Lecture

Foundations of Artificial Intelligence

Part 3 – Agents

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Recall…

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Offen im Denken

- **What is (artificial) intelligence?** The ability to acquire and apply knowledge and skills to achieve complex goals.

Recall…

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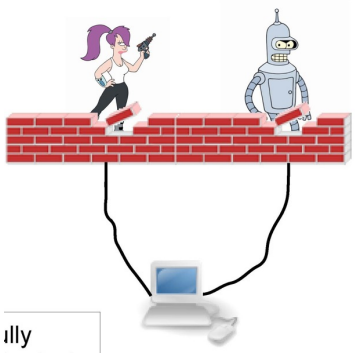
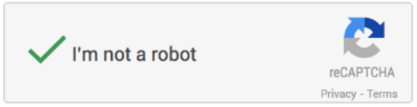
Offen im Denken

- **What is (artificial) intelligence?** The ability to acquire and apply knowledge and skills to achieve complex goals.
  - Turing Test



  - Captchas

CAPTCHA:
Completely Automated Public Turing test to tell Computers and Humans Apart



Recall…

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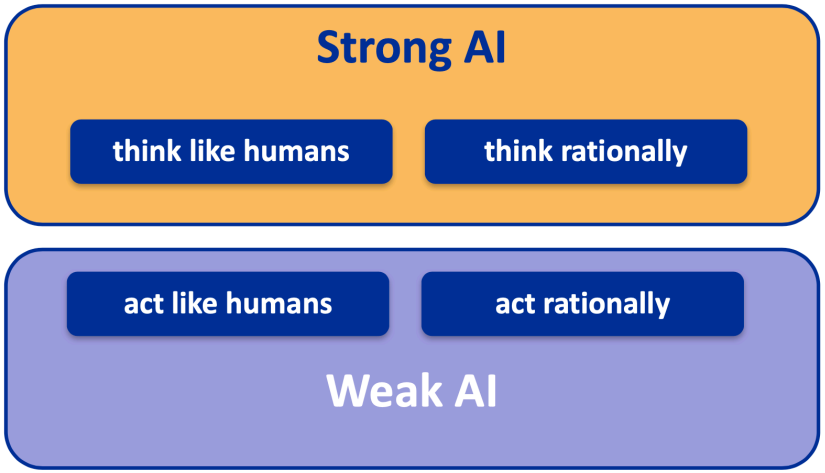
Offen im Denken

- **What is (artificial) intelligence?** The ability to acquire and apply knowledge and skills to achieve complex goals.
  - Turing Test
  - Captchas

- Strong AI vs weak AI

- Ethical concerns



Any other open questions?

Goal: In this lecture you learn …

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- **PEAS framework**
- **Performance measure**
- **Environment**
  - How to **formulate** it?
- **Agent**
  - **Architecture** and **program**
  - **Agent types**
    - **Simple reflex** agents
    - **Model-based** agents
    - **Goal-based** agents
    - **Utility-based** agents
    - **Learning-based** agents

(Artificial) Intelligence

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- AI is the ability to achieve a **goal** or conduct a **task**

- A clear definition of **goal/task** helps find and formulate interesting problems

What is the goal of sudoku?

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- To fill a 9 × 9 grid with digits so that each column, each row, and each of the nine 3 × 3 subgrids that compose the grid contain all of the digits from 1 to 9

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

What is the goal of chess?

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- **To checkmate the opponent's king**, whereby the king is under immediate attack (in "check") and there is no way for it to escape.

What is the goal of poker?

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- **To win money by capturing the pot**, which contains bets made by various players during the hand.

What is the goal of backgammon?

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- To move the fifteen pieces around the board and be first to bear off, i.e. remove them from the board.

What is the goal of taxi driving?

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- Driving safely from source to destination with enough hospitality
- …

What is the goal of image analysis?

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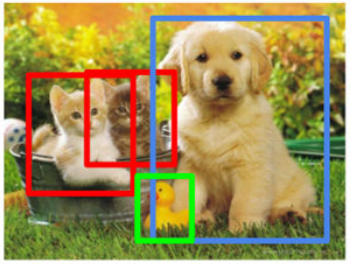
- Interpreting the content of an image
  - Detecting objects
  - Classifying an image

Classification

CAT

Object Detection



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What is the goal of part picking?

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- A simple goal of part-picking is to choose parts that come off a production line or from a previous operation

What is the goal of the vacuum-cleaner world?

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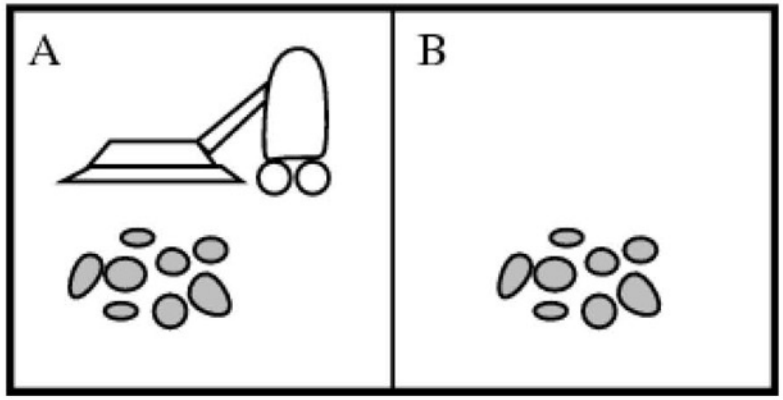
- To clean a house consisting of two rooms where each room may or may not have dust



PEAS Framework (Description)

PEAS framework

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- This framework specifies the setting for achieving a goal or conducting a task using AI

PEAS framework

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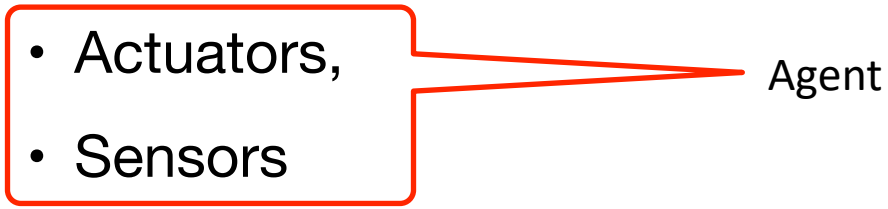
- This framework specifies the setting for achieving a goal or conducting a task using AI

- PEAS:
  - Performance measure,
  - Environment,
  - Actuators,
  - Sensors



Performance Measure

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A function that evaluates how successfully a defined goal is achieved.

Vacuum-World

Reward for the amount of dust cleaned

- one point per square cleaned up in time T
- can be maximized by dumping dust on the floor again...

Reward for clean floors

- one point per clean square per time step
- might move around too much

Penalty for consumed energy

- minus one per move?

Performance Measure

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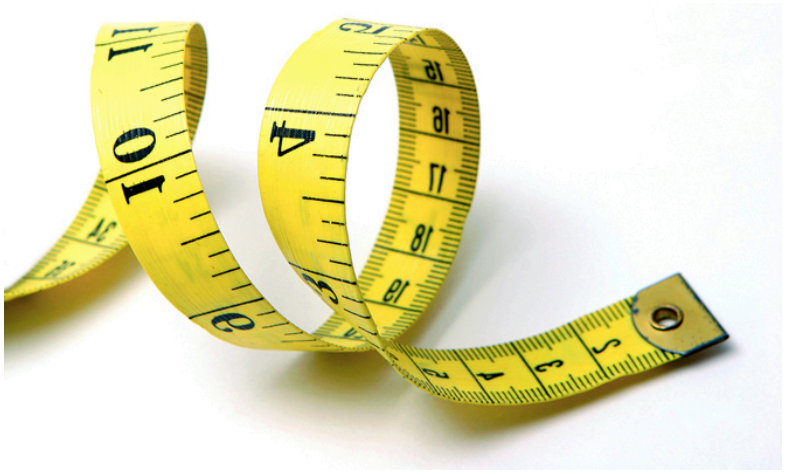
General rule for designing performance measures:

- **Based on desired goal**
- **Not on desired AI behavior**

→ What do you want?



Environment

Environment variables

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- **Observability**: fully vs partial
- **Certainty**: deterministic vs strategic vs stochastic
- **Temporal succession**: episodic vs sequential
- **Continuity**: static vs dynamic
- **Scale**: discrete vs continuous
- **Population**: single-agent vs multi-agent

Observability

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Fully observable

- the complete state of the environment can be observed (relevant parts)
- no need to keep track of internal states

Partially observable

- parts of the environment cannot be observed

https://mewiseminar.wordpress.com/2014/01/11/zdf-mit-dem-zweiten-sieht-man-besser/

Observability

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- Fully vs partial

Task	Observability
Sudoku	Fully

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Observability

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- Fully vs partial

Task	Observability
Sudoku	Fully
Chess with clock	Fully

Observability

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- Fully vs partial

Task	Observability
Sudoku	Fully
Chess with clock	Fully
Poker	Partial

Observability

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- Fully vs partial

Task	Observability
Sudoku	Fully
Chess with clock	Fully
Poker	Partial
Backgammon	Fully

Observability

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- Fully vs partial

Task	Observability
Sudoku	Fully
Chess with clock	Fully
Poker	Partial
Backgammon	Fully
Taxi Driving	Partial

Observability

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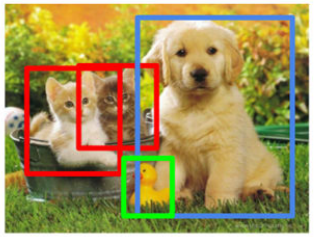
- Fully vs partial

Task	Observability
Sudoku	Fully
Chess with clock	Fully
Poker	Partial
Backgammon	Fully
Taxi Driving	Partial
Image Analysis	Fully

Classification

CAT

Object Detection



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Observability

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- Fully vs partial

Task	Observability
Sudoku	Fully
Chess with clock	Fully
Poker	Partial
Backgammon	Fully
Taxi Driving	Partial
Image Analysis	Fully
Part-picking	Partial

Certainty

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Deterministic

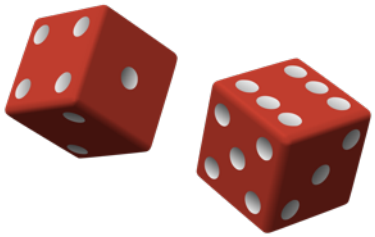
- next environment state is determined only by current state and executed action

Strategic

- only the opponents' actions cannot be foreseen

Stochastic

- next environment state is uncertain (e.g., throwing dices).



https://commons.wikimedia.org/wiki/File:Two_red_dice_01.svg

Certainty

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- Deterministic vs strategic vs stochastic

Task	Certainty
Sudoku	Deterministic

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Certainty

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- Deterministic vs strategic vs stochastic

Task	Certainty
Sudoku	Deterministic
Chess with clock	Strategic

Certainty

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- Deterministic vs strategic vs stochastic

Task	Certainty
Sudoku	Deterministic
Chess with clock	Strategic
Poker	Stochastic

Certainty

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- Deterministic vs strategic vs stochastic

Task	Certainty
Sudoku	Deterministic
Chess with clock	Strategic
Poker	Stochastic
Backgammon	Stochastic

Certainty

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- Deterministic vs strategic vs stochastic

Task	Certainty
Sudoku	Deterministic
Chess with clock	Strategic
Poker	Stochastic
Backgammon	Stochastic
Taxi Driving	Stochastic

Certainty

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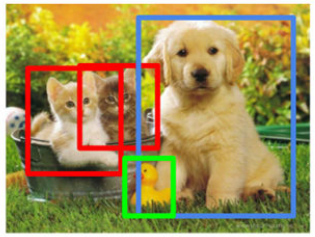
- Deterministic vs strategic vs stochastic

Task	Certainty
Sudoku	Deterministic
Chess with clock	Strategic
Poker	Stochastic
Backgammon	Stochastic
Taxi Driving	Stochastic
Image Analysis	Deterministic

Classification

CAT

Object Detection



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Certainty

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- Deterministic vs strategic vs stochastic

Task	Certainty
Sudoku	Deterministic
Chess with clock	Strategic
Poker	Stochastic
Backgammon	Stochastic
Taxi Driving	Stochastic
Image Analysis	Deterministic
Part-picking	Stochastic

Temporal succession

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Episodic

- If the choice of an action does not depend on previous actions

Sequential

- the current action affect future actions

Temporal succession

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- Sequential vs Episodic

Task	Succession
Sudoku	Sequential

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Temporal succession

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- Sequential vs Episodic

Task	Succession
Sudoku	Sequential
Chess with clock	Sequential

Temporal succession

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- Sequential vs Episodic

Task	Succession
Sudoku	Sequential
Chess with clock	Sequential
Poker	Sequential

Temporal succession

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- Sequential vs Episodic

Task	Succession
Sudoku	Sequential
Chess with clock	Sequential
Poker	Sequential
Backgammon	Sequential

Temporal succession

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- Sequential vs Episodic

Task	Succession
Sudoku	Sequential
Chess with clock	Sequential
Poker	Sequential
Backgammon	Sequential
Taxi Driving	Sequential

Temporal succession

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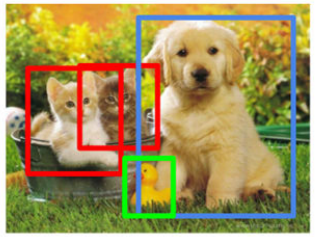
- Sequential vs Episodic

Task	Succession
Sudoku	Sequential
Chess with clock	Sequential
Poker	Sequential
Backgammon	Sequential
Taxi Driving	Sequential
Image Analysis	Episodic

Classification

CAT

Object Detection



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Temporal succession

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- Sequential vs Episodic

Task	Succession
Sudoku	Sequential
Chess with clock	Sequential
Poker	Sequential
Backgammon	Sequential
Taxi Driving	Sequential
Image Analysis	Episodic
Part-picking	Episodic

Continuity

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Static

- the environment does not change

Semi-dynamic

- the environment does not change but the performance score may

Dynamic

- the environment may change

Continuity

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- Static vs semi-dynamic vs dynamic

Task	Continuity
Sudoku	Static

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Continuity

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- Static vs semi-dynamic vs dynamic

Task	Continuity
Sudoku	Static
Chess with clock	Semi

Continuity

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- Static vs semi-dynamic vs dynamic

Task	Continuity
Sudoku	Static
Chess with clock	Semi
Poker	Static

Continuity

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- Static vs semi-dynamic vs dynamic

Task	Continuity
Sudoku	Static
Chess with clock	Semi
Poker	Static
Backgammon	Static

Continuity

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- Static vs semi-dynamic vs dynamic

Task	Continuity
Sudoku	Static
Chess with clock	Semi
Poker	Static
Backgammon	Static
Taxi Driving	Dynamic

Continuity

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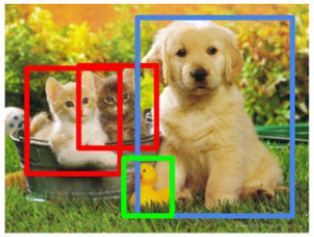
- Static vs semi-dynamic vs dynamic

Task	Continuity
Sudoku	Static
Chess with clock	Semi
Poker	Static
Backgammon	Static
Taxi Driving	Dynamic
Image Analysis	Semi

Classification

CAT

Object Detection



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Continuity

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- Static vs semi-dynamic vs dynamic

Task	Continuity
Sudoku	Static
Chess with clock	Semi
Poker	Static
Backgammon	Static
Taxi Driving	Dynamic
Image Analysis	Semi
Part-picking	Dynamic

Scale

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Discrete

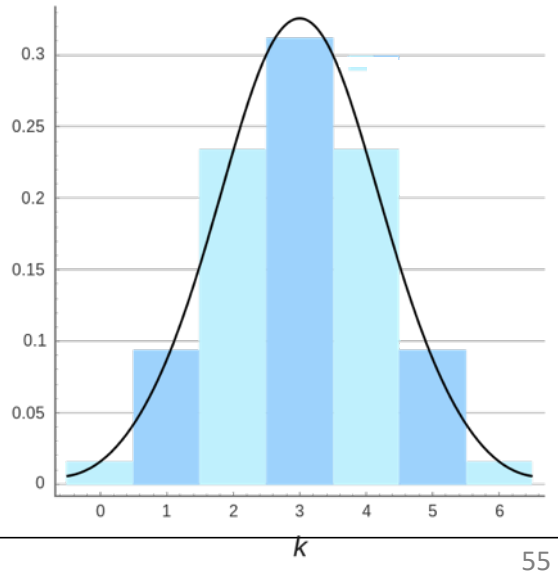
- A finite number of environment states / percepts

Continuous

- A continuous range of values

- This distinction applies separately to
  - actions
  - states
  - percepts

→ Can be mixed in individual tasks



Scale

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- Continuous vs discrete

Task	Scale
Sudoku	Discrete

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Scale

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- Continuous vs discrete

Task	Scale
Sudoku	Discrete
Chess with clock	Discrete

Scale

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- Continuous vs discrete

Task	Scale
Sudoku	Discrete
Chess with clock	Discrete
Poker	Discrete

Scale

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- Continuous vs discrete

Task	Scale
Sudoku	Discrete
Chess with clock	Discrete
Poker	Discrete
Backgammon	Discrete

Scale

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- Continuous vs discrete

Task	Scale
Sudoku	Discrete
Chess with clock	Discrete
Poker	Discrete
Backgammon	Discrete
Taxi Driving	Continuous

Scale

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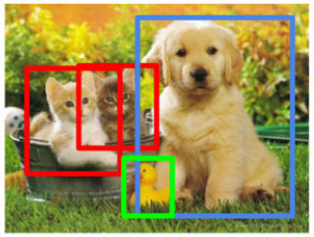
- Continuous vs discrete

Task	Scale
Sudoku	Discrete
Chess with clock	Discrete
Poker	Discrete
Backgammon	Discrete
Taxi Driving	Continuous
Image Analysis	Continuous

Classification

CAT

Object Detection



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Scale

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- Continuous vs discrete

Task	Scale
Sudoku	Discrete
Chess with clock	Discrete
Poker	Discrete
Backgammon	Discrete
Taxi Driving	Continuous
Image Analysis	Continuous
Part-picking	Continuous

Population

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Single-agent

- No other agents
- Other agents may be part of the environment though

Multi-agent

- Does the environment contain other agents whose performance measures depend on my actions?
- Other agents may be *co-operative* or *competitive*

Population

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- Single-agent vs multi-agent

Task	Population
Sudoku	Single

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Population

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- Single-agent vs multi-agent

Task	Population
Sudoku	Single
Chess witch clock	Multi

Population

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- Single-agent vs multi-agent

Task	Population
Sudoku	Single
Chess witch clock	Multi
Poker	Multi

Population

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- Single-agent vs multi-agent

Task	Population
Sudoku	Single
Chess witch clock	Multi
Poker	Multi
Backgammon	Multi

Population

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- Single-agent vs multi-agent

Task	Population
Sudoku	Single
Chess witch clock	Multi
Poker	Multi
Backgammon	Multi
Taxi Driving	Multi

Population

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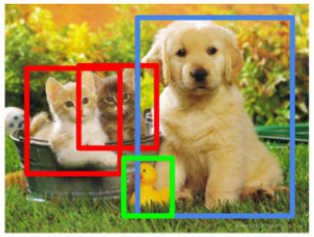
- Single-agent vs multi-agent

Task	Population
Sudoku	Single
Chess witch clock	Multi
Poker	Multi
Backgammon	Multi
Taxi Driving	Multi
Image Analysis	Single

Classification

CAT

Object Detection



CAT, DOG, DUCK

Population

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- Single-agent vs multi-agent

Task	Population
Sudoku	Single
Chess witch clock	Multi
Poker	Multi
Backgammon	Multi
Taxi Driving	Multi
Image Analysis	Single
Part-picking	Multi

Environment descriptions

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Task	Observability	Certainty	Succession	Continuity	Scale	Population
Sudoku	Fully	Deterministic	Sequential	Static	Discrete	Single
Chess w. 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
Image Analysis	Fully	Deterministic	Episodic	Semi	Continuous	Single
Part-picking	Partially	Stochastic	Episodic	Dynamic	Continuous	Multi

Challenging environments

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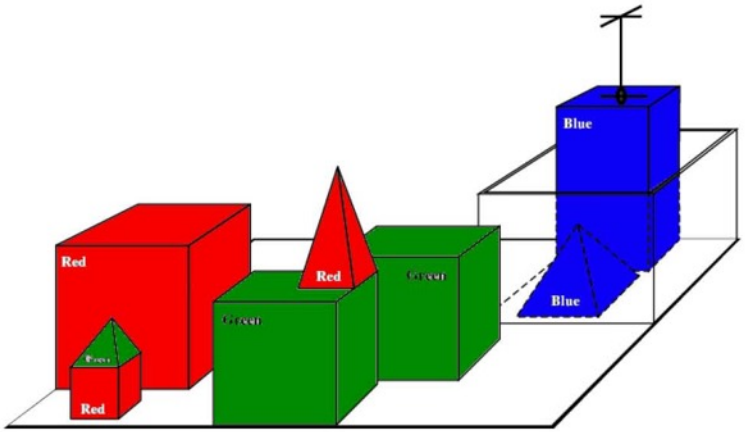
Rather simple:

- fully observable
- deterministic
- episodic
- static
- discrete
- single-agent



Pretty hard:

- ◊ partially observable
- ◊ stochastic
- ◊ sequential
- ◊ dynamic
- ◊ continuous
- ◊ multi-agent

Agent

Agents

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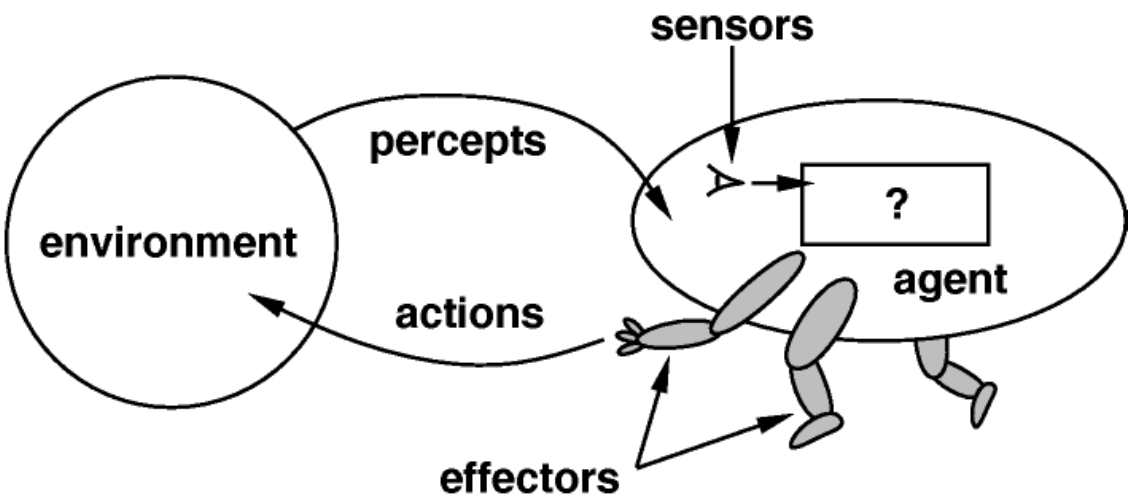
- **What is an agent?**
  An entity that **perceives (observes)** an environment through its **sensors** and **acts** upon that environment through **actuators**

- **Human agents**
  - Sensors: eyes, ears, and other organs for sensors
  - Actuators: hands, legs, mouth, and other body parts for actuators

- **Artificial agents**
  - Sensors: Camera and infrared range finders, microphone, keyboard, …
  - Actuators: Various motors for movement, displays, sound generator, …

Agents and environment



Example: The vacuum-cleaner world

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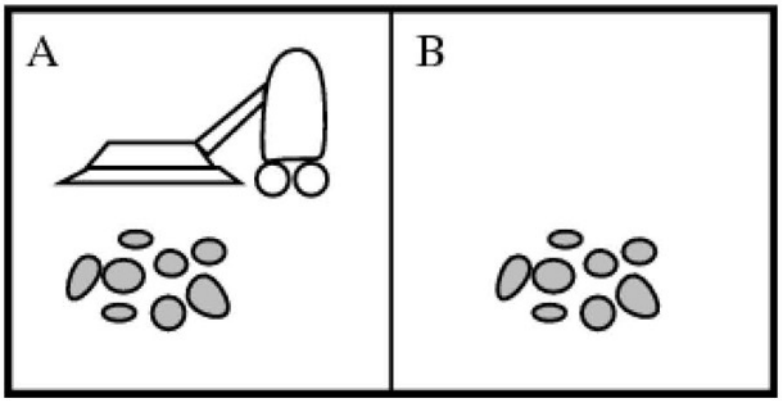
A robot-vacuum-cleaner that operates in a very simple world.

Environment:

- Virtual house with room A and room B

Percepts:

- The robot can sense pairs **[*<location>*, *<status>*]**
  - Location: room A or room B
  - Status: The room is Clean or Dirty



Actions:

- Left, Right, Suck, NoOp

Rational Agent

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- 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.

Rational Agent

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Rational ≠ omniscient

- Percepts may not supply all relevant information
- E.g., in poker, don't know cards of others.

Rational ≠ successful

- Rationality maximizes expected (not actual) performance
- Successful but not rational:
  - playing in the lottery/casino
- Rational but not successful
  - Agent is destroyed by a meteorite while behaving fully rational

Autonomy in Agents

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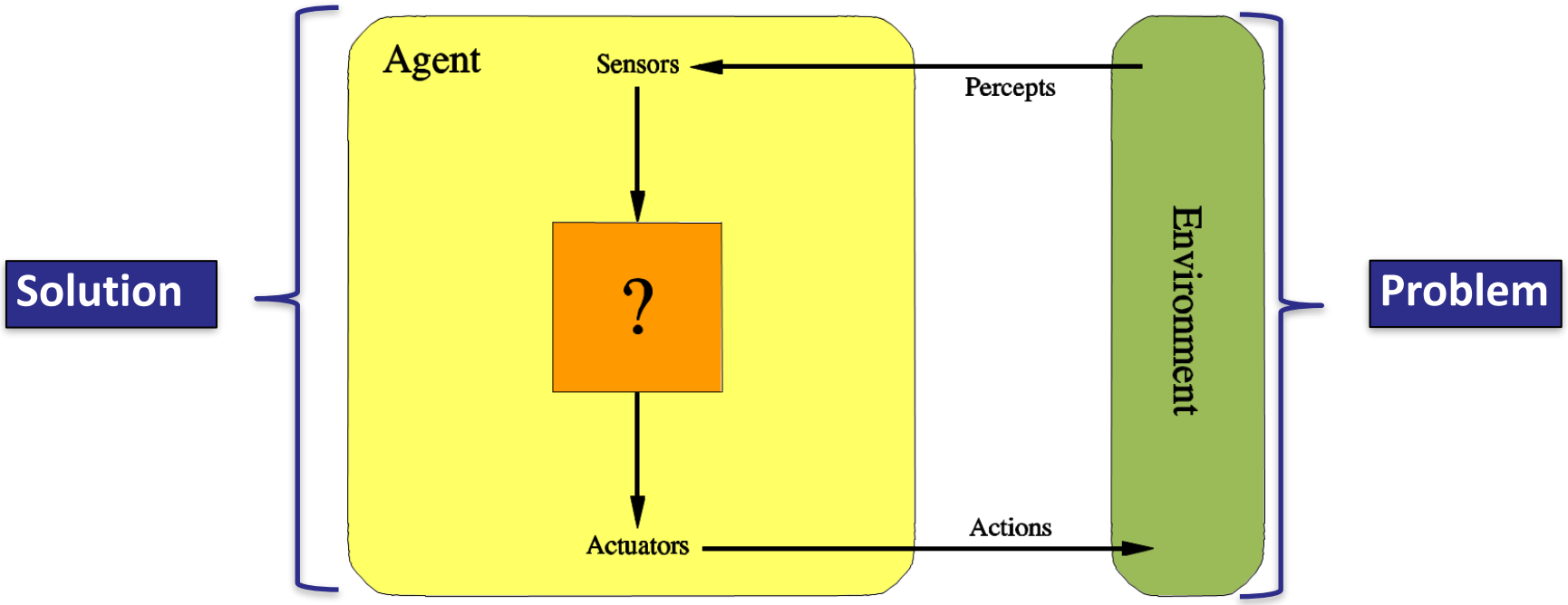
- The **autonomy** of an agent is the extent to which its actions are determined by its own experience, rather than knowledge of designer.

- **No autonomy** – ignores environment/data
- **Complete autonomy** – must act randomly/no program

- Example: baby learning to crawl

- **Ideal:** agents to have some autonomy
  - Possibly become more autonomous with experience

Agent function



An **agent function** maps percept histories to actions

- internally represented by the **agent program**

Agent architecture and program

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- The **agent program** runs on the **physical architecture** to produce ***agent function***
- Agent = **architecture** + **program**

A simple vacuum-cleaner agent

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Agent's function is a look-up function

Percept sequence	Action
[A, clean]	Right
[A, dirty]	Suck
[B, clean]	Left
[B, dirty]	Suck
[A, clean], [A, clean]	Right
[A, clean], [A, dirty]	Suck
...	...

A program for the simple vacuum agent

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Percept	Action
[A, clean]	*Right*
[A, dirty]	*Suck*
[B, clean]	*Left*
[B, dirty]	*Suck*

```
function REFLEX-VACUUM-AGENT( [location,status]) returns an action
    if status = Dirty then return Suck
    else if location = A then return Right
    else if location = B then return Left
```

Agent types

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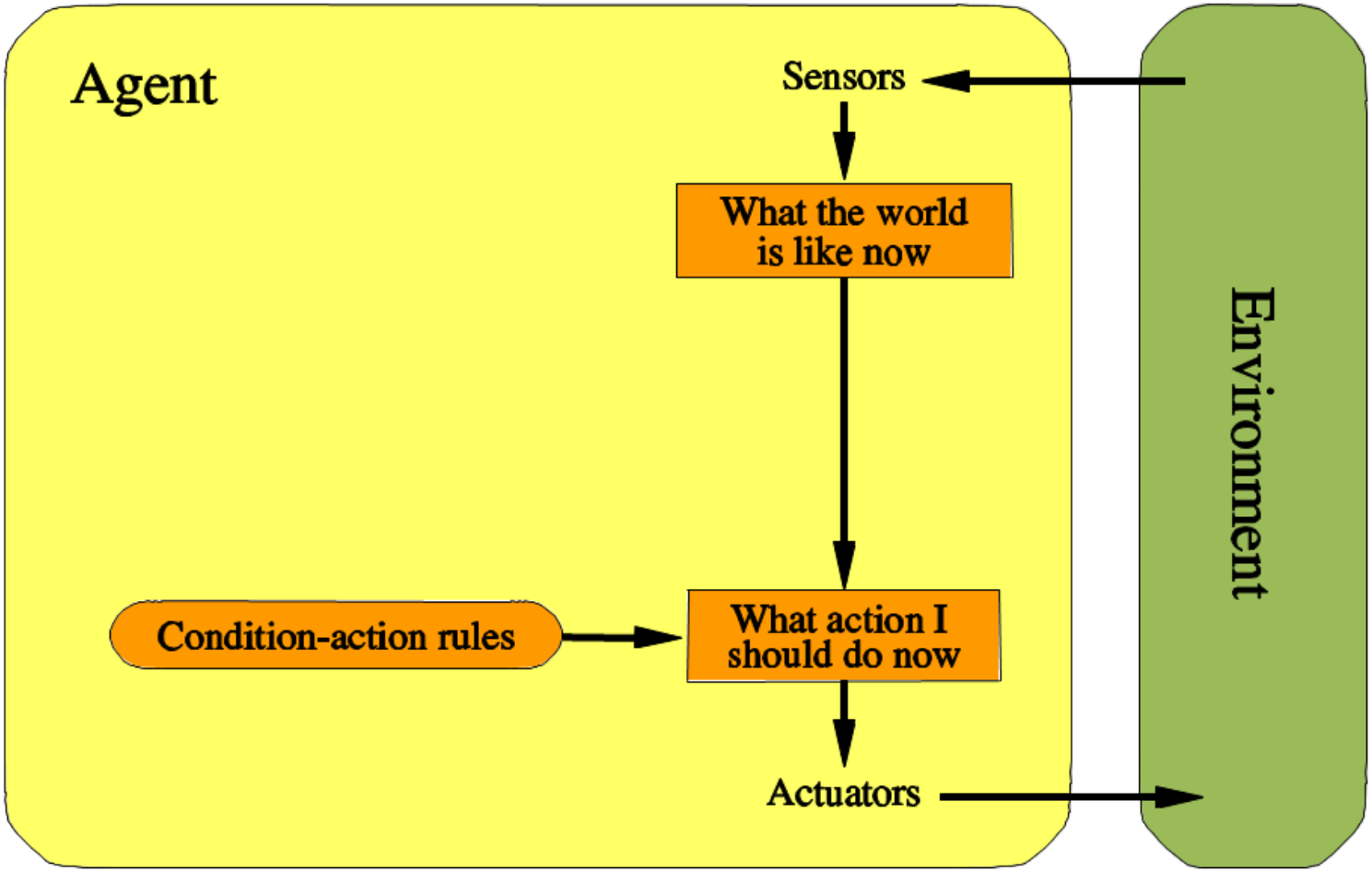
- Simple reflex agent
- Model-based agent
- Goal-based agent
- Utility-based agent
- Learning agent

Simple reflex agent



Simple reflex agent

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Selected action is exclusively based on current percept

- Ignores the percept history

Implemented through condition-action rules

- Large reduction in possible percept-action situations

Will make a very bad chess player

- Does not look at the board, only at the opponent's last move

Simple reflex agent

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Rules are just used as a concept here

- actual implementation could, e.g. be logical circuitry

Will only work if the environment is ***fully observable***

- everything important needs to be determinable from the sensory input
- otherwise infinite loops may occur
  - e.g. in the vacuum world the agent may not know whether to move right or left to get to the next room
  - possible solution: randomization

Model-based agent

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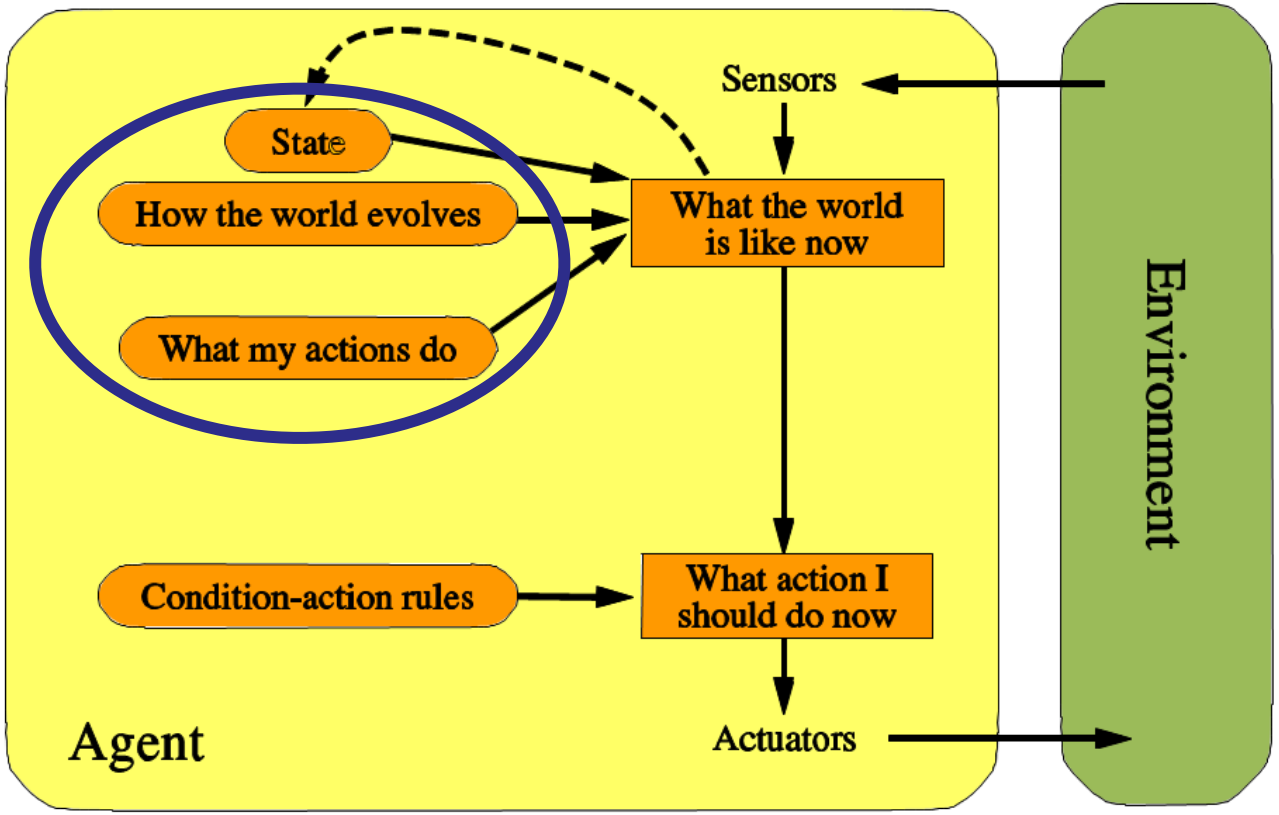
Keep track of the state of the world

- better way to fight partial observability



Model-based agent

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Input is mapped onto an internal state description (a world model)

- chess agent: keep a model of the current board situation

Internal state is also used for interpreting subsequent percepts

- the world model may include effects of own actions!

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

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

Goal-based Agent

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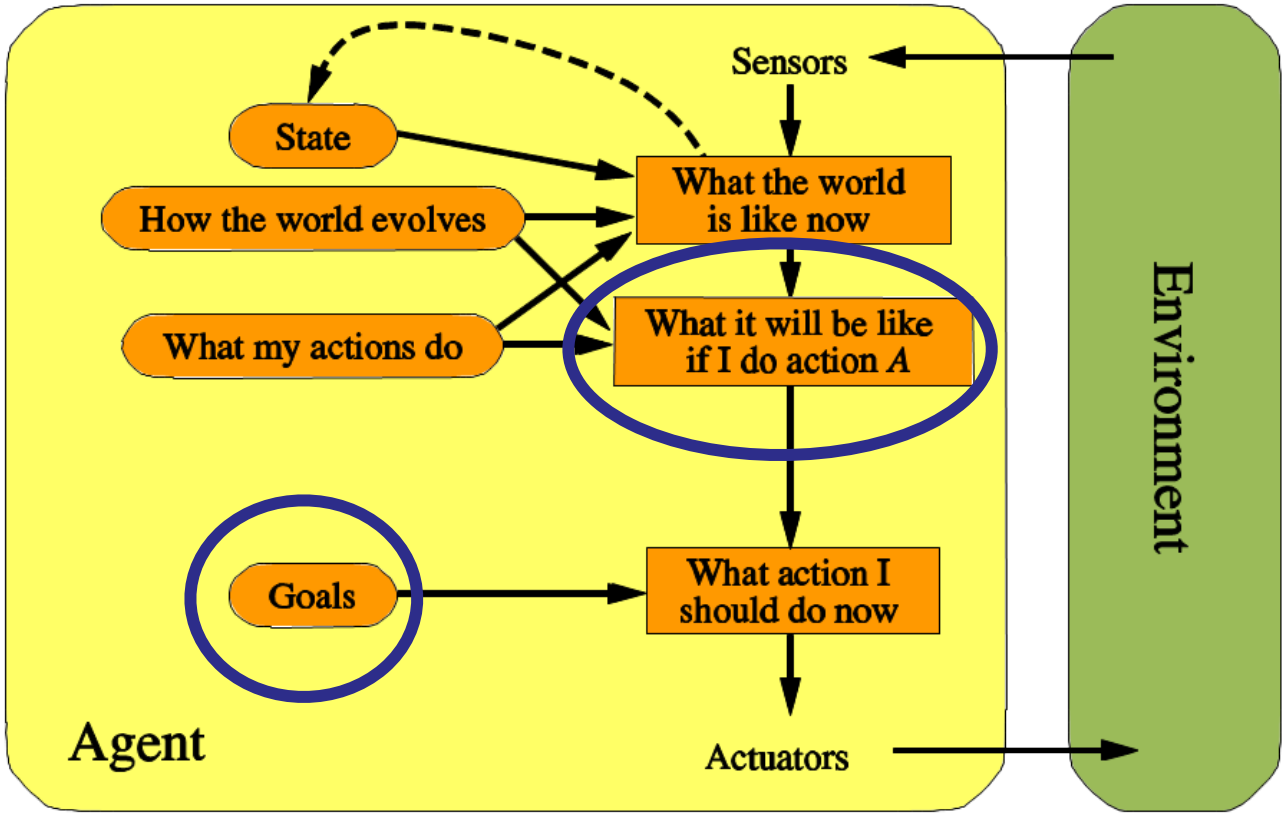
The agent knows what states are desirable

- choose an action that leads to a desirable state



Goal-based agent

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- Choose an action that leads to the goal. **Problem:**
  A goal can often only be reached after a sequence of actions

  → search and planning algorithms required
- Main difference from previous agents: oriented towards the future.
  - ◊ *What will happen if I do such-and-such?*
  - ◊ *Will this make me reach my goal?*
- Goals provide just a binary happy/unhappy distinction. Certain goals can be reached in different ways
  - *In the taxi driving task, the destination can be reached in different ways ..*
  - Some ways are quicker, safer, more reliable, cheaper, ...

Utility-based agent

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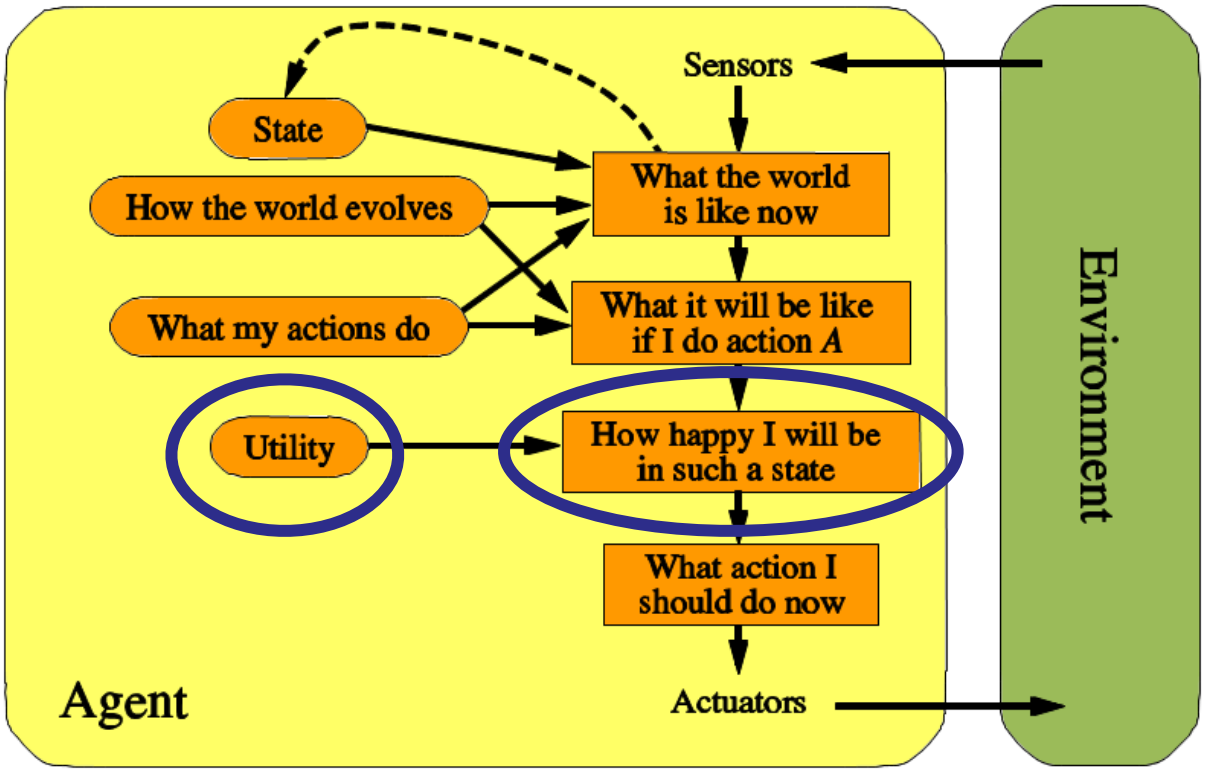
- Utility functions provide a continuous scale



Utility-based agent

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Goals provide just a binary happy/unhappy distinction

- utility functions provide a continuous scale
- → have a higher utility

Utility function

- maps a state (or a sequence of states) onto a real number

Improves on goals:

- selection between conflicting goals (e.g. speed and safety)
- selection between goals based on trade-off between likelihood of success and importance of goal

Learning-based agents

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All previous agent programs assume some knowledge for selecting actions.

- Where does this knowledge come from?

Learning mechanisms can be used for acquiring knowledge.

- Teach the agent instead of instructing it
- Every part of the previous agents can be improved with learning

Advantage: robustness in initially unknown environments

Reinforcement learning

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Learning Scenario

- a learning agent
- S: a set of possible states
- A: a set of possible actions
- a state transition function $\delta: S \times A \rightarrow S$
- a reward function $r: S \times A \rightarrow \mathbb{R}$
- Environment:
  the agent repeatedly chooses an action according to some policy $\pi: S \rightarrow A$
- this will put the agent into a new state according to δ
- in some states the agent receives feedback from the environment
  → reinforcement

AI

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- The ability to acquire and apply knowledge and skills to achieve complex goals.

Summary

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PEAS framework

- Performance, environment, actions, sensors

Environment variables

- Observability, certainty, temporal succession, continuity, scale, population

Performance measures

- Careful what you ask for

Agent Types

- Simple reflex agent
- Model-based agent
- Goal-based agent
- Utility-based agent
- Learning agent

Readings

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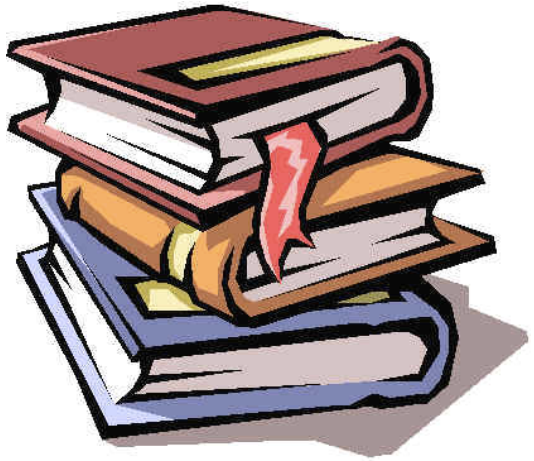
Mandatory

- Russell & Norvig, Section 2 *Intelligent Agents,* 2.1 – 2.4

Optional

- Russell & Norvig, Rest of Section 2



Next lecture: Search Problems

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