**INTELLIGENT AGENTS**

Outline
- Introduction
- How Agents Should Act
- Structure of Intelligent Agents
- Environments

Based on the textbook by S. Russell & P. Norvig: Artificial Intelligence, A Modern Approach, Chapter 2

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**INTRODUCTION**

- Russell and Norvig define agents as follows:
  
  "An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors."

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**HOW AGENTS SHOULD ACT**

- A rational agent should do the right thing, but how and when do we evaluate agent's success?
- A performance measure determines how successful an agent is (by an outside observer).

Problems:
- Self-deception: humans typically say they did not really want something after they are unsuccessful at getting it.
- Malpractice if performance is measured only instantly.
- You get what you ask for! (Performance measures have to be carefully chosen.)

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Examples:

A physical robot
- Sensors: video camera, laser scanner, microphone, ...
- Effectors: motor, switch, display, speaker, ...

A software robot (softbot)
- Percepts: encoded bit strings
- Sensors and effectors:
  - calls to operating system, libraries or other programs
- Calls to sensor programs provide input for the agent.
Omniscience vs. Rationality

An omniscient agent
- knows the actual outcomes of its actions and acts accordingly.
- is impossible in reality.

Example. A person is crossing a street, as (s)he noticed a friend across the street and there is no traffic nearby.
- Is this person acting rationally if (s)he is crashed by a cargo door falling off a passing airplane?

Rationality: expected success given what has been perceived.

Example. Often begin rational requires performing actions in order to acquire information about the environment.
- For instance, crossing a street without looking is too risky.

Example. A clock can be thought as a simple (even degenerate) agent that keeps moving its hands (or displaying digits) in the proper way.
- This can be thought as rational action given what kind of functionality one expects from a clock in general.
- However, many clocks are unable to take changing time zones into account automatically. This is quite acceptable if the clock does not have a mechanism for perceiving time zones.

Ideal Rational Agent

Rationality depends on four things:
- Performance measure which defines degree of success
- Percept sequence (complete perceptual history)
- Agent’s knowledge about the environment
- Agent’s actions

Definition. (Ideal rational agent)
For each possible percept sequence, an ideal rational agent should do whatever action which is expected to maximize its performance measure, on the basis of the evidence provided by the percept sequence and whatever built-in knowledge the agent has.

Mapping Percept Sequences to Actions

- Agent’s behavior depends only on its percept sequence to date.
- An ideal agent can be designed by
  “specifying which action an agent ought to take in response to any given percept sequence”.
- The mapping can be represented as a table or as a program.

Example. Consider a calculator agent that computes square roots of positive integers (accurate to 15 decimals).
- Approach 1: store square roots in a very large table.
- Approach 2: implement the ideal mapping as a program.
  The latter approach is clearly more compact and flexible.
An agent lacks autonomy if its actions depend solely on its built-in knowledge about the environment.

A system is autonomous to the extent that its behavior is determined by its own experience.

Flexible operation in a variety of environments demands ability to learn (in addition to initial knowledge).

Example. After digging its nest and laying its eggs, a dung beetle fetches a ball of dung to plug the entrance.

Even if the ball is removed from its grasp en route, the beetle continues and mimics the procedure to the very end.

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**Examples. PACE descriptions for some types of agents.**

<table>
<thead>
<tr>
<th>Agent Type</th>
<th>Percepts</th>
<th>Actions</th>
<th>Goals</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical diagnosis system</td>
<td>Symptoms, findings, patient’s answers</td>
<td>Question, tests, treatments</td>
<td>Healthy patient, minimize costs</td>
<td>Patient, hospital</td>
</tr>
<tr>
<td>Satellite image analysis system</td>
<td>Peak of varying intensity, color</td>
<td>Print a categorization of scene</td>
<td>Correct categorization</td>
<td>Images from orbiting satellite</td>
</tr>
<tr>
<td>Part-picking robot</td>
<td>Peak of varying intensity</td>
<td>Pick up parts and sort into bins</td>
<td>Place parts in connections</td>
<td>Conveyor belt, with parts</td>
</tr>
<tr>
<td>Refinery controller</td>
<td>Temperature, pressure readings</td>
<td>Open, close valves, adjust temperature</td>
<td>Maintain purity, yield, safety</td>
<td>Refinery</td>
</tr>
<tr>
<td>Interactive English tutor</td>
<td>Typed words</td>
<td>Print exercises, suggestions, corrections</td>
<td>Maintain student’s score on test</td>
<td>Set of students</td>
</tr>
</tbody>
</table>

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**Structure of Intelligent Agents**

- The goal is to design an agent program which implements the mapping from percepts to actions.
- An architecture is a computing device that makes percepts available, runs the program and feeds action choices to effectors.
- Summarizing: agent = architecture + program.
- Agents can be roughly categorized by identifying their percepts, actions, goals and environments (so-called PACE descriptions).

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**Agent Programs**

A skeleton for agent programs:

- A single percept is obtained as input.
- Memory is used for storing the percept history (if necessary).
- The program chooses and outputs an action to be executed next.

```java
function SKELETON-AGENT(percept) returns action
    static memory = the agent's memory of the world
    memory += UPDATE-MEMORY(memory, percept)
    action += CHOOSE-BEST-ACTION(memory)
    memory += UPDATE-MEMORY(memory, action)
    return action
```

- The performance measure is not a part of the program.
Using Lookup Tables

An agent program that looks up the action from a table:

```c
function TABLE-DRIVEN-AGENT(percept) return action
    static: percept, a sequence, initially empty
    a table, indexed by percept sequences, initially fully specified
    append percept to the end of percept
    action ← LOOKUP(percept, table)
    return action
```

Drawbacks of lookup table agents:
1. The lookup table becomes easily very large
   (a chess playing agent would need a table with 35^{100} entries).
2. The table is difficult to build and maintain.
3. The resulting agent does not have autonomy at all.

Different Kinds of Agent Programs

In the sequel, we will consider four kinds of agent programs:

- Simple reflex agent
- Agents that keep track of the world
- Goal-based agents
- Utility-based agents

Example

Consider designing an automated taxi driving agent with the following PAGE description:

<table>
<thead>
<tr>
<th>Agent Type</th>
<th>Percepts</th>
<th>Actions</th>
<th>Goals</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi-driver</td>
<td>Cameras, speedo,</td>
<td>Steer, accelerate, brake,</td>
<td>Safe, fast, legal,</td>
<td>Roads, other</td>
</tr>
<tr>
<td></td>
<td>GPS, sonar, micro</td>
<td>talk to passenger</td>
<td>comfortable trip,</td>
<td>traffic, pedestrians</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>maximize profits</td>
<td>customers</td>
</tr>
</tbody>
</table>

The full driving task is extremely open-ended; an unlimited number of novel combinations of circumstances can arise.

Performance measures: (i) getting to the correct destination, (ii) minimizing fuel consumption, trip time/cost, and traffic violations, (iii) maximizing safety, passenger comfort, and profits.

Simple Reflex Agents

- Condition-action rules provide a way to represent common regularities appearing in input/output associations:
  
  ```
  if car-in-front-is-braking then initialize-braking
  ```
- It is even possible to learn such rules on the fly.
- Humans also have many such connections some of which are learned responses and some of which are innate reflexes (such as eye blinking in order to protect the eye).
- Mimicking reflexes of living creatures, a reflex agent chooses the next action on the basis of the current percept.
- No track of the world/environment is kept.
The structure of a simple reflex agent as a schematic diagram and the corresponding skeletal agent program:

![Diagram of a simple reflex agent]

Rules provide an efficient representation, but one problem is that decision making is seldom possible on the basis of a single percept.

Reflex Agents with Internal State

- The choice of actions may depend on the entire percept history.
- Sensors do not necessarily provide access to the complete state of the environment.
- The agent keeps track of the world by extracting relevant information from percepts and storing it in its memory.
- Using a model of the environment, the agent may try to estimate
  1. how the environment evolves in the (near) future, and
  2. how the environment is affected by the agent's actions.

Example. In our taxi driving example, actions may depend on the state, e.g. the position of an overtaking car.

Goal-based agents

- Knowing about the current state of the environment is not necessarily enough for deciding what to do.
- In addition, the agent may need goals to distinguish which situations are desirable and which are not.
- Goal information can be combined with the agent's knowledge about the results of possible actions in order to choose an action leading to a goal.
- Problem: goals are not necessarily achievable by a single action.
- Search and planning are subfields of AI devoted to finding actions sequences that achieve the agent's goals.
A schematic diagram for a goal-based agent:

- Additional flexibility compared to previous designs: the behavior of a goal-based agent can be changed by changing its goal(s).

Utility-based agents

- Goals alone are not sufficient for decision making if there are several ways of achieving them.
- Further problem: agents may have several conflicting goals that cannot be achieved simultaneously.
- If an agent prefers one world state to another state then the former state has higher utility for the agent.
- Utility is a function that maps a state onto a real number.
- Utility can be used for (i) choosing the best plan, (ii) resolving conflicts among goals, and (iii) estimating the successfulness of an agent if the outcomes of actions are uncertain.

A schematic diagram for a utility-based agent:

- An agent that possesses an explicit utility function can make rational decisions, but may have to compare the utilities achieved by different courses of actions.

Environments

- All the preceding agent designs are based on the same interconnection between an agent and its environment:
  1. The agent performs actions on the environment.
  2. The environment provides percepts to the agent.
- Environments can be distinguished by their properties which in turn affect the design of respective agents.
- Environment programs (that simulate particular environments) can be used as testbeds for agent programs.
Properties of Environments

Environments can be categorized by several aspects such as

- Accessible vs. inaccessible
- Deterministic vs. nondeterministic (from the agent's point of view)
- Episodic vs. nonepisodic
- Static vs. dynamic
- Discrete vs. continuous

Examples. Analyzing properties of a number of familiar environments.

<table>
<thead>
<tr>
<th>Environment</th>
<th>Accessible</th>
<th>Deterministic</th>
<th>Episodic</th>
<th>Static</th>
<th>Discrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chess with a clock</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Semi</td>
<td>Yes</td>
</tr>
<tr>
<td>Chess without a clock</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Poker</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Backgammon</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Taxi driving</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Medical diagnosis system</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Image analysis system</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Semi</td>
<td>No</td>
</tr>
<tr>
<td>Part-picking robot</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Retail inventory controller</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Interactive English tutor</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- Some of the properties are dependent on how the environments and agents are conceptualized.

The performance of agents can be measured by inserting special measurement code to simulator programs.
**SUMMARY**

- An agent program maps a percept (sequence) to an action.
- Agent = architecture + agent program
- An ideal agent maximizes its performance measure.
- An agent can be described by its percepts, actions, goals and environment (PAGE description).
- Various agent types: reflex agents with(out) internal state, goal-based agents, utility-based agents
- Important aspects of agent program design: efficiency, compactness, flexibility

**Knowledge-based Agents**

```plaintext
function KB-AGENT(percept) returns an action
    static: KB, a knowledge base
    t, a counter, initially 0, indicating time
    TELL(KB, MAKE-PERCEPT-SENTENCE(percept, t))
    action ← ASK(KB, MAKE-ACTION-QUERY())
    TELL(KB, MAKE-ACTION-SENTENCE(action, t))
    t ← t + 1
    return action
```

- Incomplete information
- Uncertainty
- Probability

**Planning Agents**

```plaintext
function SIMPLE-PLANNING-AGENT(percept) returns an action
    static: KB, a knowledge base (includes action descriptions)
    p, a plan, initially NoPlan
    t, a counter, initially 0, indicating time
    local variables: G, a goal
    current, a current state description
    TELL(KB, MAKE-PERCEPT-SENTENCE(percept, t))
    current ← STATE-DESCRIPTION(KB, t)
    if p = NoPlan then
        G ← ASK(KB, MAKE-GOAL-QUERY())
        p ← IDEAL-PLANNER(current, G, KB)
    if p = NoPlan or p is empty then action ← NoOp
    else
        action ← FIRST(p)
        p ← REST(p)
        TELL(KB, MAKE-ACTION-SENTENCE(action, t))
        t ← t + 1
    return action
```
Questions

- Analyze soccer playing agents by writing down
  1. a PAGE description, and
  2. main properties of the environment.

- Consider the following designs for soccer playing agents:
  1. Simple reflex agent
  2. Reflex agent with internal state
  3. Agent with explicit goals
  4. Utility-based agent
  5. Planning agent
  6. Learning agent
What kind of functionality can be implemented using these?