Foundations of AI

2. Rational Agents

Nature and structure of rational agents and their environments

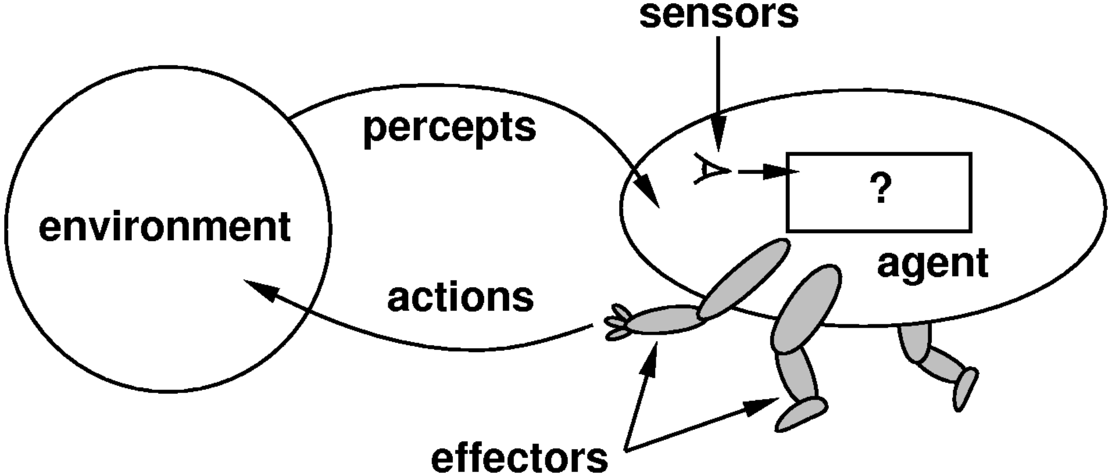
Wolfram Burgard, Andreas Karwath, Bernhard Nebel, and Martin Riedmiller

Contents

- What is an agent?
- What is a *rational agent*?
- The structure of rational agents
- Different classes of agents
- Types of environments

Agents

- Perceive the environment through sensors
  (→ Percepts)
- Act upon the environment through actuators
  (→ Actions)



Examples: Humans and animals, robots and software agents (softbots), temperature control, ABS, …

Rational Agents

… do the “right thing”!

In order to evaluate their performance, we have to define a performance measure.

Autonomous vacuum cleaner example:

- m^2 per hour
- Level of cleanliness
- Energy usage
- Noise level
- Safety (behavior towards hamsters/small children)

Optimal behavior is often unattainable

- Not all relevant information is perceivable
- Complexity of the problem is too high

Rationality vs. Omniscience

- An *omniscient agent* knows the *actual effects* of its *actions*
- In comparison, a *rational agent* behaves according to its *percepts* and *knowledge* and attempts to *maximize the expected performance*
- Example: If I look both ways before crossing the street, and then as I cross I am hit by a meteorite, I can hardly be accused of lacking rationality.

The Ideal Rational Agent

Rational behavior is dependent on

- Performance measures (goals)
- Percept sequences
- Knowledge of the environment
- Possible actions

Ideal rational agent: *For each possible percept sequence, a rational agent should select an action that is expected to maximize its performance measure, given the evidence provided by the percept sequence and whatever built-in knowledge the agent has.*

Active perception is necessary to avoid trivialization.

The ideal rational agent acts according to the function

Percept Sequence x World Knowledge → Action

Examples of Rational Agents

Agent Type	Performance Measure	Environment	Actuators	Sensors
Medical diagnosis system	healthy patient, minimize costs, lawsuits	patient, hospital, stuff	display questions, tests, diagnoses, treatments, referrals	keyboard entry of symptoms, findings, patient’s answers
Satellite image analysis system	correct image categorization	downlink from orbiting satellite	display categorization of scene	color pixel arrays
Part-picking robot	percentage of parts in correct bins	conveyor belt with parts, bins	jointed arm and hand	camera, joint angle sensors
Refinery controller	maximize purity, yield safety	refinery, operators	valves, pumps, heaters, displays	temperature, pressure, chemical sensors
Interactive English tutor	maximize student’s score on test	set of students, testing agency	display exercises, suggestions, corrections	keyboard entry

Structure of Rational Agents

Realization of the ideal mapping through an

- *Agent program*, executed on an
- *Architecture* which also provides and interface to the environment (percepts, actions)

→ Agent = Architecture + Program

The Simplest Design: Table-Driven Agents

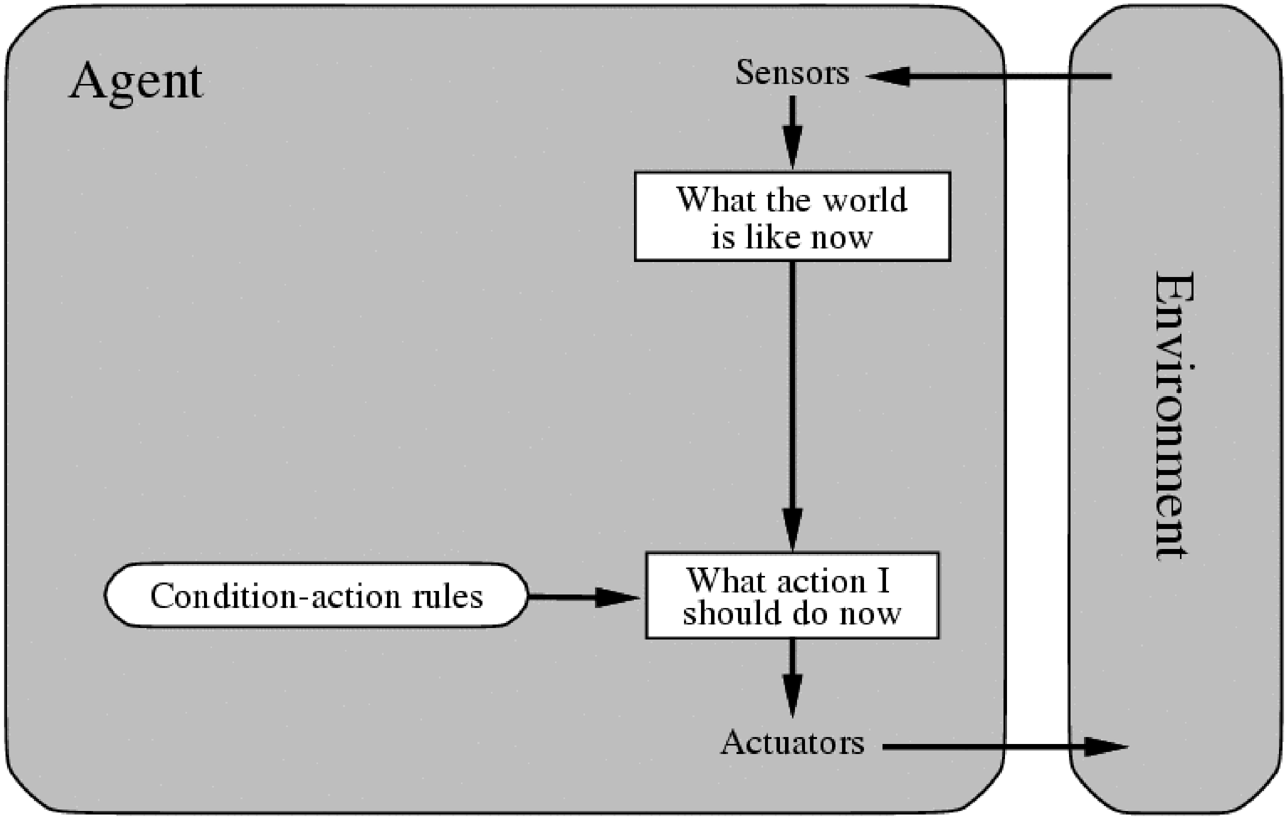
```
function TABLE-DRIVEN-AGENT(percept) returns an action
  static: percepts, a sequence, initially empty
          table, a table of actions, indexed by percept sequences, initially fully specified

  append percept to the end of percepts
  action ← LOOKUP(percepts, table)
  return action
```

Problems:

- The table can become very large
- and it usually takes a very long time for the designer to specify it (or to learn it)
- … practically impossible

Simple Reflex Agent



Direct use of perceptions is often not possible due to the large space required to store them (e.g., video images).

Input therefore is often interpreted before decisions are made.

Interpretative Reflex Agents

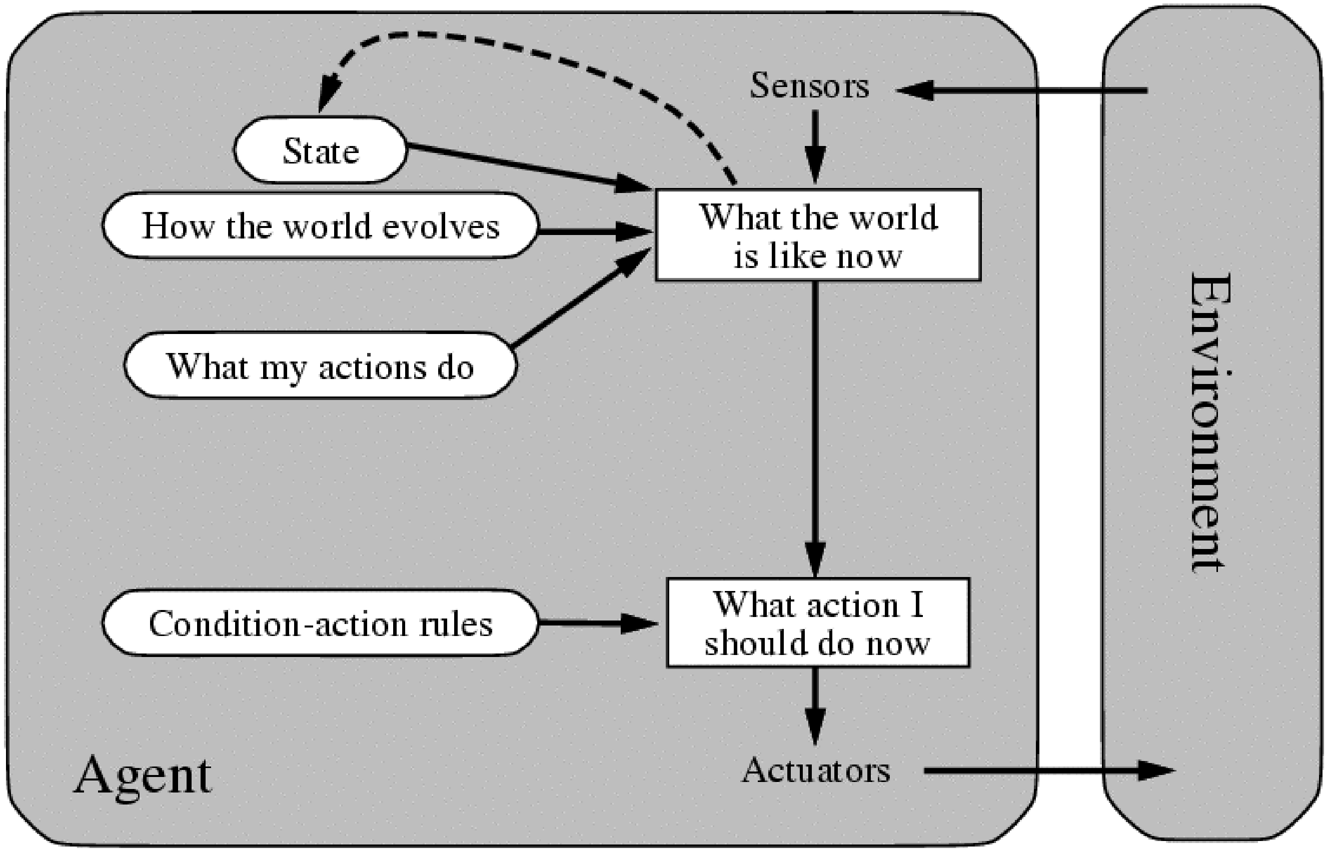
Since storage space required for perceptions is too large, direct interpretation of perceptions

```
function SIMPLE-REFLEX-AGENT(percept) returns action
  static: rules, a set of condition-action rules

  state ← INTERPRET-INPUT(percept)
  rule ← RULE-MATCH(state, rules)
  action ← RULE-ACTION[rule]
  return action
```

Structure of Model-based Reflex Agents

In case the agent's history in addition to the actual percept is required to decide on the next action, it must be represented in a suitable form.



A Model-based Reflex Agent

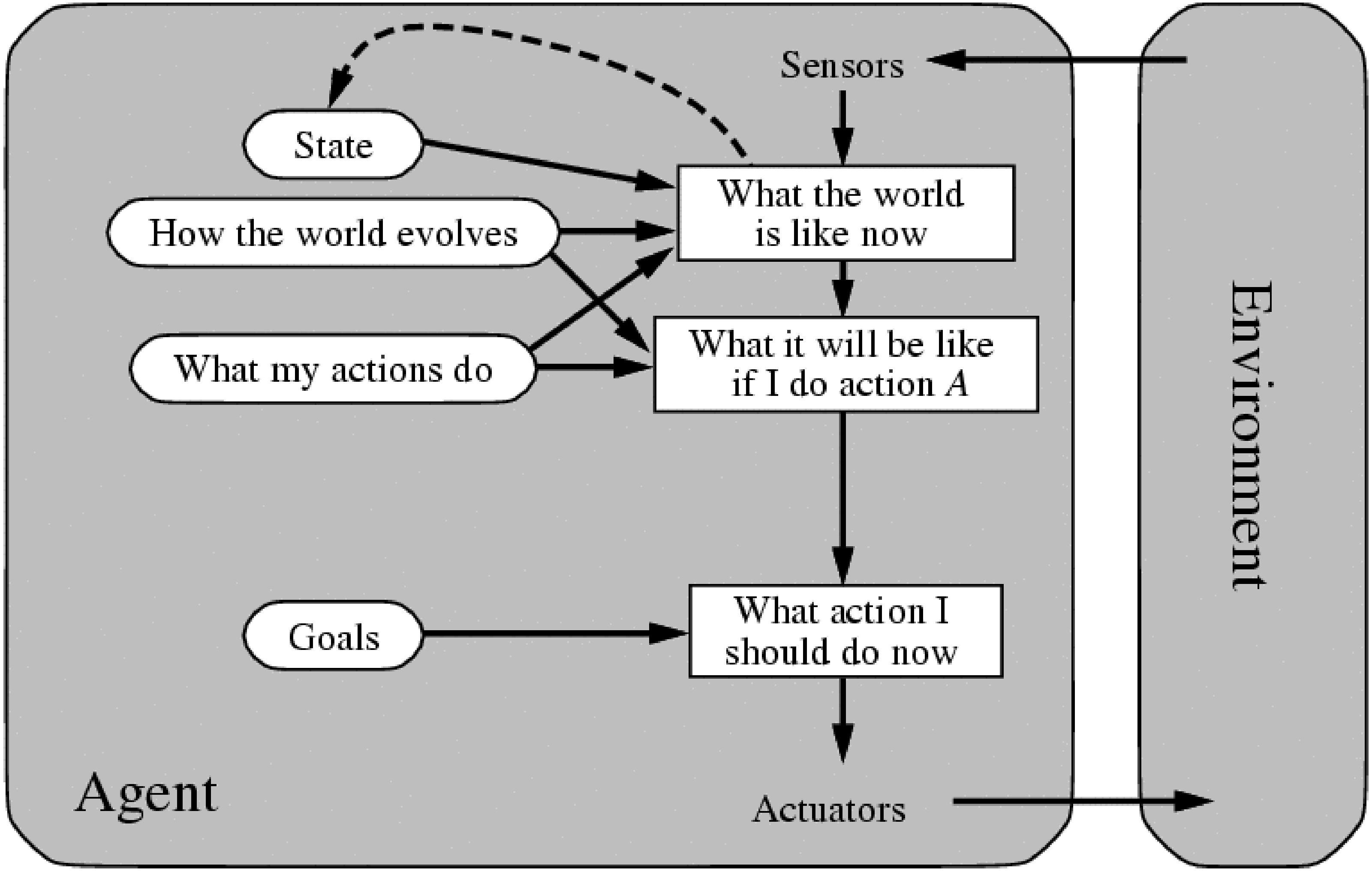
```
function REFLEX-AGENT-WITH-STATE(percept) returns an action
  static: state, a description of the current world state
          rules, a set of condition-action rules
          action, the most recent action, initially none

  state ← UPDATE-STATE(state, action, percept)
  rule ← RULE-MATCH(state, rules)
  action ← RULE-ACTION[rule]
  return action
```

Model-based, Goal-based Agents

- Often, percepts alone are insufficient to decide what to do.
- This is because the correct action depends on the given explicit goals (e.g., go towards X).
- The model-based, goal-based agents use an explicit representation of goals and consider them for the choice of actions.

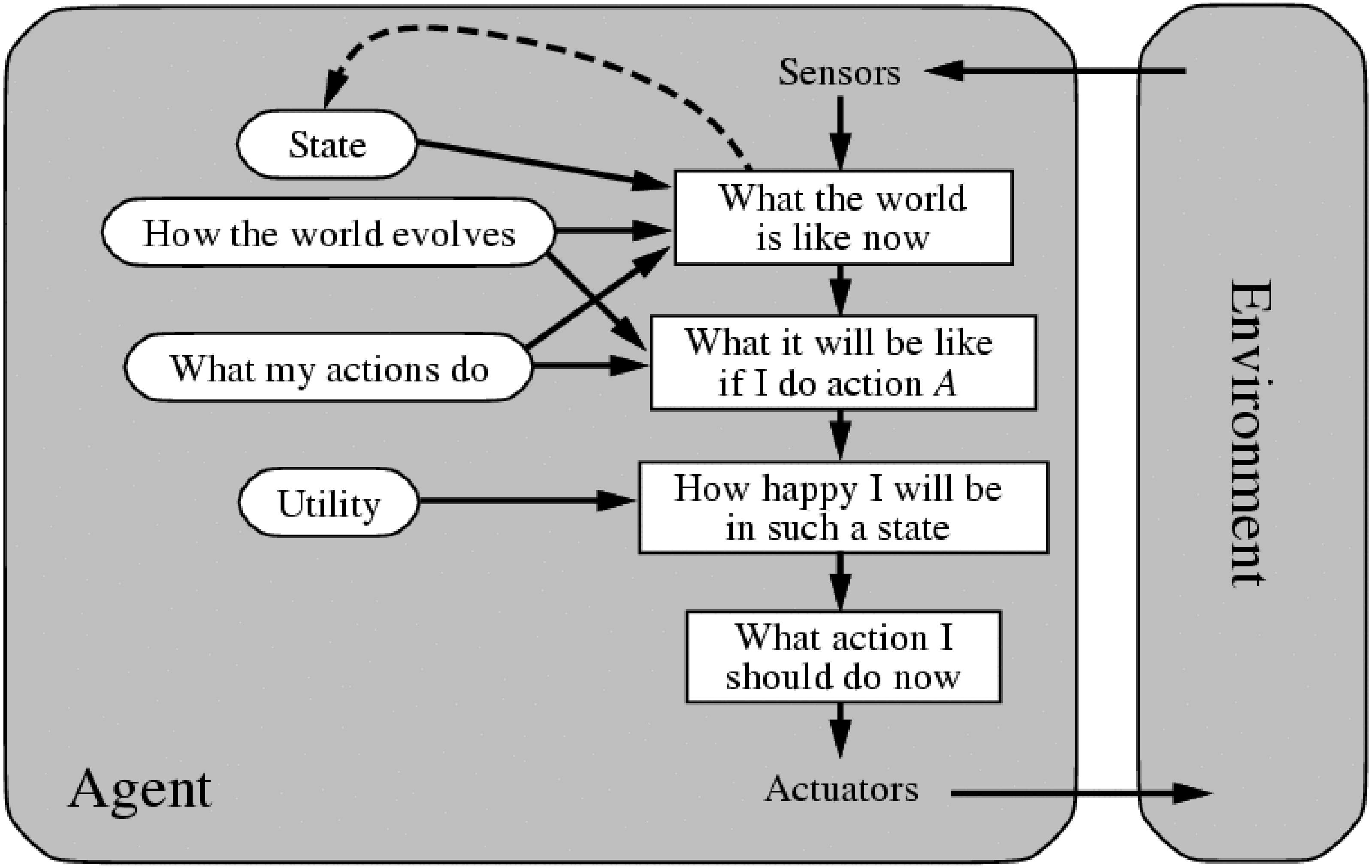
Model-based, Goal-based Agents



Model-based, Utility-based Agents

- Usually, there are several possible actions that can be taken in a given situation.
- In such cases, the utility of the next achieved state can come into consideration to arrive at a decision.
- A utility function maps a state (or a sequence of states) onto a real number.
- The agent can also use these numbers to weigh the importance of competing goals.

Model-based, Utility-based Agents



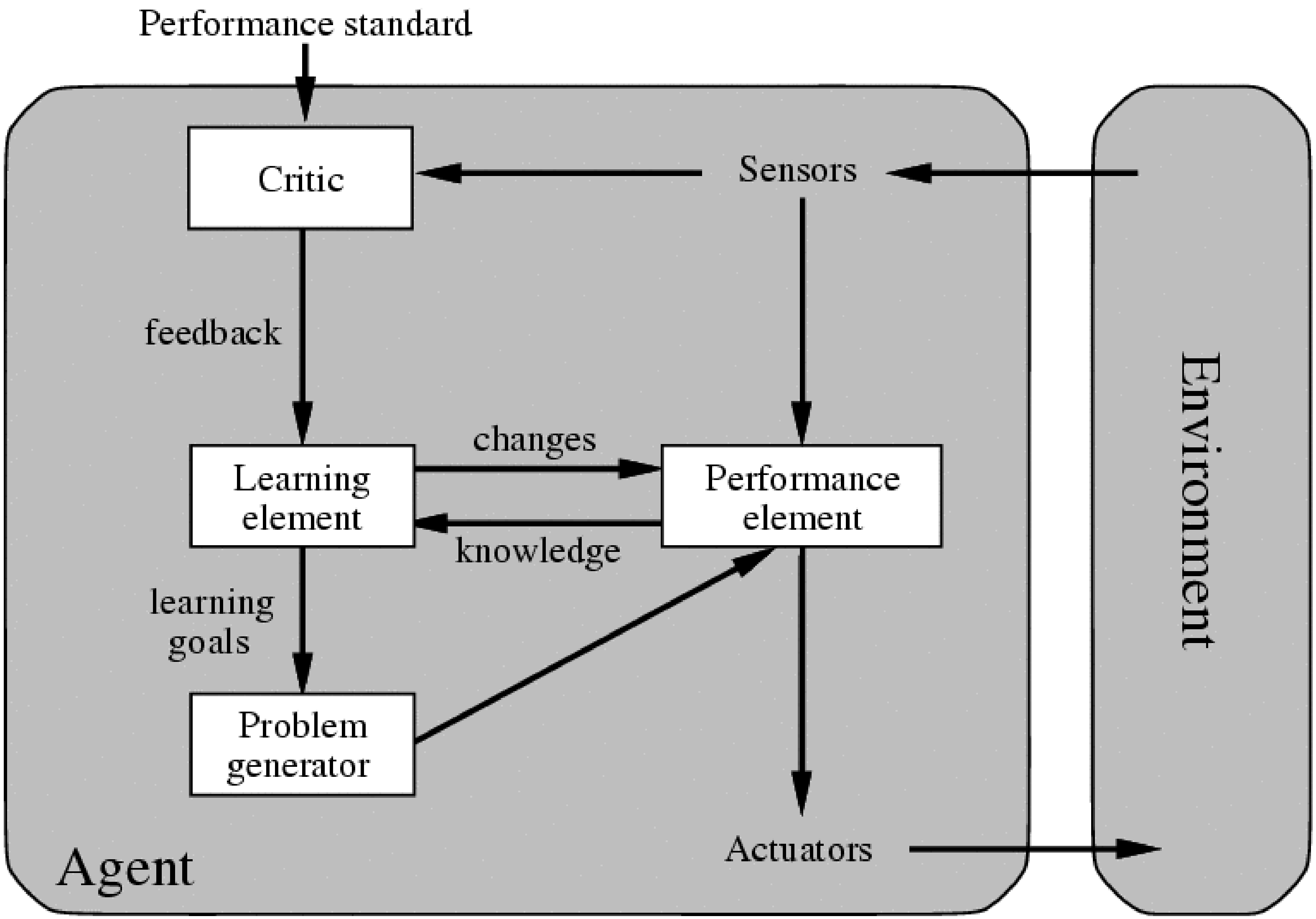
Learning Agents

- Learning agents can become more competent over time.
- They can start with an initially empty knowledge base.
- They can operate in initially unknown environments.

Components of Learning Agents

- learning element (responsible for making improvements)
- performance element (has to select external actions)
- critic (determines the performance of the agent)
- problem generator (suggests actions that will lead to informative experiences)

Learning Agents



The Environment of Rational Agents

- Accessible vs. inaccessible (fully observable vs. partially observable)

  Are the relevant aspects of the environment accessible to the sensors?
- Deterministic vs. stochastic

  Is the next state of the environment completely determined by the current state and the selected action? If only actions of other agents are nondeterministic, the environment is called strategic.
- Episodic vs. sequential

  Can the quality of an action be evaluated within an episode (perception + action), or are future developments decisive for the evaluation of quality?
- Static vs. dynamic

  Can the environment change while the agent is deliberating? If the environment does not change but if the agent's performance score changes as time passes by the environment is denoted as semi-dynamic.
- Discrete vs. continuous

  Is the environment discrete (chess) or continuous (a robot moving in a room)?
- Single agent vs. multi-agent

  Which entities have to be regarded as agents? There are competitive and cooperative scenarios.

Examples of Environments

Task	Observable	Deterministic	Episodic	Static	Discrete	Agents
Crossword puzzle	fully	deterministic	sequential	static	discrete	single
Chess with a clock	fully	strategic	sequential	semi	discrete	multi
poker	partially	stochastic	sequential	static	discrete	multi
backgammon	fully	stochastic	sequential	static	discrete	multi
taxi driving	partially	stochastic	sequential	dynamic	continuous	multi
medical diagnosis	partially	stochastic	sequential	dynamic	continuous	single
image analysis	fully	deterministic	episodic	semi	continuous	single
part-picking robot	partially	stochastic	episodic	dynamic	continuous	single
refinery controller	partially	stochastic	sequential	dynamic	continuous	single
Interactive English tutor	partially	stochastic	sequential	dynamic	discrete	multi

Whether an environment has a certain property also depends on the conception of the designer.

Summary

- An agent is something that perceives and acts. It consists of an architecture and an agent program.
- An ideal rational agent always takes the action that maximizes its performance given the percept sequence and its knowledge of the environment.
- An agent program maps from a percept to an action.
- There are a variety of designs
  - Reflex agents respond immediately to percepts.
  - Goal-based agents work towards goals.
  - Utility-based agents try to maximize their reward.
  - Learning agents improve their behavior over time.
- Some environments are more demanding than others.
- Environments that are partially observable, nondeterministic, strategic, dynamic, and continuous and multi-agent are the most challenging.