all the relevant tests.
- In general there are an infinite number of preconditions for the represented action to adequately model the real world action.
- This representation problem is known as the *qualification* problem.

Action Representation cont'd

- It could also fail if our effects don't capture all the relevant results.
- In general there are an infinite number of effects for the represented action to adequately model the real world action.
- This representation problem is known as the *ramification* problem.

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Simulation Process

- How do we use the action descriptions to simulate the effect of executing that action in a given situation?
  - The parameters must be instantiated.
  - Simulation checks the action's instantiated preconditions are satisfied by the situation.
  - Positive effect literals are added to the situation and negative effect literals are removed from it.

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Plans & Planning

- Given a problem description with an initial situation description and a goal description, find a plan that transforms initial situation into one that satisfies the goal description.
- How are we going to represent a plan?
  - As a sequence (i.e., list) of steps.
  - A *step* is an instantiated action schema that is part of a plan. Note: there may be many steps that have the same instantiated action schema.

Plans & Planning cont'd

- Note: given a plan and an initial situation, we can simulate the effect of executing each step of the plan upon the resulting situations.

Plans & Planning cont'd

- How do we find an adequate plan?
- One way is the following:
  - Transform the problem description into an initially "empty" plan.
  - Add actions into the "partial" plan until it represents a solution to the problem.

Summary

- Planning is how an intelligent agent figures out how to achieve its goals.
- Planning is becoming quite important as we attempt to build evermore competent agents.
- Newell's Problem Space Hypothesis: problem-solving can be described as states, operators, and search control knowledge.

Summary cont'd

- A problem is an initial situation and a goal description.
- A situation is a set of positive ground object-level literals.
- A goal description is a set of possibly both positive and negative object- and meta-level terms.

Summary cont'd

- A plan is a sequence of steps.
- A step is a domain action.
- A domain action has a name, set of parameters, precondition, and effects.

Summary cont'd

- Creating the predicates and the action descriptions is part of domain engineering.

- Describing domain actions has two problems:
  - Qualification Problem
  - Ramification Problem

Summary cont'd

- We can create pseudo-steps that represent the initial situation and the goal description.
- With these pseudo-steps, we can create empty plans.
- Planning becomes a plan refinement process.
- We will look at one such process next time.