Embodiment

4-15-16
Good old-fashioned artificial intelligence

In the early days of AI, symbol manipulation was seen as the key to intelligence.

Some of the techniques we’ve studied (e.g. state space search) come from the GOFAI tradition.

Today, we’ll take a whirlwind tour of some GOFAI techniques. In some AI classes you would have studied them for at least a month.
GOFAI: logic

- Agent’s knowledge is represented as boolean propositions about the world.
  - ON(book, bigCube); ON(bigCube, table)
- Other propositions can be inferred from those that are given.
  - A = True and A \Rightarrow B, therefore B = True
- An agent’s actions may change which propositions are true.

Physical symbol system hypothesis: "A physical symbol system has the necessary and sufficient means for general intelligent action."
Some problems with GOFAI logic

- T/F propositions don’t capture uncertainty.
  - The agent’s knowledge will always be incomplete.
  - Some knowledge is inherently probabilistic.
- Propositional logic doesn’t capture time.
- Changes in the state of the world hard to track.
Our alternatives to GOFAI logic

- State space representations.
  - This suffers many of the same problems.
  - State spaces aren’t as committed to completeness and determinism.
- Machine learning approach: generalize from data.
  - Explicitly acknowledges that we are modeling the world approximately.
  - Models can be updated with additional data, rather than discarded.
GOFAI: planning

- The agent’s actions can change which propositions are true.
- Actions have prerequisite propositions.
- Goals are stated as propositions that the agent wants to make true.
- The agent devises a plan of legal actions to achieve the goal propositions.

- Planning : state space search :: approximate Q-learning : Q-learning.
Some problems with GOFAI planning

- Relies on the flawed GOFAI-logic representation of the world.
- Propositions are often a factorization of the state space. The logic representation may be more compact than the state space representation, but the algorithms to find a solution that were polynomial in the state space become combinatorial in the logic representation.
- Deterministic plans don’t work in the real world (recall the eyes-arm-brain demo from last time).
Our alternatives to GOFAI planning

- Q-learning and approximate Q-learning
  - Learn a policy that accounts for uncertainty.
  - Adapt the policy based on experiences.

- Monte Carlo tree search
  - Don’t worry about devising a complete plan from the beginning.
  - Put some effort (simulation) into taking a *reasonable* action at each step.
Frame problem

Which aspects of the world are relevant? Which aspects can change?

How do they change as a result of the agent’s actions?
Symbol grounding problem

What does a variable in a program mean?

This is closely related to the syntax vs. semantics distinction in linguistics.
Embodiment

An embodied agent is one that physically interacts with its environment.

- Embodiment complicates abstract reasoning: we have to deal with error and uncertainty.
- Embodiment simplifies modeling: instead of maintaining a perfect model, just sense the world and react to it.

Embodiment hypothesis: “Intelligence can emerge only from embodied agents.”
An argument for embodiment: evolutionary time

<table>
<thead>
<tr>
<th>Years ago</th>
<th>Types of organisms</th>
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<tbody>
<tr>
<td>3.5 billion</td>
<td>Single cell</td>
</tr>
<tr>
<td>550 million</td>
<td>Fish and invertebrates</td>
</tr>
<tr>
<td>450 million</td>
<td>Insects</td>
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<tr>
<td>370 million</td>
<td>Reptiles</td>
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<tr>
<td>330 million</td>
<td>Dinosaurs</td>
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<tr>
<td>250 million</td>
<td>Mammals</td>
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<tr>
<td>120 million</td>
<td>Primates</td>
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<td>18 million</td>
<td>Great apes</td>
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<tr>
<td>2.5 million</td>
<td>Humans</td>
</tr>
<tr>
<td>5 thousand</td>
<td>Written language</td>
</tr>
</tbody>
</table>
Discussion: hypothesis comparison

Physical symbol system hypothesis: "A physical symbol system has the necessary and sufficient means for general intelligent action."

Embodiment hypothesis: “Intelligence can emerge only from embodied agents.”
Subsumption architecture

A subsumption architecture does away with the idea that one module should be responsible for all deliberation.

Instead, different modules are responsible for different behaviors, and each has access to sensors and actuators.

Modules are organized hierarchically, and if their actions conflict, the higher level asserts control.
Subsumption architecture demo

Level 4: FoundLight
Level 3: AvoidObstacles
Level 2: SeekLight
Level 1: WallFollow
Level 0: Wander