Deliberative Agents

1 Thinking Ahead

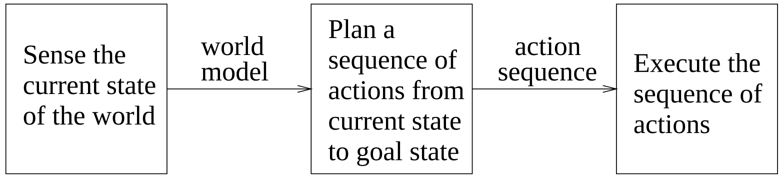
We've assumed that our agents implement, in some form, a sense/plan/act cycle. But so far, the plan phase has been quite simple. In particular, our agents have not done any thinking ahead. In general, to build a more intelligent agent, we require that the plan phase be more deliberative. To choose between actions, agents must think through the consequences of actions 'in their heads' prior to execution. It will often be better still to consider whole *sequences* of actions. (For example, consider the way players think ahead in chess.)

Thinking ahead is a form of simulation: trying out an action or a sequence of actions on a mental representation prior to executing the action(s) in the actual world. Let me stress: during deliberation (simulation), the effects of chosen actions are used to update only the model of the world. There is no execution of actions on the environment during this phase. Only once the plan phase has been completed and an action that we hope will be effective has been chosen, do we move on to the act phase of the cycle and actually execute the action.

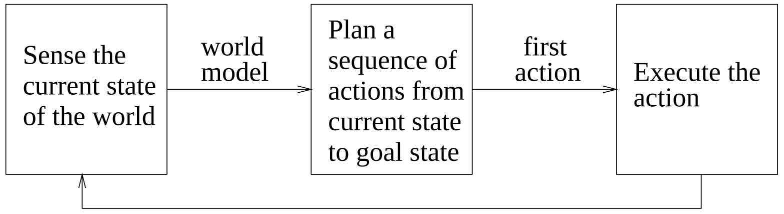
Class exercise. *Can you give more precise reasons why this kind of thinking ahead is advantageous: what can go wrong if you don't think ahead?*

Class exercise. *Are there times when thinking ahead is disadvantageous: what can go wrong if you do think ahead?*

As mentioned above, it is often going to be the case that, during the plan phase, the agent investigates whole sequences of actions. But this gives us at least two ways of constructing our agent. On the one hand, the agent could sense the current state of the world, run its simulation to decide on a sequence of actions that would transform the world from its current state to a goal state, hand this sequence over to the execution phase, and then execute the whole sequence. Such an agent would need to work through the sense/plan/act cycle only once:


Sense the current state of the world
world model
Plan a sequence of actions from current state to goal state
action sequence
Execute the sequence of actions

On the other hand, the agent could sense the current state of the world, run its simulation to decide on a sequence of actions that would transform the world from its current state to a goal state, hand only the first of the actions in the sequence over to the execution phase, and then execute this one action. It would then repeat this sense/plan/act cycle. So, in this scenario, although whole sequences of actions are being investigated, only the first action in the sequence is being executed for real:


Sense the current state of the world
world model
Plan a sequence of actions from current state to goal state
first action
Execute the action

Class exercise. *The second approach appears to be wasteful. But the first approach is suitable only for certain environments. What kinds of environments?*

Of course, these two approaches are extremes. One can imagine intermediate approaches where a handful of actions from the action sequence are executed before the next sense/plan/act cycle.

In what follows, I shall write these notes as if we were using the first approach. This is done for no reason other than to simplify the explanation.

We are also, for the moment, going to assume that we use analogical representations for our models of the world. More complicated algorithms are needed for logical representations, so we postpone looking at them for a while.

Finally, we're going to assume (for no reasons again other than simplicity and concreteness) that our models of the world are always correct and fully-specified (e.g. there will be no 'unknowns' as there were in the lawn mower example).

2 State Space Search

We've been using phrases such as thinking ahead/ planning ahead/ deliberation/ simulation. But the way we implement this process is using *search*.

Unfortunately, the word 'search' has two meanings in AI (and, to a lesser extent, in Computer Science). (Actually, they're not really different, but your understanding might be improved if we keep them separate.)

There is its 'traditional' meaning: where we are seeking some item in a data structure (e.g. linear search or binary search of an array, linked list, file or database table). Obviously, in AI, we sometimes need to carry out such operations (e.g. searching for the first rule in a production system whose condition is true), and so we sometimes use the word 'search' with this 'traditional' meaning.

The other meaning is the more common one in AI, where we have a *graph* (nodes and edges) and we are searching for (trying to find) a *path* (sequences of connected edges) in the graph from one node to another.

Deliberation, then, is about searching for paths in graphs. In this case, we're using *directed graphs* (where each edge has a direction, indicated by an arrowhead). The nodes of the graph represent possible states the world can be in. Each edge between two nodes represents execution of an action, transforming one state to another. One of the nodes represents the initial state of the world, the *start state*. One or more nodes represent *goal states*. The task is to find a path from the node labelled by the start state to one of the nodes labelled by goal states.

Such a graph, of states reachable by sequences of actions from some start state, is called a *state space*.

But...

In Computer Science and Mathematics, such graphs are specified quite *explicitly*. Mathematically, you are given two finite sets: the set of nodes and the set of edges. Implementationally, the graph will typically be stored in memory as a node-and-pointer data structure.

In AI, the graphs (state spaces) can be very large. (Very very large.) (Some people even consider the possibility of graphs with an infinite number of states. But we won't.) Therefore, we do not (and maybe cannot) specify them explicitly. We use an *implicit* specification. State spaces are specified by giving:

- the *start state*;
- the *set of operators* for transforming states to other states; and
- the *goal condition* that can detect whether a state is a goal state or not.

While the graph itself is not usually explicitly given (because it's generally too large), it is, in principle, possible to make it explicit from this implicit specification. Indeed, as search proceeds, the search algorithm will explicitly construct *parts* of the graph in memory.

Note that it is also common to associate numbers with each operator, representing the cost or benefit (in terms of time, money, energy, or whatever) of using the corresponding action. We can then compute the total cost of a path in the graph by summing the costs of the edges along that path. This *path cost function* is typically called g.

3 The 8-Puzzle

Here's an example of a state space. It's a toy example, but it's a huge space. If toy examples give such huge spaces, imagine what real world problems might be like.

In the 8-puzzle, 8 uniquely-numbered tiles sit in a 3×3 grid. The task for an agent is to find a sequence of tile-sliding actions that transforms some initial configuration to some goal configuration. An obvious (analogical) representation for the states is a 3×3 array of integers.

Let's specify a state space for this puzzle.

- The start state might be:

2	8	3
1	6	4
7		5

- It's tempting to think that there are 32 operators: move 1 up, move 1 left, move 1 right, move 1 down, move 2 up,.... But, more compactly, if we can swallow the seeming absurdity of it, we need only 4 operators: for moving the blank:

  if blank is not at top edge **then** move it up
  if blank is not at left edge **then** move it left
  if blank is not at right edge **then** move it right
  if blank is not at bottom edge **then** move it down

- The goal state might be:

1	2	3
8		4
7	6	5

In the lecture, we'll make explicit a small part of this implicitly-specified graph.

This state space has $9! = 362,880$ states.

4 The Water Jugs Problem

Here's another state space example.

An agent has a 4-gallon and a 3-gallon jug. Neither jug has any measuring markers on it. Also available are a tap and a drain, and nothing else. The jugs are initially empty. The goal is to get *exactly* 2 gallons of water into the 4-gallon jug.

An obvious (analogical) representation for the states is a pair of integers $\langle x, y\rangle$, where x is the amount of water in the 4-gallon jug ($x \in \{0, 1, 2, 3, 4\}$) and y is the amount of water in the 3-gallon jug ($y \in \{0, 1, 2, 3\}$).

- The start state is represented by $\langle 0, 0\rangle$.

- The operators are:
  1. **if** $x < 4$ **then** $\langle 4, y\rangle$
  2. **if** $y < 3$ **then** $\langle x, 3\rangle$
  3. **if** $x > 0$ **then** $\langle 0, y\rangle$
  4. **if** $y > 0$ **then** $\langle x, 0\rangle$
  5. **if** $x + y \geq 4 \wedge y > 0$ **then** $\langle 4, y - (4 - x)\rangle$
  6. **if** $x + y \geq 3 \wedge x > 0$ **then** $\langle x - (3 - y), 3\rangle$
  7. **if** $x + y \leq 4 \wedge y > 0$ **then** $\langle x + y, 0\rangle$
  8. **if** $x + y \leq 3 \wedge x > 0$ **then** $\langle 0, x + y\rangle$
- The goal states are any that match the pattern $\langle 2, n\rangle$.

In the lecture, we'll make explicit a small part of this implicitly-specified graph.

This state space has only 20 states, but there are numerous cyclic paths through the graph.

Exercises

Hint (and rant). In these exercises you are asked for analogical representations for states. I am sick (!) of student answers to these questions involving arrays. Just because the 8-tiles puzzle uses arrays, doesn't mean that all answers use arrays. Re-read the notes from the lecture about analogical representations. Use arrays only if they seem like a suitable analogical representation. Otherwise consider the numerous other possibilities: pairs, triples, and more generally, n-tuples; lists; sets; bags; stacks; queues; trees, ...

1. (*Past exam question*) **The Towers of Hanoi Problem**

   There are 3 poles, and there are five disks of different diameters each having a hole in its centre so that it can be slotted onto the poles. The disks are all on the first of the poles and must be moved to the third of the poles. Only one exposed disk may be moved at a time. At all times, the disks on a pole will be in decreasing order of size (smallest on the top).

   While there are straightforward (recursive and non-recursive) algorithms to solve this problem, in this question you formulate it as an AI search problem. You must develop the problem representation on which search algorithms could be used. (Extra marks will be gained for precision.)

   (a) Give an analogical representation for the *states*.
   (b) Give the *start state*.
   (c) Give the *goal state*.
   (d) Give the *operators*. (The easiest formulation uses six operators. Showing one of the six and giving a sentence that explains briefly how the rest differ will suffice.)

2. **The Towers of Brahma Problem**

   There are 3 poles, arranged in a row; there are five disks of different diameters, each having a hole in its centre so that it can be slotted onto the poles. The disks are all on the first of the poles and must be moved to the third of the poles. Only one exposed disk may be moved at a time. At all times, the disks on a pole will be in decreasing order of size (smallest on the top). When moving a disk, it can only be moved to an adjacent tower, i.e. a disk cannot be moved from the leftmost of the 3 poles to the rightmost (or vice versa) in a single move.

If you were formulating this problem as an AI search problem, how would your formulation differ from the one you gave for the Towers of Hanoi, above?

3. (*Very, very hard!*) Consider the following scenario.

   > *Five men and five women have just been married on a tropical island. All now wish to return to the mainland. A boat, which can carry at most three people, is available to ferry the newly-weds back to the mainland. The boat must be crewed by at least one person, male or female, on every trip it makes.*
   >
   > *Libidos are at full stretch and the couples have agreed that no woman should at any point find herself in the company of the other men (even if those men are with their wives!) unless her husband is with her.*

   You must develop the problem representation on which search algorithms could be used. (Extra marks will be gained for precision.)

   (a) Give an analogical representation for the states.
   Give the start state.
   Give the goal state.

   (b) Give the operators.