CS 5/7320 Artificial Intelligence

Intelligent Agents
AIMA Chapter 2

Slides by Michael Hahsler
based on slides by Svetlana Lazepnik
with figures from the AIMA textbook.

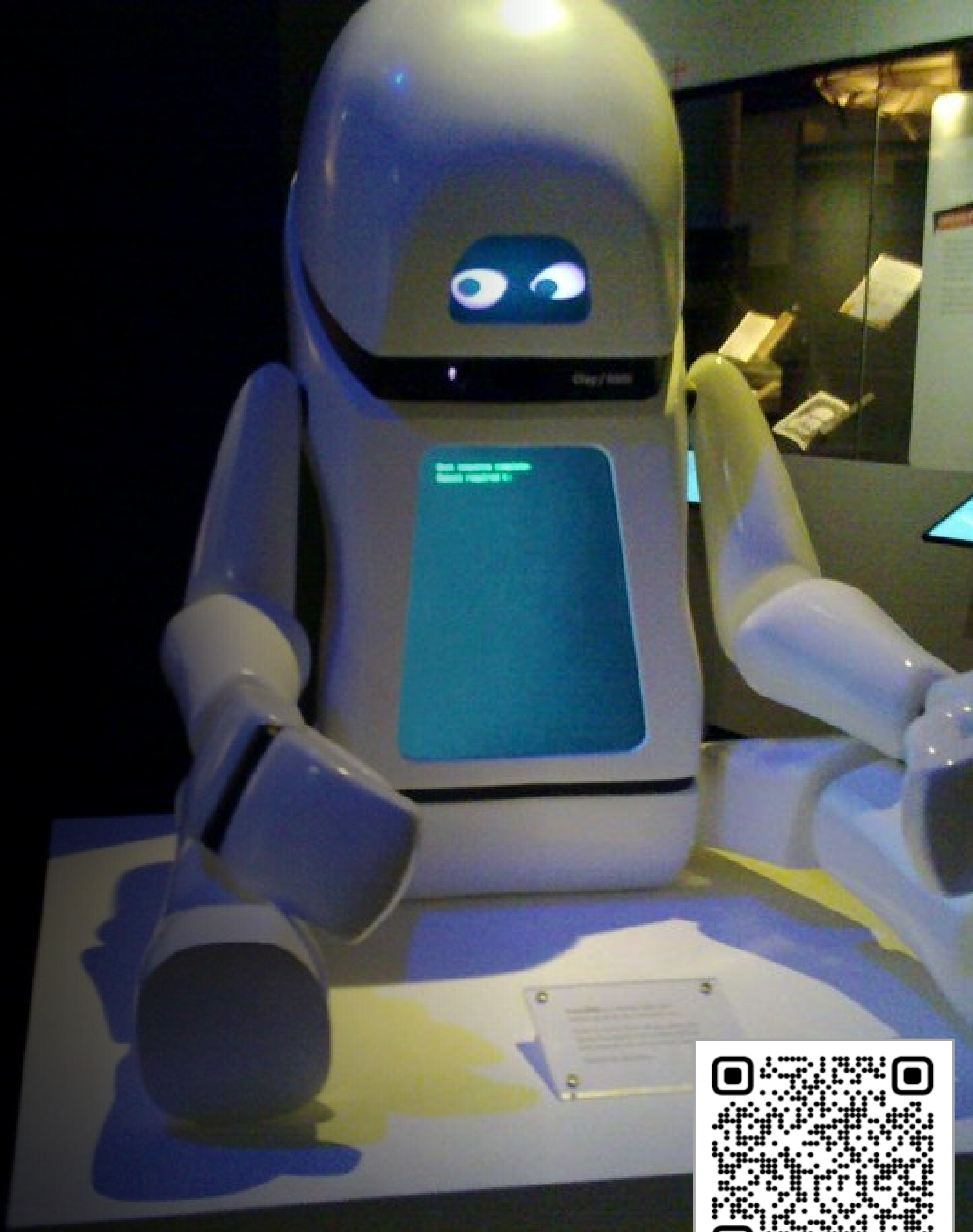

Image: "Robot at the British Library Science Fiction Exhibition" by BadgerGravling

Online Material

Outline

- What is an intelligent agent?
- Rationality
- PEAS (Performance measure, Environment, Actuators, Sensors)
- Environment types
- Agent types

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- What is an intelligent agent?
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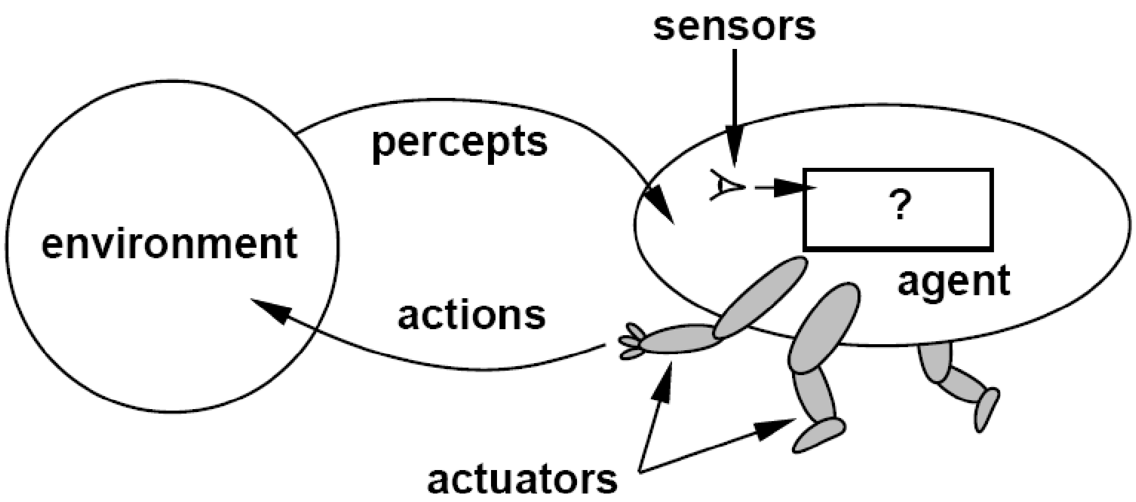
What is an Agents?

- An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators.

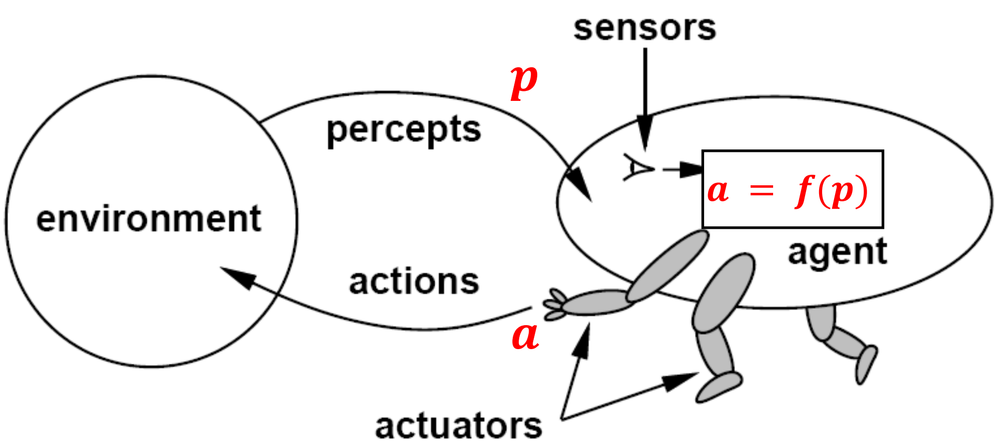


- **Control theory**: A **closed-loop control system** (= feedback control system) is a set of mechanical or electronic devices that automatically regulate a process variable to a desired state or set point without human interaction. The agent is called a controller.
- **Softbot**: Agent is a software program that runs on a host device.

Agent Function and Agent Program

The agent function maps from the set of all possible *percept sequences* P^* to the *set of actions* A formulated as an abstract mathematical function.

$$f : P^* \rightarrow A$$

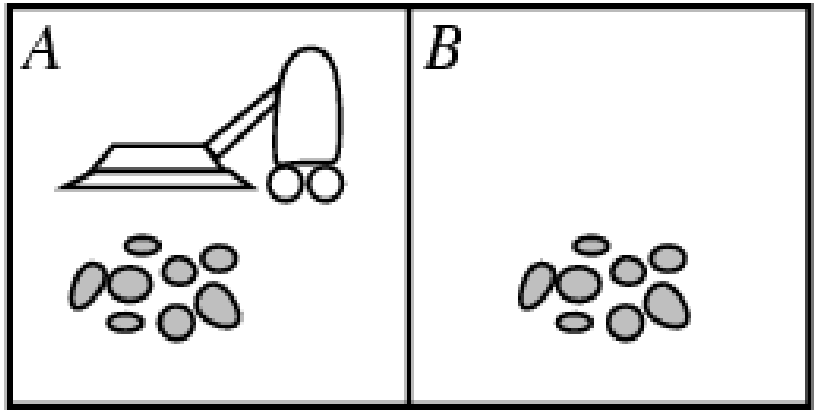


The agent program is a concrete implementation of this function for a given physical system.

Agent = architecture (hardware) + agent program (implementation of f)

- Sensors
- Memory
- Computational power

Example: Vacuum-cleaner World



- **Percepts:**
  Location and status,
  e.g., [A, Dirty]
- **Actions:**
  Left, Right, Suck, NoOp

Most recent Percept p

Agent function: $f : P^* \rightarrow A$

Percept Sequence	Action
[A, Clean]	Right
[A, Dirty]	Suck
…	
[A, Clean], [B, Clean]	Left
…	
[A, Clean], [B, Clean], [A, Dirty]	Suck
…	

Implemented agent program:

function Vacuum-Agent([location, status])
returns an action a

```
if status = Dirty then return Suck
else if location = A then return Right
else if location = B then return Left
```

Problem: This table can become infinitively large!

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- What is an intelligent agent?
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Rational Agents: What is Good Behavior?

Foundation

- **Consequentialism**: Evaluate behavior by its consequences.
- **Utilitarianism**: Maximize happiness and well-being.

Definition of a rational agent:

*"For each possible percept sequence, a rational agent should select an **action** that **maximizes its expected performance measure**, given the evidence provided by the **percept sequence** and the **agent's built-in knowledge**."*

- **Performance measure**: An *objective* criterion for success of an agent's behavior (often called utility function or reward function).
- **Expectation**: Outcome averaged over all possible situations that may arise.

Rule: Pick the action that maximize the expected utility

$$a = \mathrm{argmax}_{a \in \mathrm{A}} \, E(U \mid a)$$

Rational Agents

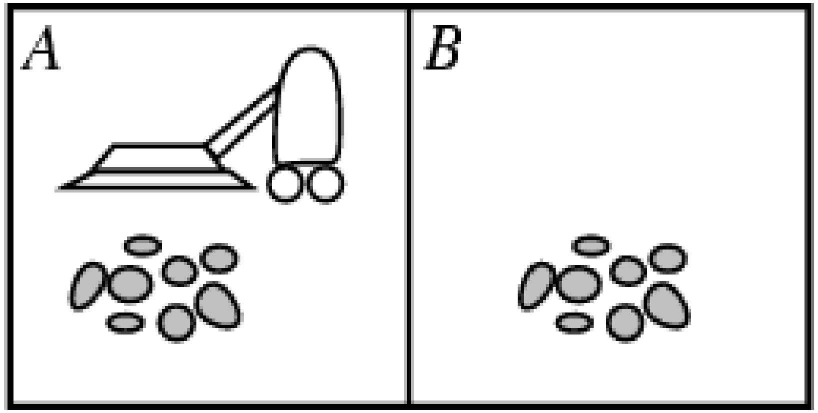
Rule: Pick the action that maximize the expected utility

$$a = \text{argmax}_{a \in \text{A}}\, E(U \mid a)$$

This means:

- **Rationality is an ideal** – it implies that no one can build a better agent
- **Rationality ≠ Omniscience** – rational agents can make mistakes if percepts and knowledge do not suffice to make a good decision
- **Rationality ≠ Perfection** – rational agents maximize **expected** outcomes not actual outcomes
- **It is rational to explore and learn** – I.e., **use percepts** to supplement prior knowledge and become autonomous
- **Rationality is often bounded** by available memory, computational power, available sensors, etc.

Example: Vacuum-cleaner World



- **Percepts:**
  Location and status,
  e.g., [A, Dirty]
- **Actions:**
  Left, Right, Suck, NoOp

Agent function:

Percept Sequence	Action
[A, Clean]	Right
[A, Dirty]	Suck
…	
[A, Clean], [B, Clean]	Left
…	

Implemented agent program:

function Vacuum-Agent([location, status])
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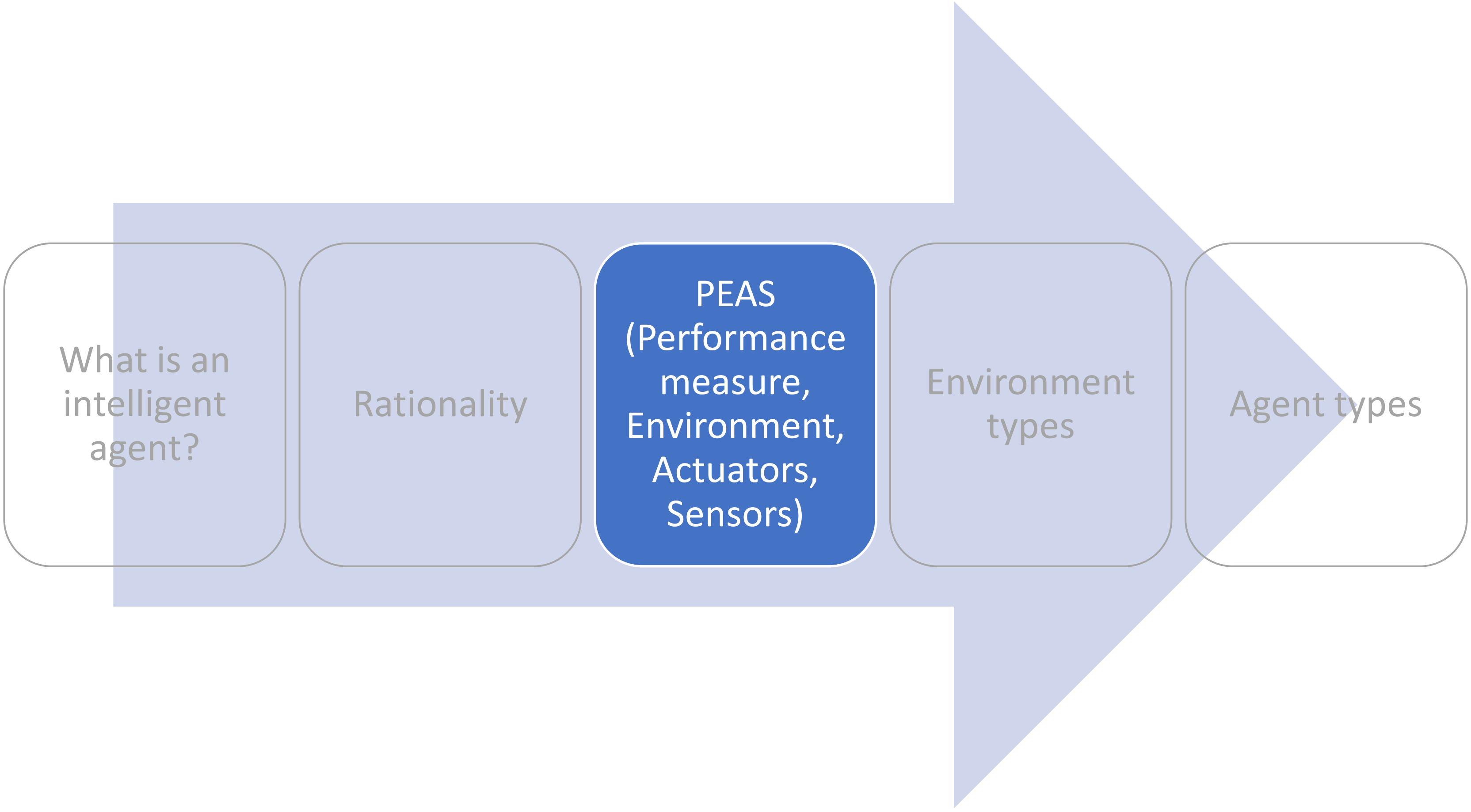
```

What could be a performance measure?
Is this agent program rational?

Outline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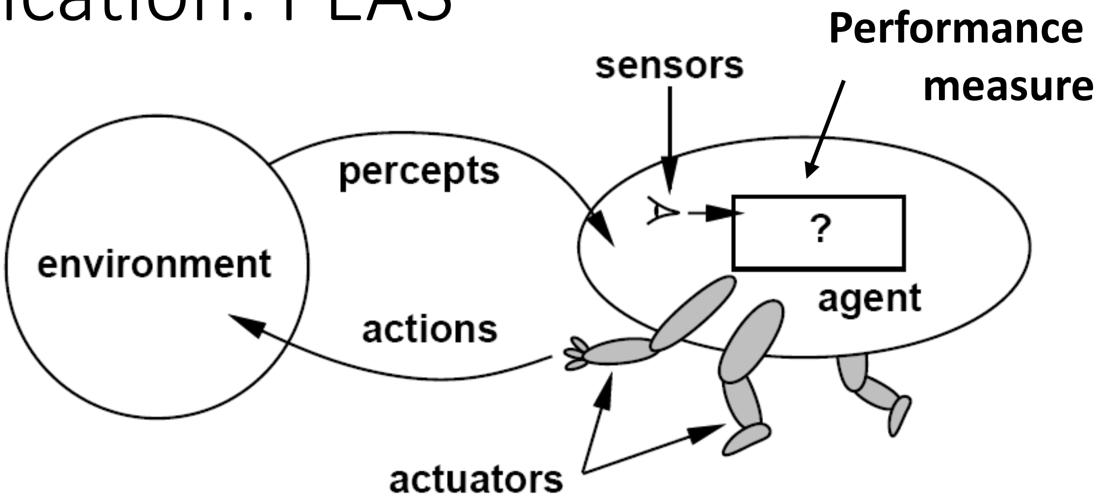
Problem Specification: PEAS



Performance measure	Environment	Actuators	Sensors

Defines utility and what is rational

Components and rules of how actions affect the environment.

Defines available actions

Defines percepts

Example: Automated Taxi Driver

Performance measure	Environment	Actuators	Sensors
• Safe • fast • legal • comfortable trip • maximize profits	• Roads • other traffic • pedestrians • customers	• Steering wheel • accelerator • brake • signal • horn	• Cameras • sonar • speedometer • GPS • Odometer • engine sensors • keyboard

Example: Spam Filter

Performance measure	Environment	Actuators	Sensors
• Accuracy: Minimizing false positives, false negatives	• A user's email account • email server	• Mark as spam • delete • etc.	• Incoming messages • other information about user's account

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- What is an intelligent agent?
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- **Environment types**
- Agent types

Environment Types

Fully observable: The agent's sensors give it access to the complete state of the environment. The agent can “see” the whole environment.

vs.

Partially observable: The agent cannot see all aspects of the environment. E.g., it can’t see through walls

Deterministic: Changes in the environment is completely determined by the current state of the environment and the agent’s action.

vs.

Stochastic: Changes cannot be determined from the current state and the action (there is some randomness).
Strategic: The environment is stochastic and adversarial. It chooses actions strategically to harm the agent. E.g., a game where the other player is modeled as part of the environment.

Known: The agent knows the rules of the environment and can predict the outcome of actions.

vs.

Unknown: The agent cannot predict the outcome of actions.

Environment Types

Static: The environment is **not** changing while agent is deliberating.
Semidynamic: the environment is static, but the agent's performance score depends on how fast it acts.

vs.

Dynamic: The environment is changing while the agent is deliberating.

Discrete: The environment provides a fixed number of distinct percepts, actions, and environment states. Time can also evolve in a discrete or continuous fashion.

vs.

Continuous: Percepts, actions, state variables or time are continuous leading to an infinite state, percept or action space.

Episodic: Episode = a self-contained sequence of actions. The agent's choice of action in one episode does not affect the next episodes. The agent does the same task repeatedly.

vs.

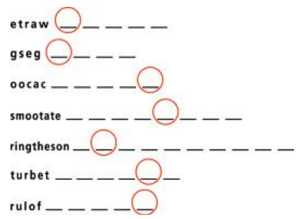
Sequential: Actions now affect the outcomes later. E.g., learning makes problems sequential.

Single agent: An agent operating by itself in an environment.

vs.

Multi-agent: Agent cooperate or compete in the same environment.

Examples of Different Environments



	Word jumble solver	Chess with a clock	Scrabble	Taxi driving
Observable	Fully	Fully	Partially	Partially
Deterministic	Deterministic	Determ. game Mechanics + Strategic*	Stochastic +Strategic	Stochastic
Episodic?	Episodic	Episodic	Episodic	Sequential
Static	Static	Semidynamic	Static	Dynamic
Discrete	Discrete	Discrete	Discrete	Continuous
Single agent	Single	Multi*	Multi*	Multi*

* Can be models as a single agent problem with the other agent(s) in the environment.

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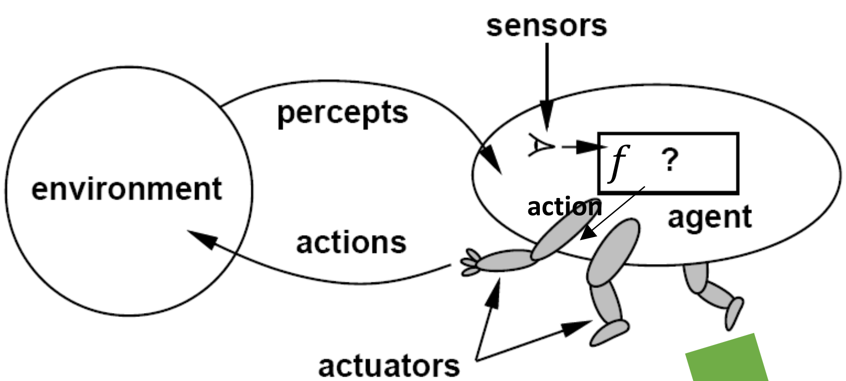
Designing a Rational Agent

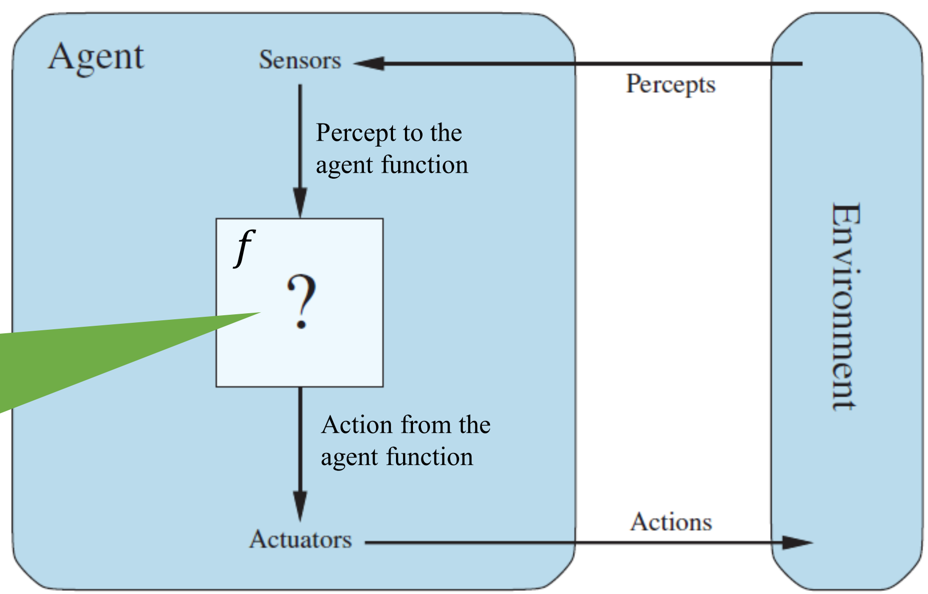


Remember the definition of a rational agent:

> *"For each possible percept sequence, a rational agent should select an* ***action*** *that* ***maximizes its expected performance measure****, given the evidence provided by the* ***percept sequence*** *and the* ***agent's built-in knowledge****."*

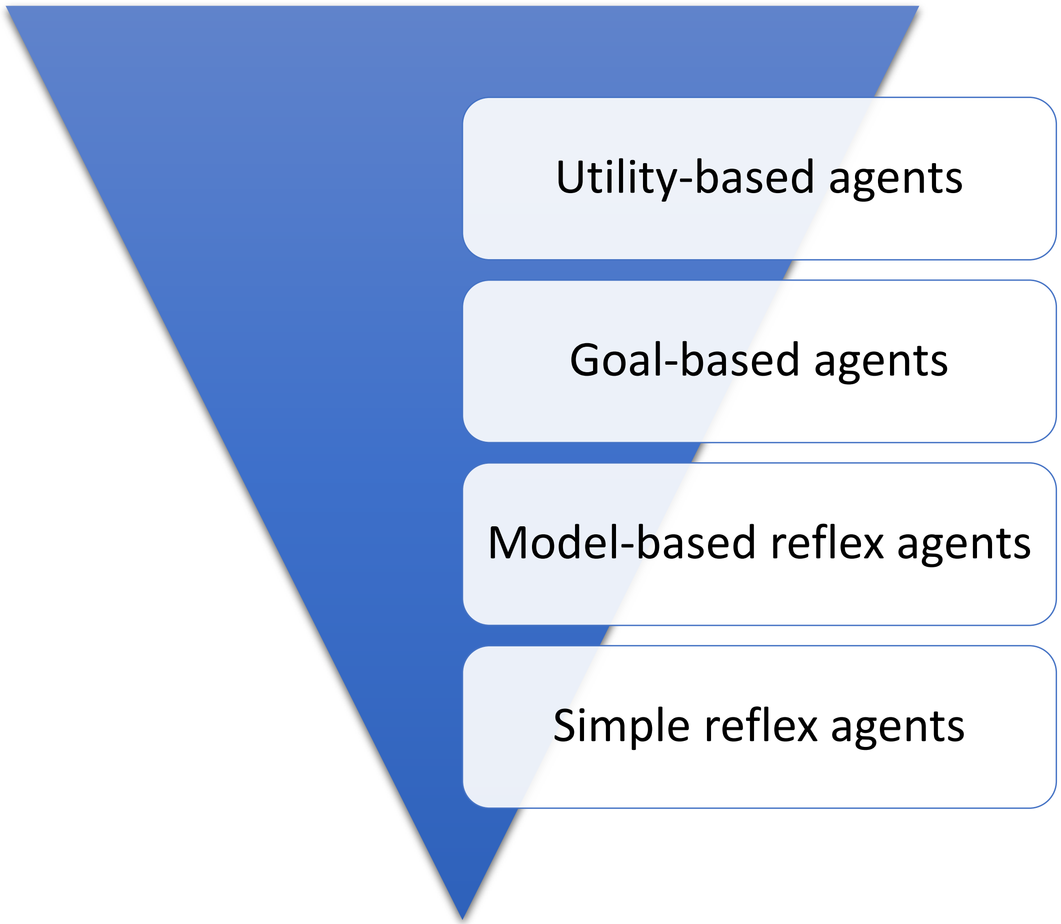
Agent Function

- Assess performance measure
- Remember percept sequence
- Built-in knowledge



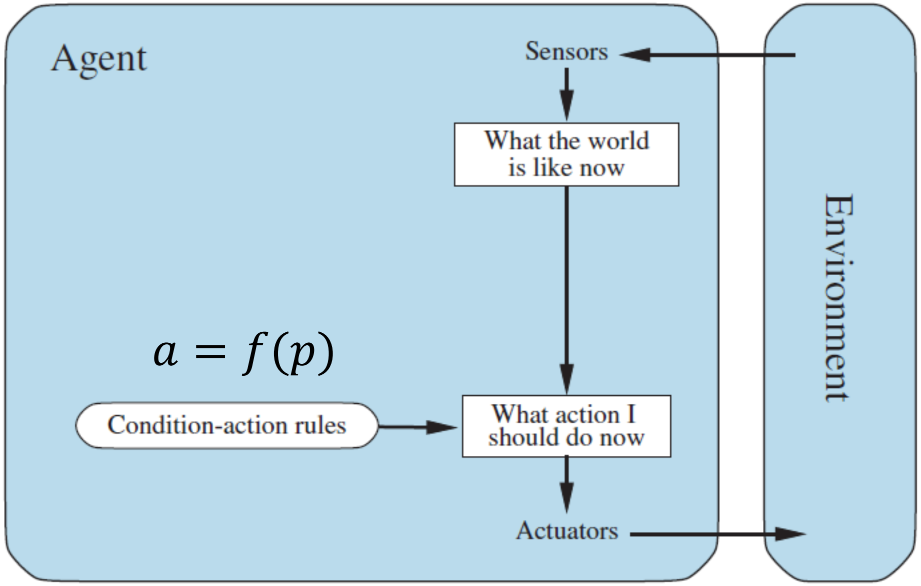
Note: Everything outside the agent function can be seen as the environment.

Hierarchy of Agent Types



Simple Reflex Agent

- Uses only built-in knowledge in the form of **rules** that select action only **based on the current percept.** This is typically very fast!
- The **agent does not know about the performance measure**! But well-designed rules can lead to good performance.
- The agent needs no memory and ignores all past percepts.

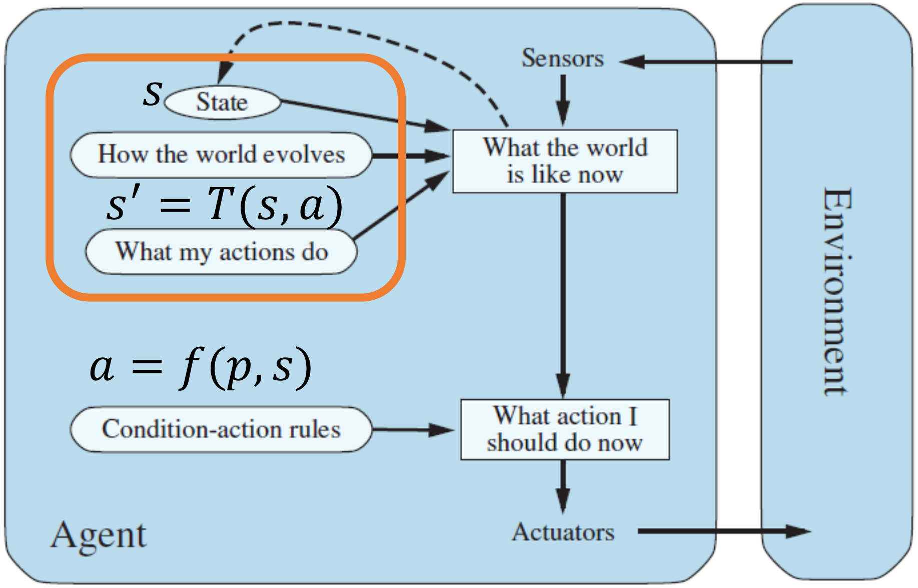


The interaction is a sequence: $p_0, a_0, p_1, a_1, p_2, a_2, \ldots p_t, a_t, \ldots$

Example: A simple vacuum cleaner that uses rules based on its current sensor input.

Model-based Reflex Agent

- Maintains a **state variable** to keeps track of aspects of the environment that cannot be currently observed. I.e., it has memory and knows how the environment reacts to actions (called **transition function**).
- The state is updated using the percept.
- There is now more information for the **rules** to make better decisions.



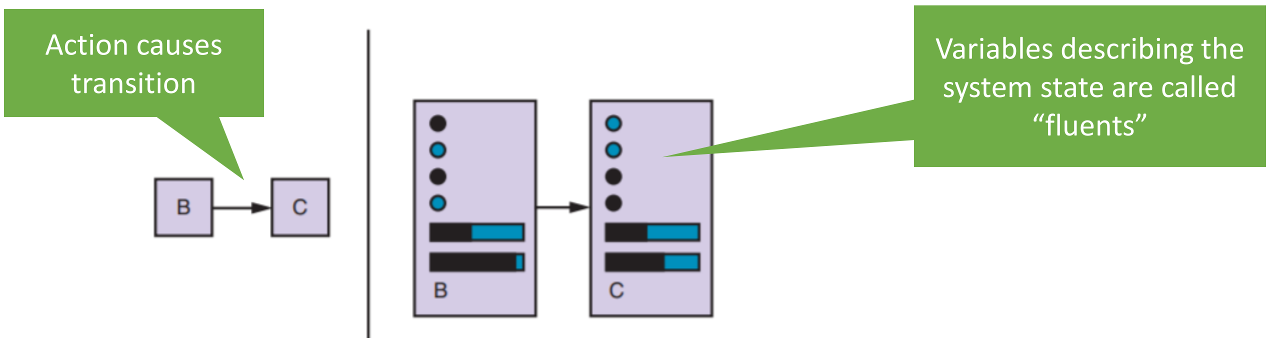
The interaction is a sequence: $s_0, a_0, p_1, s_1, a_1, p_2, s_2, a_2, p_3, \ldots, p_t, s_t, a_t, \ldots$

Example: A vacuum cleaner that remembers were it has already cleaned.

State Representation

States help to keep track of the environment and the agent in the environment. This is often also called the **system state**. The representation can be

- **Atomic**: Just a label for a black box. E.g., A, B
- **Factored**: A set of attribute values called fluents.
  E.g., [location = left, status = clean, temperature = 75 deg. F]



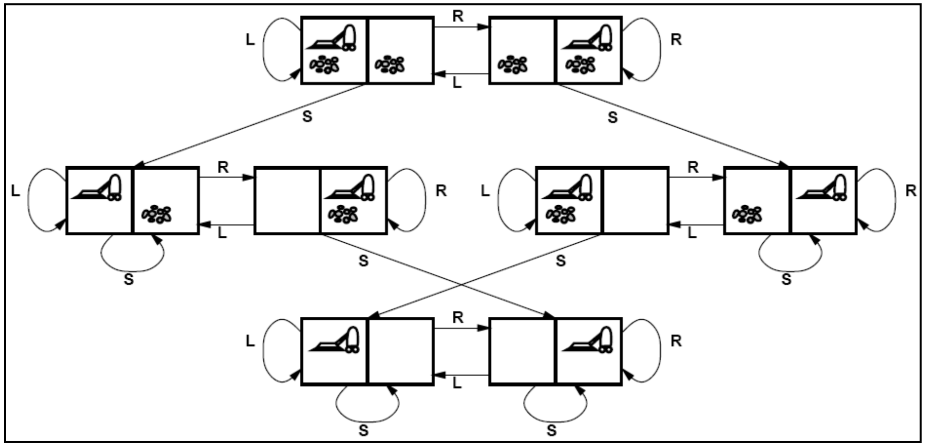
(a) Atomic (b) Factored

We often construct atomic labels from factored information. E.g.: If the agent's state is the coordinate x = 7 and y = 3, then the atomic state label could be the string "(7, 3)". With the atomic representation, we can only compare if two labels are the same. With the factored state representation, we can reason more and calculate the distance between states!

The set of all possible states is called the **state space** S. This set is typically very large!

Transition Function

- The environment is modeled as a discrete **dynamical system**.
- Example of a state diagram:



- States change because of
  a. System dynamics of the environment.
  b. The actions of the agent.

- Both types of changes are represented by the transition function written as

$T: S \times A \rightarrow S$ or $s' = T(s, a)$

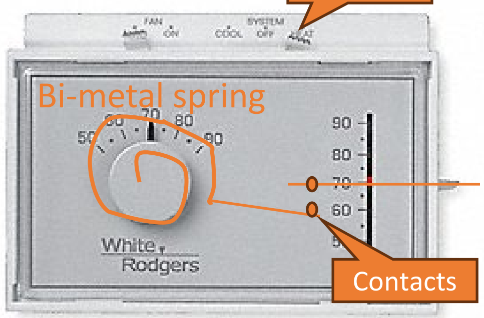
S ... set of states
A ... set of available actions
$a \in A$ ... an action
$s \in S$ ... current state
$s' \in S$ ... next state

Old-school vs. Smart Thermostat

Old-school thermostat	
Percepts	**States**

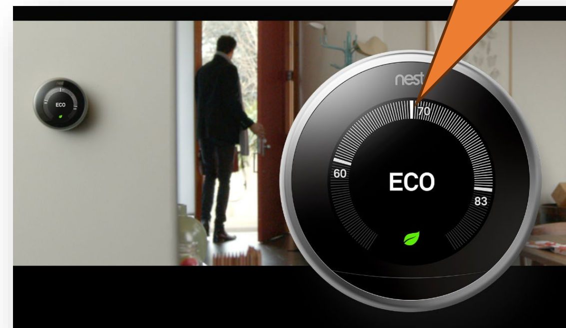
Smart thermostat	
Percepts	**States**

Old-school vs. Smart Thermostat



Set target temperature

Many sensors, internet connectivity, memory.



Change temperature when you are too cold/warm

Old-school thermostat

Percepts

Setting: Cool, off, heat

Contact: Open, closed

States

No states (only reacts to the current percepts)

Smart thermostat

Percepts

Sensors

- Temp: deg. F
- Someone walking by
- Someone changes temp.

Internet

- Outside temp.
- Weather report
- Energy curtailment
- Day & time
- …

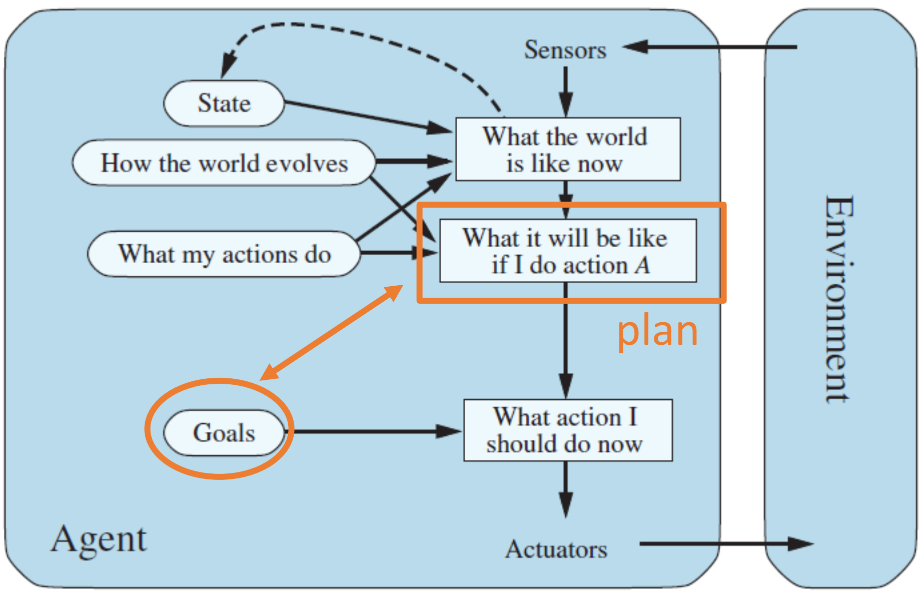
States

Factored states

- Estimated time to cool the house
- Someone home?
- How long till someone is coming home?
- Schedule
- ….

Goal-based Agent

- The agent has the task to reach a defined **goal state** and is then finished.
- The agent needs to move towards the goal. It can use **search algorithms** to plan actions that lead to the goal.
- Performance measure: the **cost to reach the goal**.



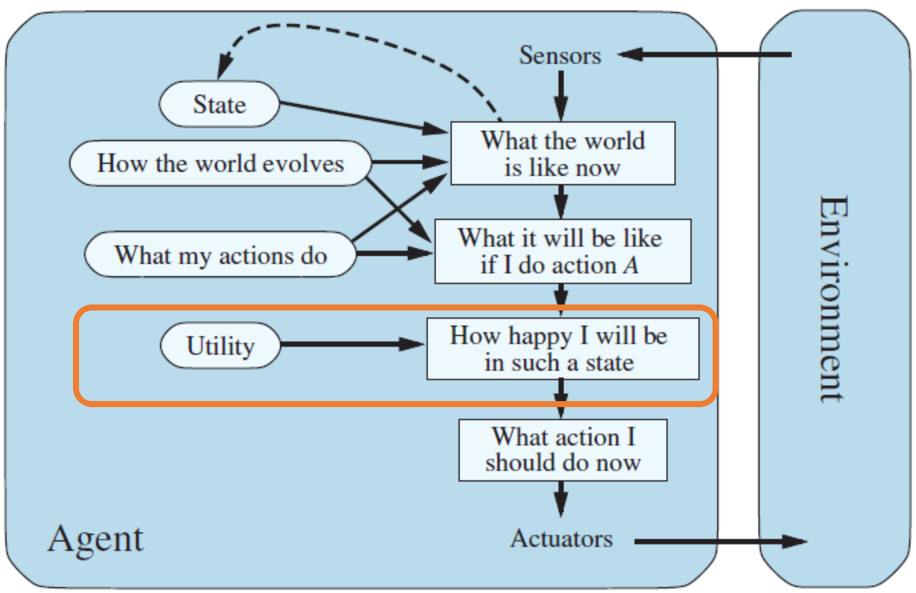
$$a = \text{argmin}_{a_0 \in A} \underbrace{\left[\sum_{t=0}^{T} c_t \,\middle|\, s_T \in S^{goal} \right]}_{\text{Sum of the cost of a planed sequence of actions that leads to a goal state}}$$

The interaction is a sequence: $\underbrace{s_0, a_0, p_1, s_1, a_1, p_2, s_2, a_2, \dots, s^{goal}}_{\text{cost}}$

Example: Solving a puzzle. What action gets me closer to the solution?

Utility-based Agent

- The agent uses a utility function to evaluate the **desirability of each possible states.** This is typically expressed as the reward of being in a state $R(s)$.
- Choose actions to stay in desirable states.
- Performance measure: The discounted sum of **expected utility over time**.



$$a = \operatorname{argmax}_{a_0 \in A} \underbrace{\mathbb{E}\left[\sum_{t=0}^{\infty} \gamma^t r_t\right]}_{\text{Utility is the expected future discounted reward}}$$

Techniques: Markov decision processes, reinforcement learning

The interaction is a sequence: $\underbrace{s_0, a_0, p_1, s_1, a_1. p_2, s_2, a_2, \ldots}_{\text{reward}}$

Example: An autonomous Mars rover prefers states where its battery is not critically low.

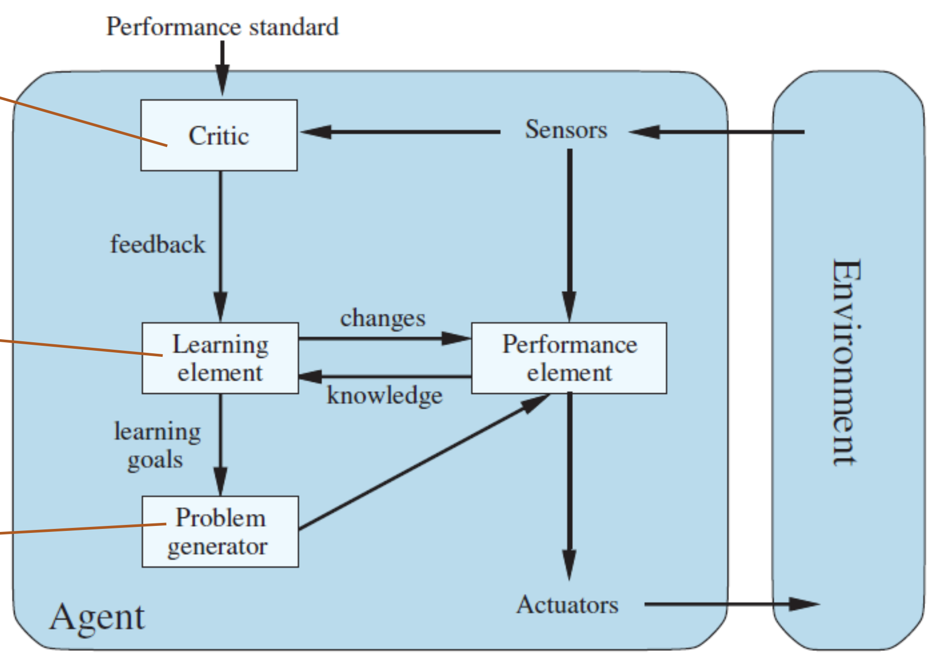
Agents that Learn

The **learning element** modifies the agent program (reflex-based, goal-based, or utility-based) to improve its performance.

How is the agent currently performing?

Updates how the performance element chooses actions.

Generate actions for exploration



Smart Thermostat: What Type of Agent is it?

Change temperature when you are too cold/warm

Simple Reflex Agent?

Model-based Reflex Agent?

Goal-based?

Utility-based?

Smart thermostat

Percepts

Sensors

- Temp: deg. F
- Someone walking by
- Someone changes temp.

Internet

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- …

States

Factored states

- Estimated time to cool the house
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- Schedule
- ….

Example: Modern Vacuum Robot

Features are:

- Control via App
- Cleaning Modes
- Navigation
- Mapping
- Boundary blockers

iRobot Roomba 960

Read TechHive's review

$247.17 See It

on Amazon (Prime Eligible)

The Roomba 960's flawless navigation, stellar cleaning, and advanced features set it apart from all other robot vacuums.

iRobot's Roomba brand has become as synonymous with robot vacuum as Q-tips is with cotton swabs. The Wi-Fi-enabled Roomba 960 is ample evidence why. It turns a tiresome chore into something you can almost look forward to. With three cleaning modes and dirt-detecting sensors, it kept all the floor surfaces in our testing immaculate, and its camera-driven navigation and mapping were superb. Its easy-to-use app provides alerts and detailed cleaning reports. The ability to control it with Amazon Alexa and Google Home voice commands are just the cherry on top.

Source: https://www.techhive.com/article/3269782/best-robot-vacuum-cleaners.html

PEAS Description of a Modern Robot Vacuum

Performance measure	Environment	Actuators	Sensors

PEAS Description of a Modern Robot Vacuum

Performance measure

- Time to clean 95%
- Does it get stuck?

Environment

- Rooms
- Obstacles
- Dirt
- People/pets

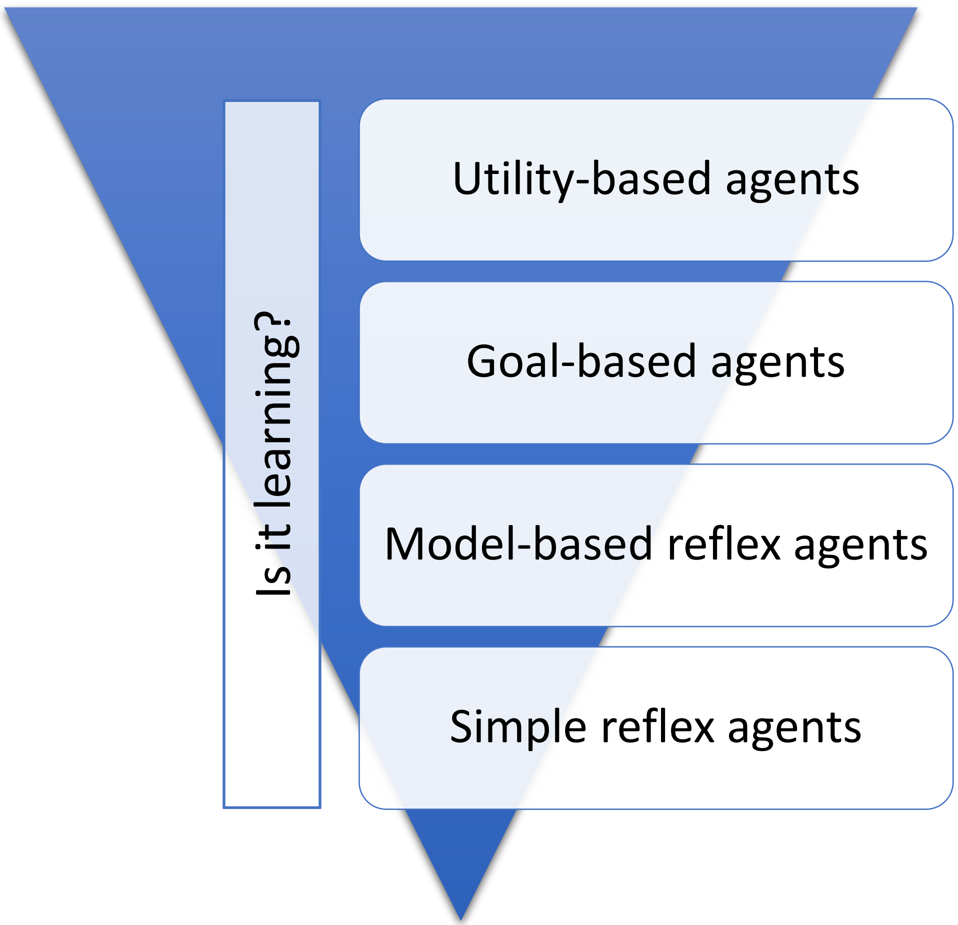
Actuators

- Wheels
- Brushes
- Blower
- Sound
- Communicate to server/app

Sensors

- Bumper
- Cameras/dirt sensor
- Laser
- Motor sensor (overheating)
- Cliff detection
- Home base locator

What Type of Intelligent Agent is a Modern Robot Vacuum?



Does it collect utility over time? How would the utility for each state be defined?

Does it have a goal state?

Does it store state information. How would they be defined (atomic/factored)?

Does it use simple rules based on the current percepts?

☑ Check what applies

Example: Large Language Models

Default (GPT-3.5)

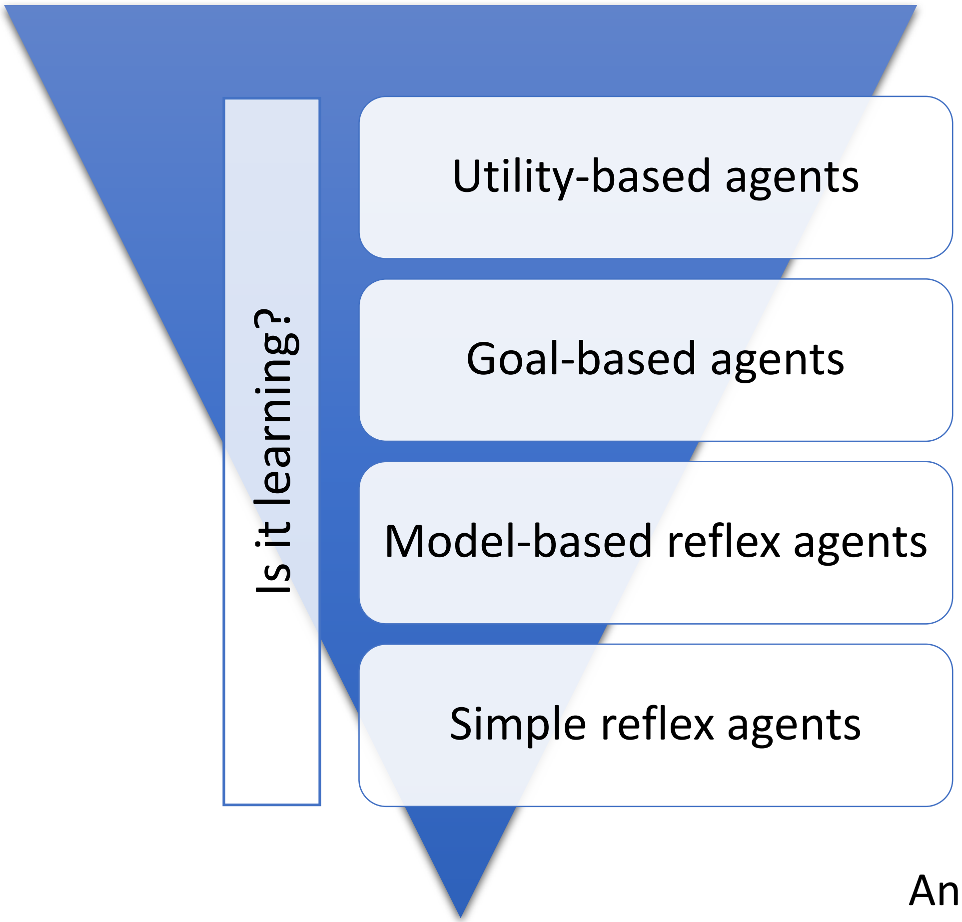
the sun is shining. It is

a beautiful day. The warm rays of sunlight illuminate the surroundings, creating a cheerful and inviting atmosphere. People are out and about, enjoying outdoor activities, and the clear blue sky adds to the overall sense of positivity. Whether you're taking a leisurely stroll, having a picnic, or simply basking in the sun's glow, it's a perfect time to appreciate the natural beauty and soak in the uplifting energy that the sunshine brings.

PEAS Description of ChatGPT

Performance measure	Environment	Actuators	Sensors

What Type of Intelligent Agent is ChatGPT?



Does it collect utility over time? How would the utility for each state be defined?

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Does it store state information. How would they be defined (atomic/factored)?

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☑ Check what applies

Answer the following questions:

- Does ChatGPT pass the Touring test?
- Is ChatGPT a rational agent? Why?

We will talk about knowledge-based agents later.

Intelligent Systems a Sets of Agents: Self-driving Car

It should learn!

Utility-based agents

Goal-based agents

Model-based reflex agents

Simple reflex agents

Make sure the passenger has a pleasant drive (not too much sudden breaking = utility)

Plan the route to the destination.

Remember where every other car is and calculate where they will be in the next few seconds.

React to unforeseen issues like a child running in front of the car quickly.

High-level planning

Low-level planning

Some Environment Types Revisited

Fully observable: The agent's sensors always show the whole **state**.

vs.

Partially observable: The agent only perceives part of the **state** and needs to remember or infer the test.

Deterministic: **Percepts** are 100% reliable and changes in the environment is completely determined by the current **state** of the environment and the agent's **action**.

vs.

Stochastic:

- **Percepts** are unreliable (noise distribution, sensor failure probability, etc.). This is called a stochastic sensor model.
- The **transition function** is stochastic leading to transition probabilities and a Markov process.

Known: The agent knows the **transition function**.

vs.

Unknown: The needs to **learn the transition function** by trying actions.

We will spend the whole semester on discussing algorithms that can deal with environments that have different combinations of these three properties.

Conclusion

Intelligent agents inspire the research areas of modern AI

Search for a goal (e.g., navigation).

Optimize functions (e.g., utility).

Stay within given **constraints**

(constraint satisfaction problem; e.g., reach the goal without running out of power)

Deal with **uncertainty** (e.g., current traffic on the road).

Learn a good agent program from data and improve over time (machine learning).

Sensing (e.g, natural language processing, vision)