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Artificial Intelligence

Intelligent Agents

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Agenda

- The Rational Agent
  - perception – cognition – action
- Properties of Environments
- Types of Agents
  - **Simple Reflex** agents respond immediately to percepts
  - **Model-based Reflex** agents are aware of action effects
  - **Goal-based** agents work towards goals
  - **Utility-based** agents try to maximize their reward
  - **Learning** agents improve their behavior over time

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Recommended Reading

§ AIMA Chapter 2: Intelligent Agents

Russell, S., & Norvig, P. (2010). Artificial intelligence: a modern approach.

3rd edition.

Link to online access via UdS VPN: see slides of lecture ai00 “about this course”

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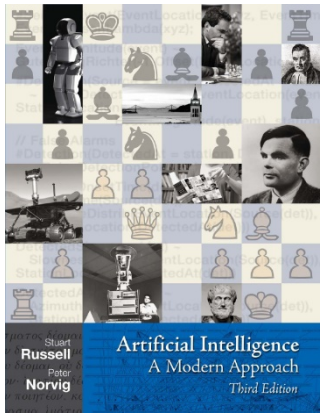
Metaphor of the Rational Agent



A central aspect of intelligence is the ability

to

act successfully in the world

- **What does it need for an agent to act at all?**
- **How can the agent act successfully?**

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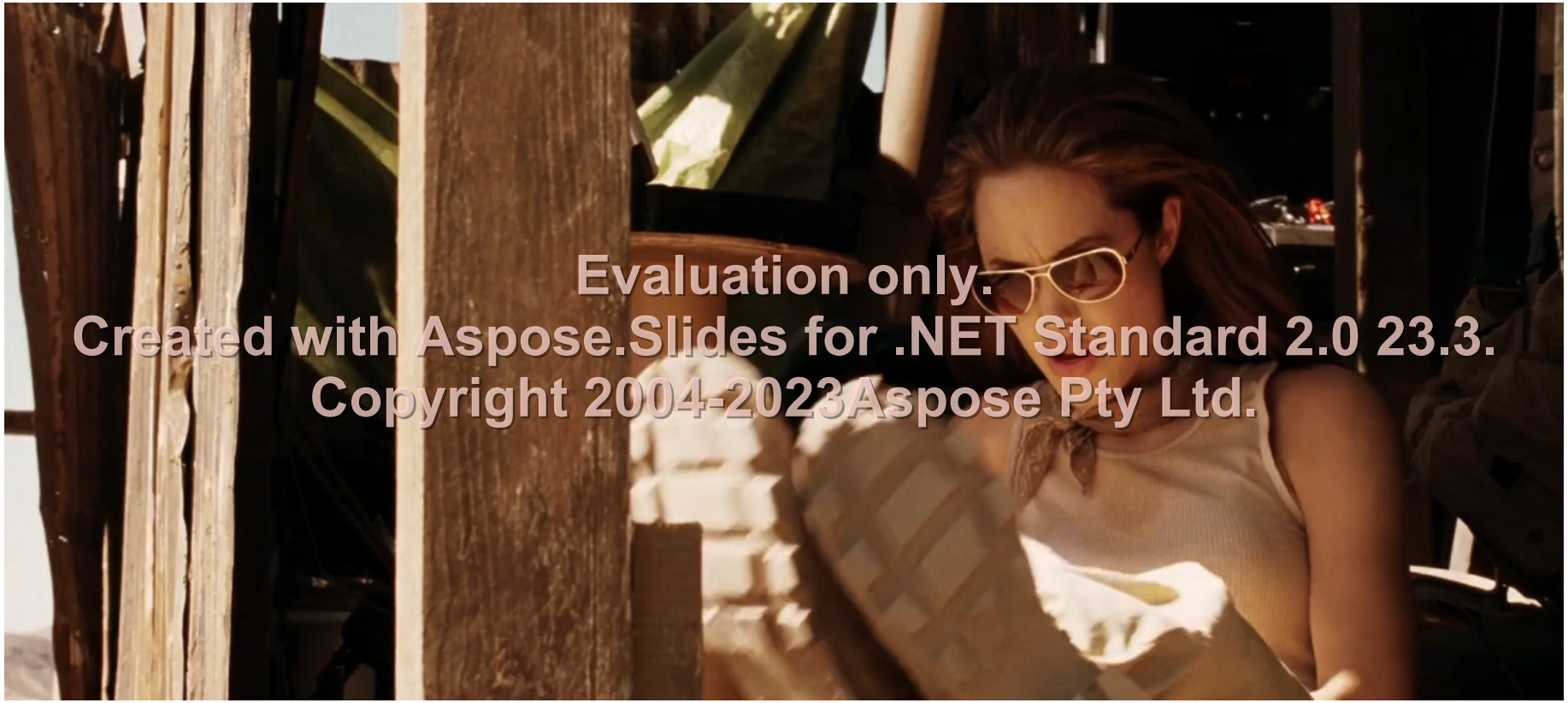
What is an Agent?



Liman, Doug (2005): Mr. & Mrs. Smith [Video], United States: Goldsman. Retrieved from https://www.youtube.com/watch?v=CQliFA1dc-Q (01.12.2020).

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The Agent Perceives the Environment

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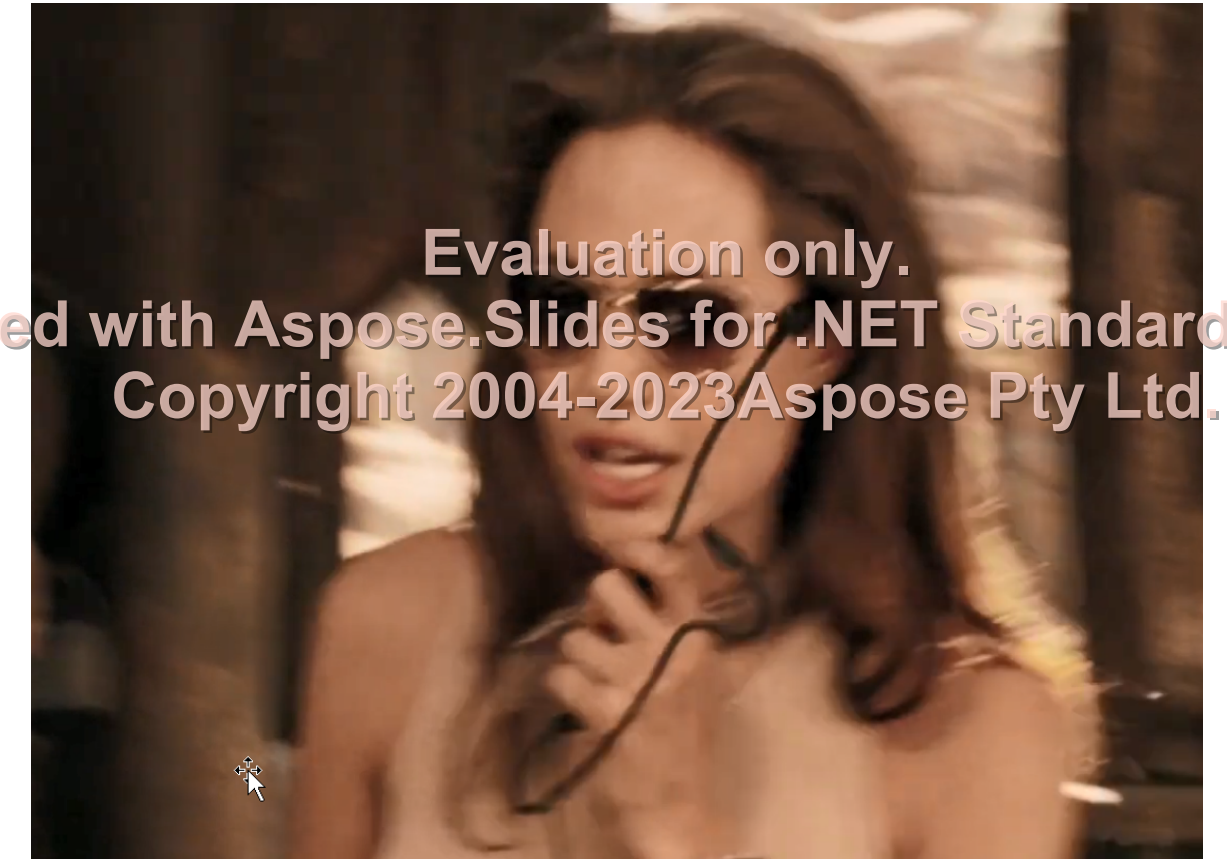
Perceptions are used to make Decisions



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Decisions result in Actions

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Agent

1) Ability to perceive environment

2) Perceptions are used to make decisions

3) Decisions will result in actions

If the agent is rational, then

4) Decisions must be RATIONAL
   - Ø Must lead to best possible action the agent can take

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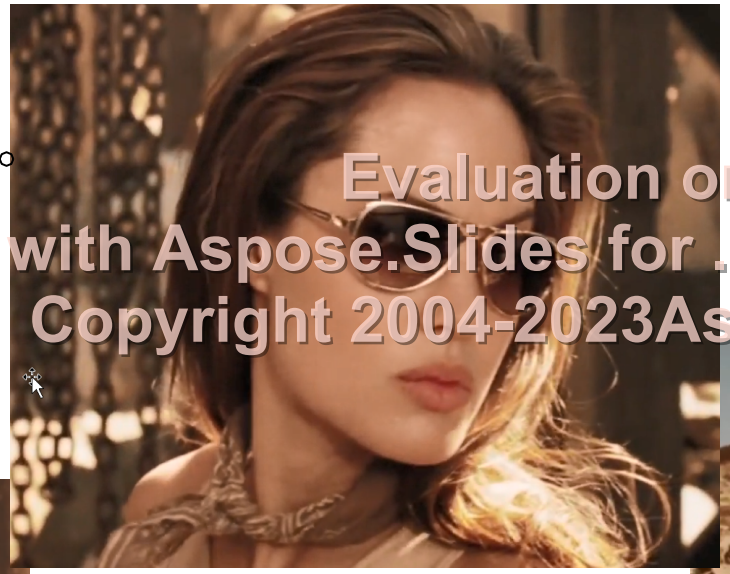
A Rational Decision



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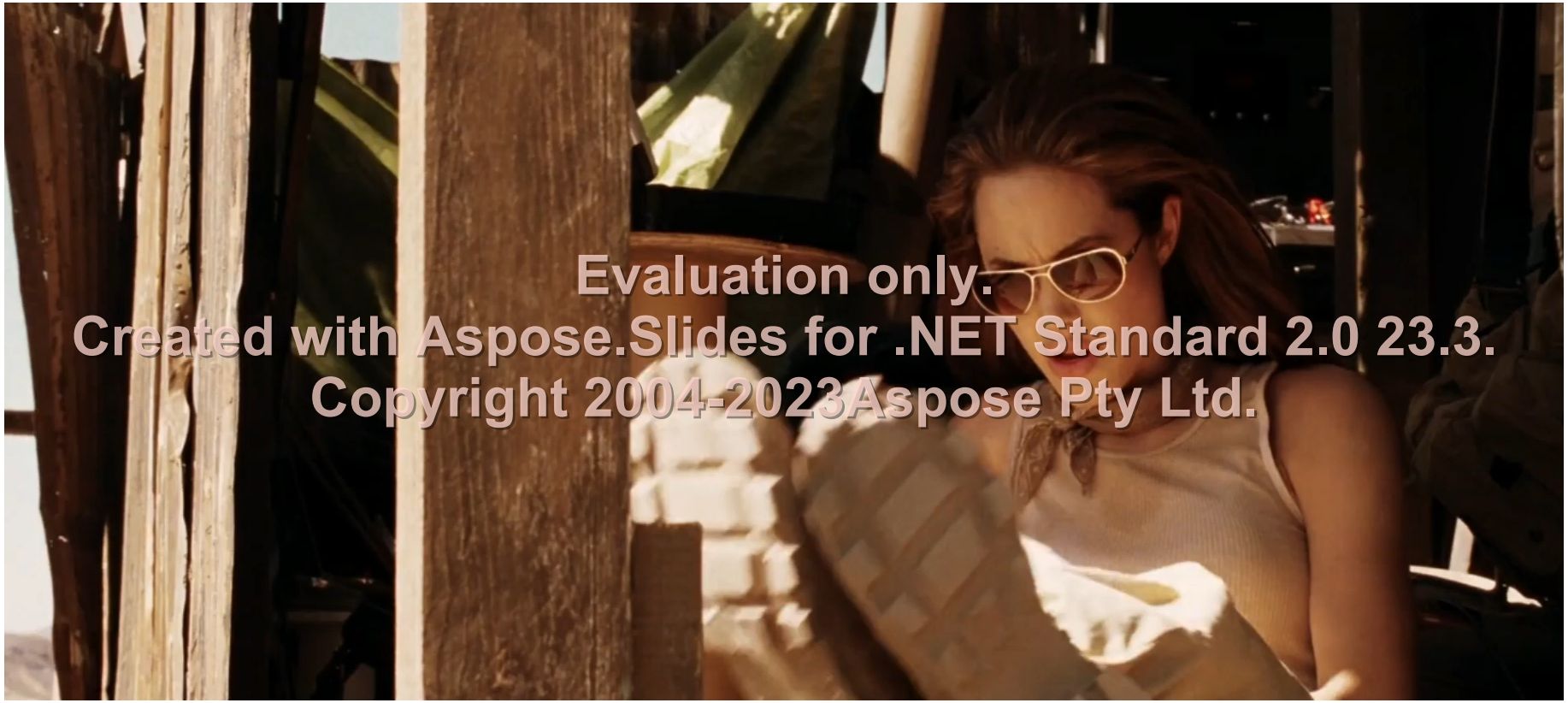
Mrs. Smith is a Rational Agent



Liman, Doug (2005): Mr. & Mrs. Smith [Video], United States: Goldsman. Retrieved from https://www.youtube.com/watch?v=CQliFA1dc-Q (01.12.2020).

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The Rational Agent

- AGENT = something that acts (latin *agere, do, make …)*
- RATIONAL AGENT = *acts so as to achieve the best expected outcome*
- Rational thinking is one possible mechanism to achieve rational behavior
- Perfect rationality cannot be achieved in complex environments
  - *LIMITED RATIONALITY = acting appropriately in a given situation under limited resources*

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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 useful results/positive outcomes of its behavior
- 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
- **Rationality** maximizes ***expected*** performance
- **Perfection** maximizes ***actual*** performance

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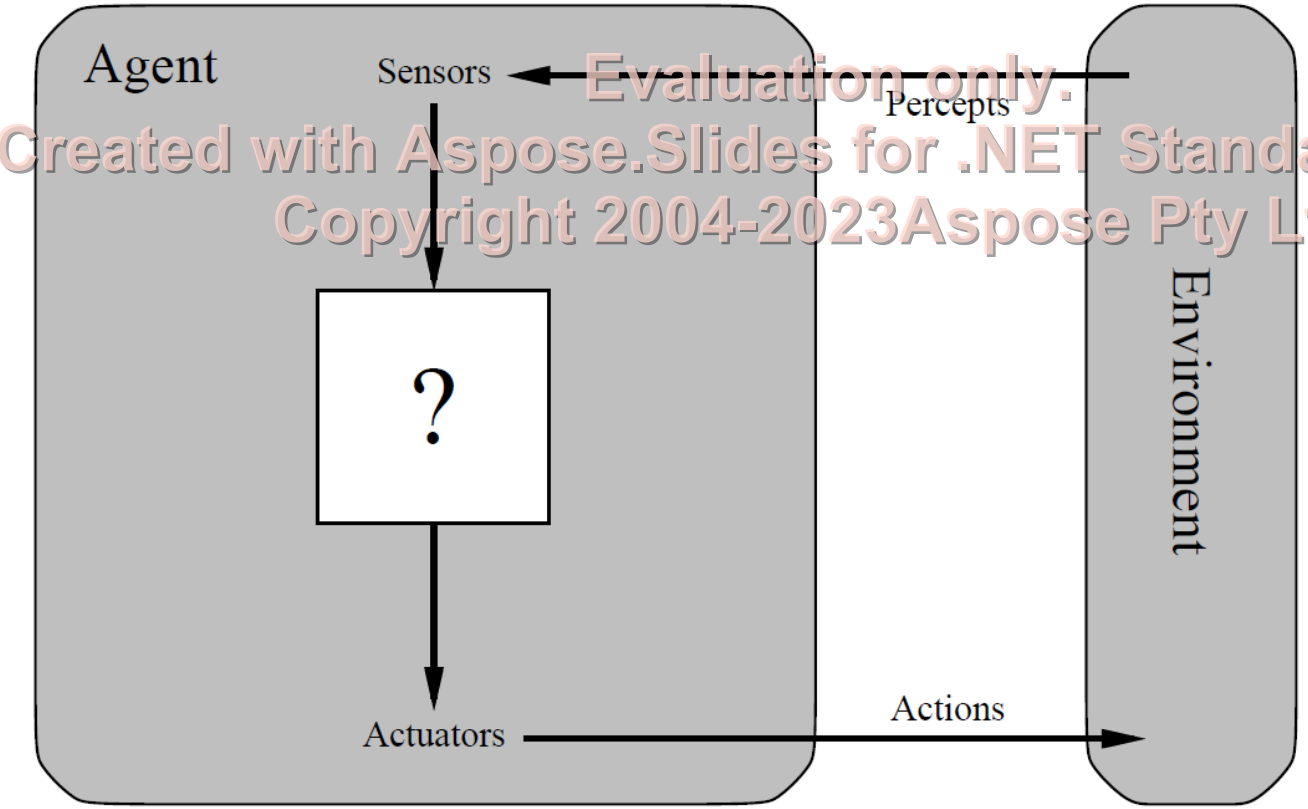
A Basic Agent Architecture

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



Russell, S., & Norvig, P. (2010). Figure 2.1

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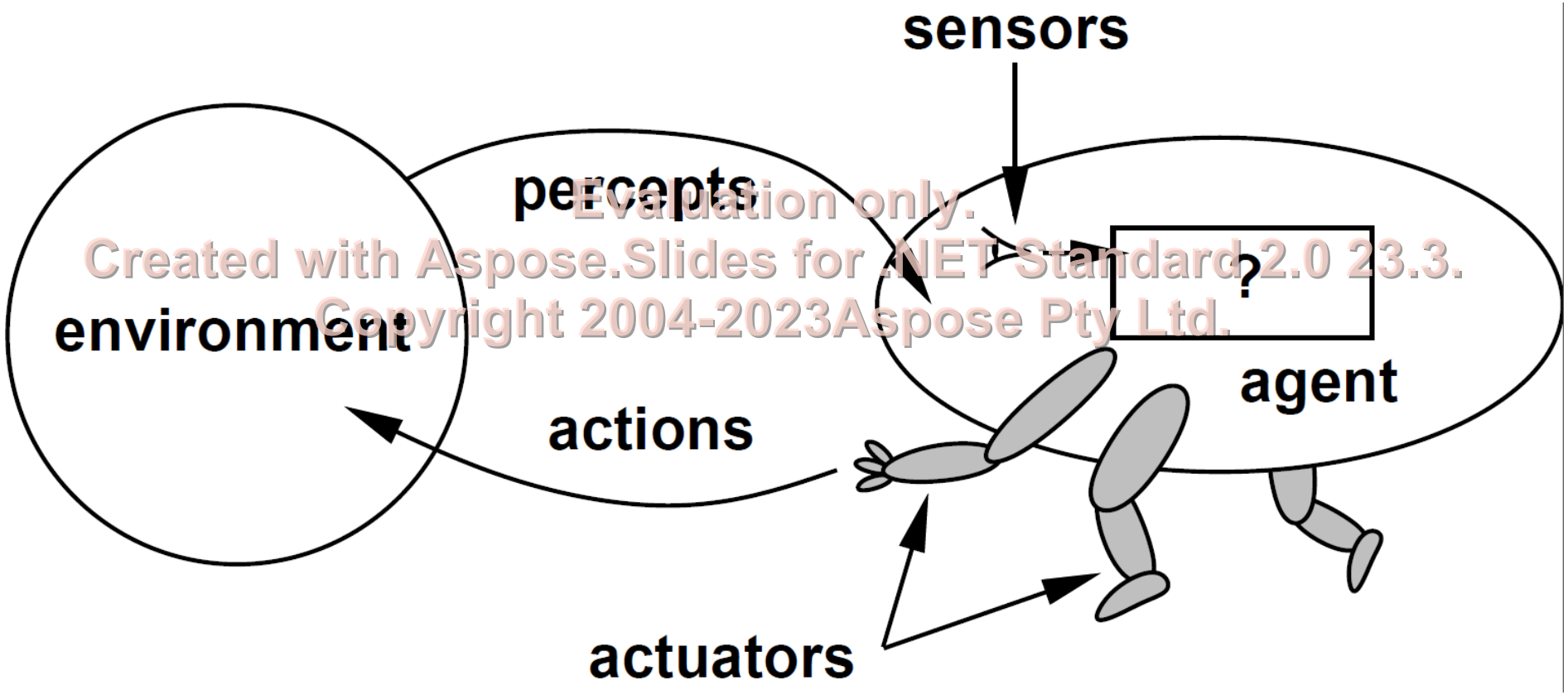
A Simplified Human Agent



Basa, Gungor (04.2018): Intelligent Agents. Blog Post “Deep Technology of Me”. Retrieved from https://gungorbasa.com/intelligent-agents-dc5901daba7d.

Actuators and Sensors in Pepper

Rigaud, Nicolas (2016): Meet pepper. Retrieved from https://de.slideshare.net/NicolasRigaud/meet-pepper .

HARDWARE OVERVIEW

BayTrail processor
Wifi / Ethernet
20 motors
120cm / 4 feet
28kg / 62 lb
12h battery

#MeetPepper

Rigaud, Nicolas (2016): Meet pepper. Retrieved from https://de.slideshare.net/NicolasRigaud/meet-pepper

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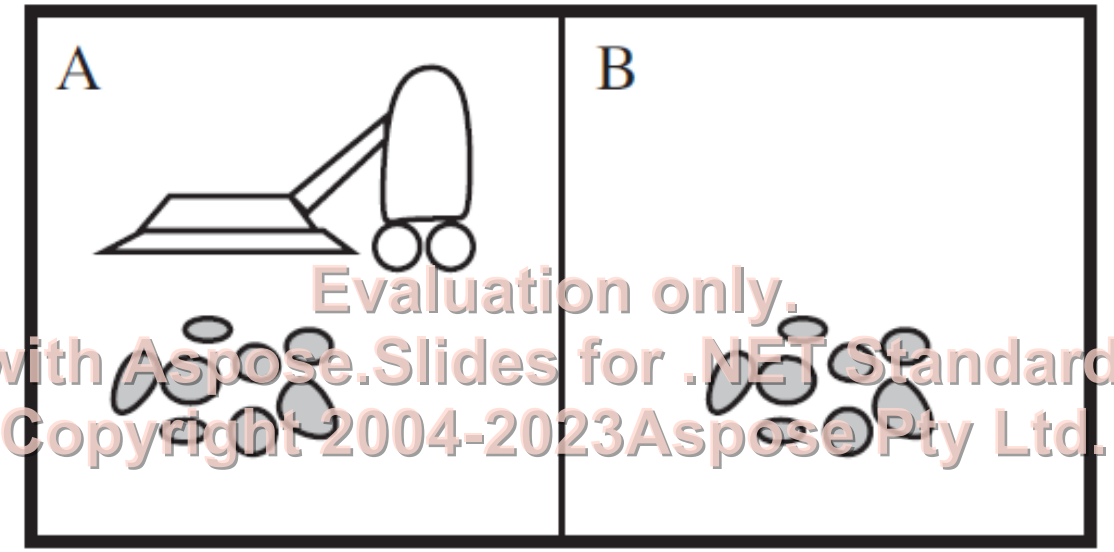
The Vacuum Cleaner Agent



Russell, S., & Norvig, P. (2010). Figure 2.2

- Percepts
  - Am I in square A or B?
  - Is the square dirty?
- Actions
  - move left, move right
  - suck
  - do nothing

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Modeling the Agent

- **Percept sequence**
  - complete history of what the agent has perceived to date
- **Agent function**
  - a function that maps any given percept sequence to an action

function TABLE-DRIVEN-AGENT(*percept*) **returns** an action
  persistent: *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*

- **Agent program**
  - takes the current percept as input from the sensors and returns an action to the actuators

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An Agent Table

Percept Sequence	Action
[A, clean]	right
[A, dirty]	suck
[B, clean]	left
[B, dirty]	suck
[A, clean], [B, clean]	left
[A, clean], [B, clean], [A, dirty]	suck
….	…

"If the current square is dirty, then suck else move to the other square."

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Performance of Rational Agents

§ . . . do the "right thing"!

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

§ Vacuum cleaner agent
  – m^2 per hour, level of cleanliness, energy usage, noise level, safety (behavior towards hamsters/small children)

Ø Optimal behavior is often unattainable
  – Not all relevant information is perceivable
  – Complexity of the problem is too high

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The Performance Measure

- Each action of the agent takes the world to another state

- If the sequence of world states is desirable for an external observer, the agent has performed well

- The performance measure evaluates the STATE of the ENVIRONMENT independent of the AGENT!
  - Otherwise, an agent could achieve perfect rationality simply by deluding itself that its performance was perfect
  - You get the behavior you reward
  - Vacuum cleaner: amount of dirt collected – suck, release, suck, release, suck

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Definition of the 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.

- Rational behavior is dependent on
  - performance measure (goal)
  - percept sequence
  - knowledge of the environment
  - possible actions

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PEAS Descriptions of Agents in Environments

PEAS Element	Content	Example
Performance Measure	*How do we measure the behaviorial sucess of the agent?*	Number of correctly answered questions
Environment	*What are key elements in the environment?*	Rigi Kaltbad Station Shop visitors
Actuators	*Capabilites for executing actions*	loud speaker
Sensors	*Capabilites to receive percepts*	camera, microphones

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More PEAS Examples

Agent Type	Performance Measure	Environment	Actuators	Sensors
Medical Diagnosis System	Number of recovered patients, costs of proposed treatments, lawsuits	Patients, doctors, diagnostic devices	Loudspeaker, Display	Cameras, other sensors of diagnostic devices, microphone, keyboard
Satellite image analysis system	Accuracy of image classification, F5 score	Earth, space center, outer space	Database of classified images	images
Part-picking robot	Number of correctly and safely picked parts	Bins with parts	Robotic gripper and arm	Camera, sensors,
Interactive English Tutor	Student´s score on tests	Cloud, user device	Loudspeaker, Display	microphone, keyboard

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Utility Function of Agent

- The utility function is used by the agent to evaluate the desirability of a state of the world
- A utility function maps a state (or a sequence of states) onto an evaluation value (usually a real number)
- The agent can use the evaluation
  - to select an action (sequence)
  - to weigh the importance of competing goals

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More formally ….

$$\text{Utility} \times \text{Percepts} \times \text{Knowledge} \rightarrow \text{Action}$$

- A selected action is ***optimal*** if it takes the agent to a state of maximum expected utility given available percepts and knowledge

- The agent is rational if it always chooses optimal actions

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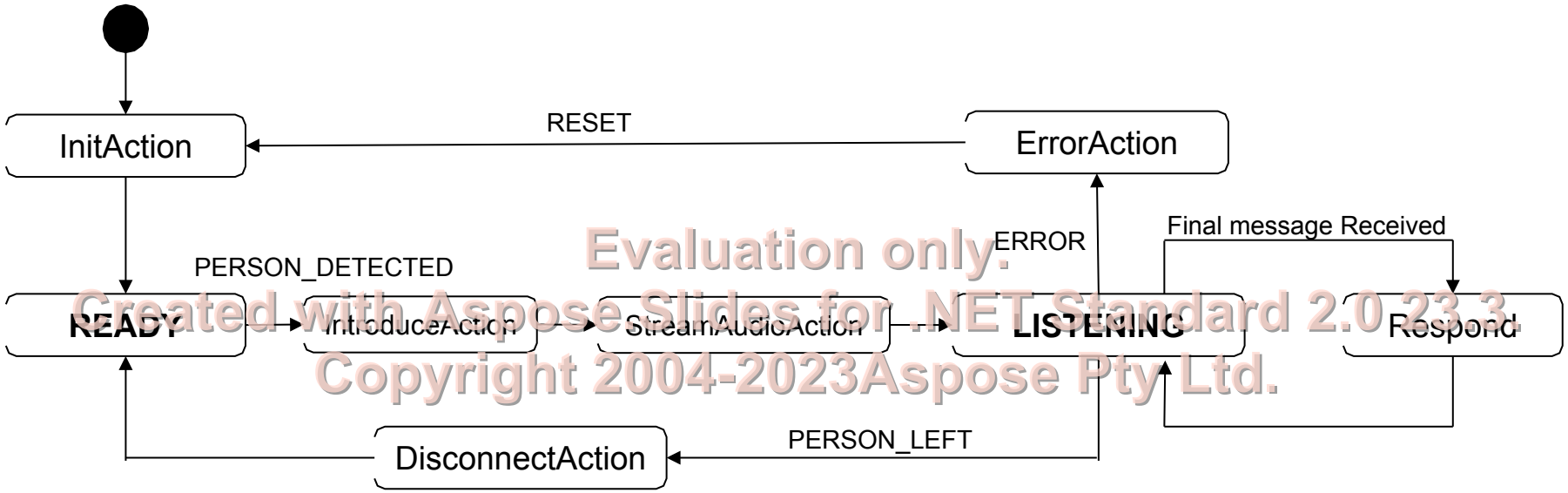
Utility Function of Rigibot



Confidence Values

- Google Speech to Text
- Microsoft QnA Maker

«Please repeat your question»

«I don't know»

<retrieved answer>

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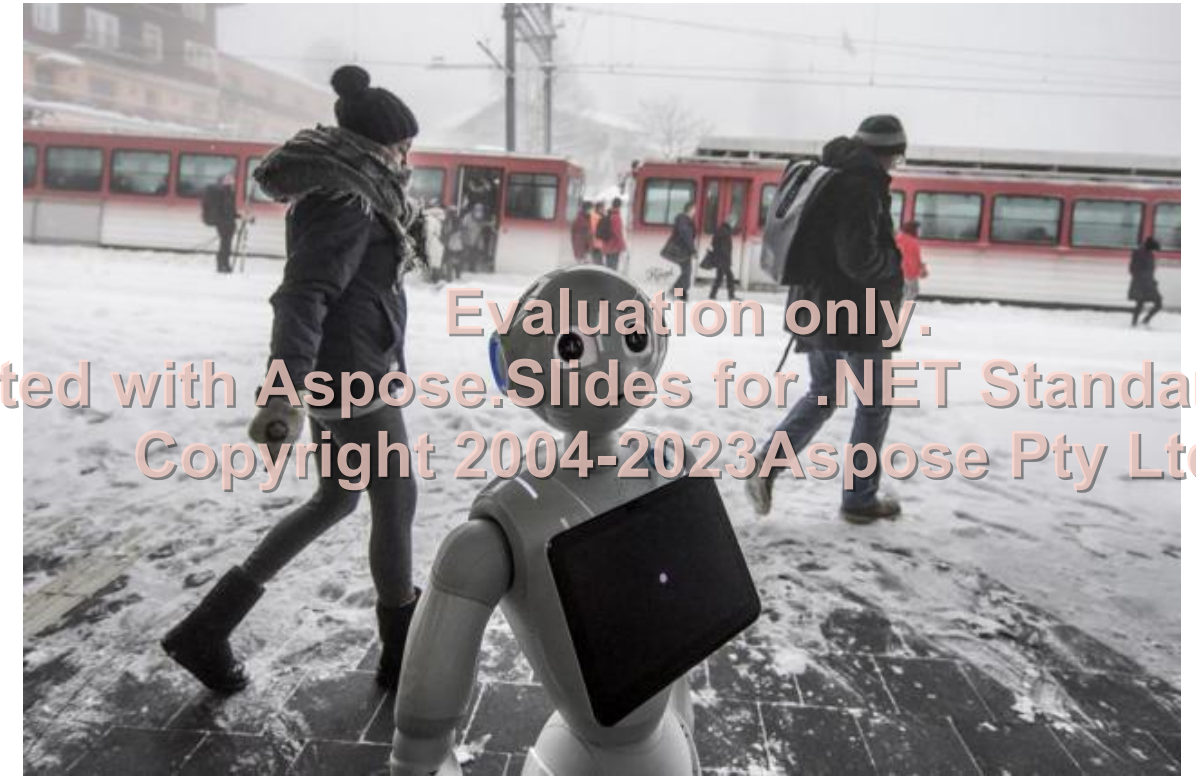
Properties of Environments



Source: Keystone

Environments that are unknown, partially observable, nondeterministic, stochastic, dynamic, continuous, and multi-agent are the most challenging.

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Properties of Environments

Question	Yes	No
Completeness of knowledge: Does the agent initially have complete **knowledge** about the environment?	Known	Unknown
Observability of environment: Can the agent **observe** all relevant aspects of the environment with its sensors?	Observable	Partially observable or unobservable
Environment dynamics: Is the environment **changing** while the agent is deliberating?	Dynamic	Static
Type of model: Are time, percepts and actions of the **model** discrete?	Discrete	Continuous

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Properties of Agent Actions

Question	Yes	No
Predictable action effects: Do effects of actions happen as planned by the agent?	Deterministic	Stochastic
Dependency of action effects: Do effects of actions depend only on the current state and the action, but not on the action history?	Episodic[1)]	Sequential[2)]
Number of agents: Can we model the AI system with only one agent?	Single-Agent	Multi-Agent

[1)] episodic memory = short-term memory
- the agent does not need to remember the past to make good decisions

[2)] sequential environments require a long-term memory
- good decisions depend on taking the right action in the past
  → actions have long-term effects
- for example, making a move in a chess game

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Simple and Difficult Environments

Property	Simple	Difficult
Knowledge	Known	Unknown
Observability	Observable	Unobservable
Dynamics of Changes	Static	Dynamic
Detail of Models	Discrete	Continuous
Short-term Action Effects	Deterministic	Stochastic
Long-term Action Effects	Episodic	Sequential
Number of Agents	Single	Multiple

Ø *The key in designing successful AI applications is to understand how we can make environments simpler for the agent!*

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Agent Architecture

- Agent = Architecture + Program
- The agent program is implemented on an architecture that determines the components on which the program can run
- The architecture defines the interfaces of the agent with the environment
  - implement the ability to receive percepts and to execute actions
- In practice, limitations of the architecture (including runtime and memory limitations) force the agent to approximate the optimal rational decision

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Types/Architectures of Agents

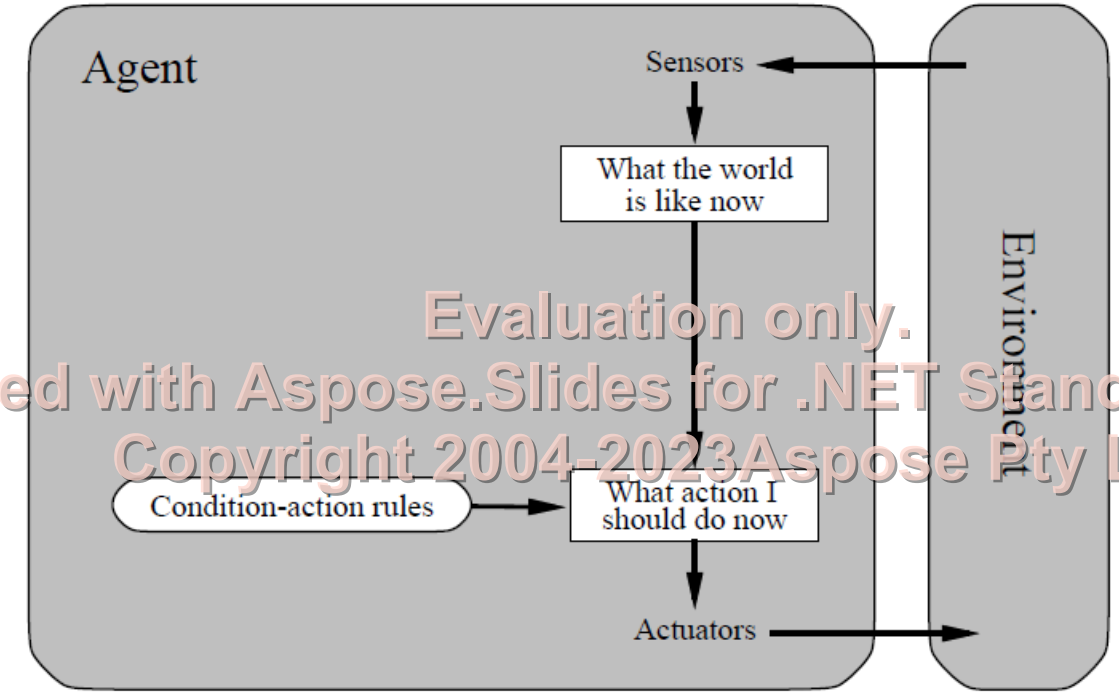
Agents differ in their capabilities

- **Exploration**: explorative actions for information gathering
- **Learning**: as much as possible from the percepts
- **Autonomy**: improve partial or incorrect knowledge

5 Types

- **Simple Reflex Agent**
- **Model-based Reflex Agent**
- **Goal-based Agent**
- **Utility-based Agent**
- **Learning Agent**

Simple Reflex Agent



Russell, S., & Norvig, P. (2010). Figure 2.9

- Senses the world and responds immediately based on simple rules that interpret the sensor input and link it to actions
  - no explicit world model, no "memory"

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Function of the Reflex Agent

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

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


Russell, S., & Norvig, P. (2010). Figure 2.6

Condition-action-rule (productions)

"**If** *car-in-front-is-braking* **then** *initiate-braking*."

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When do Simple Reflex Agents work?

- Correct decision is made based on current percepts only
  - environment must be fully observable, otherwise infinite loops can occur
  - escape from infinite loops through randomization

- Vacuum cleaner agent in two clean rooms: will move iteratively between the two rooms forever
- Vacuum cleaner agent with a coin flip to choose a move or stop moving for a while, can randomly escape a life-lock situation where it makes no progress when executing actions

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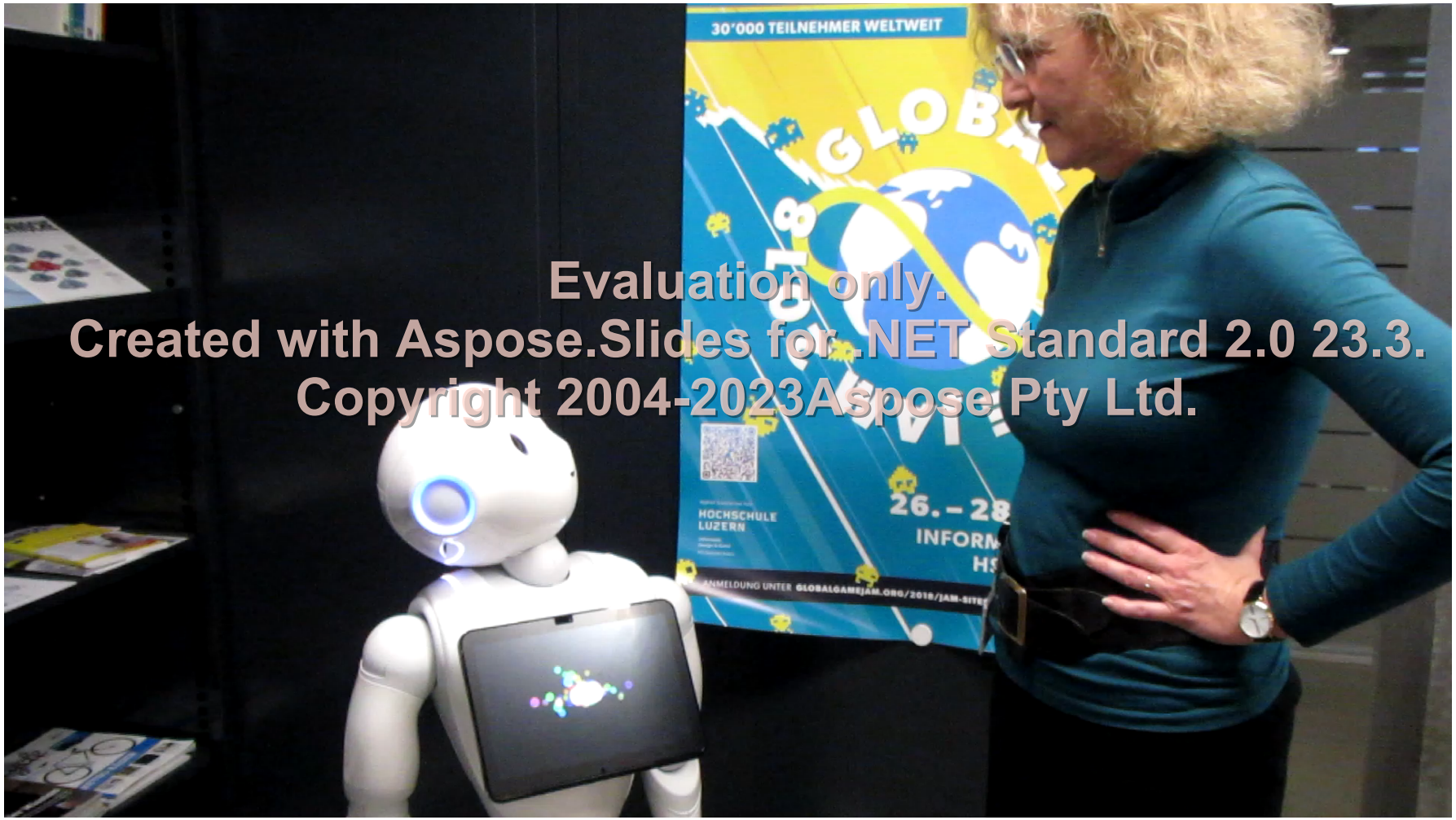
Simple Reflexes in Pepper



Watch videos about example agents in the CMS: Information > Materials > Videos

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Model-based Reflex Agent

- Keep part of the environment the agent perceived earlier
  - internal world model (agent state) that depends on the agent's percept history
- Model can serve to answer questions
  - what are the effects of agent actions?
  - how does the environment evolve (independently of the agent)?
- Uncertainty about the environment is unavoidable because of limited sensing capabilities and limited models
  - model represents the agent's "best guess“ of the environment state, the evolution of the environment, and the effects of its actions

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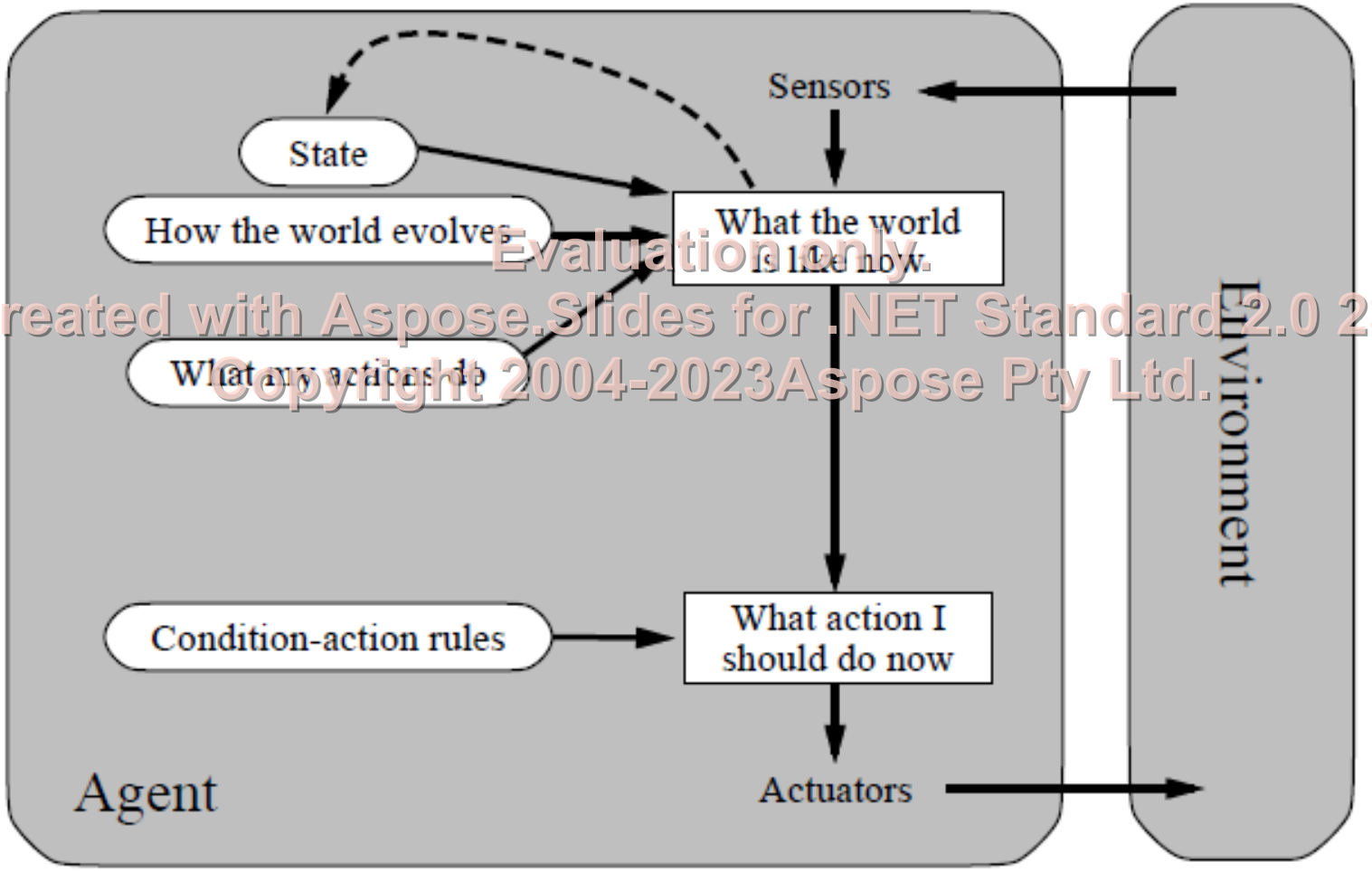
Model-based Reflex Agent



Russell, S., & Norvig, P. (2010). Figure 2.11

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Function of the Model-based Reflex Agent

```
function MODEL-BASED-REFLEX-AGENT(percept) returns an action
  persistent: state, the agent's current conception of the world state
              model, a description of how the next state depends on current state and action
              rules, a set of condition–action rules
              action, the most recent action, initially none

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


Russell, S., & Norvig, P. (2010). Figure 2.8

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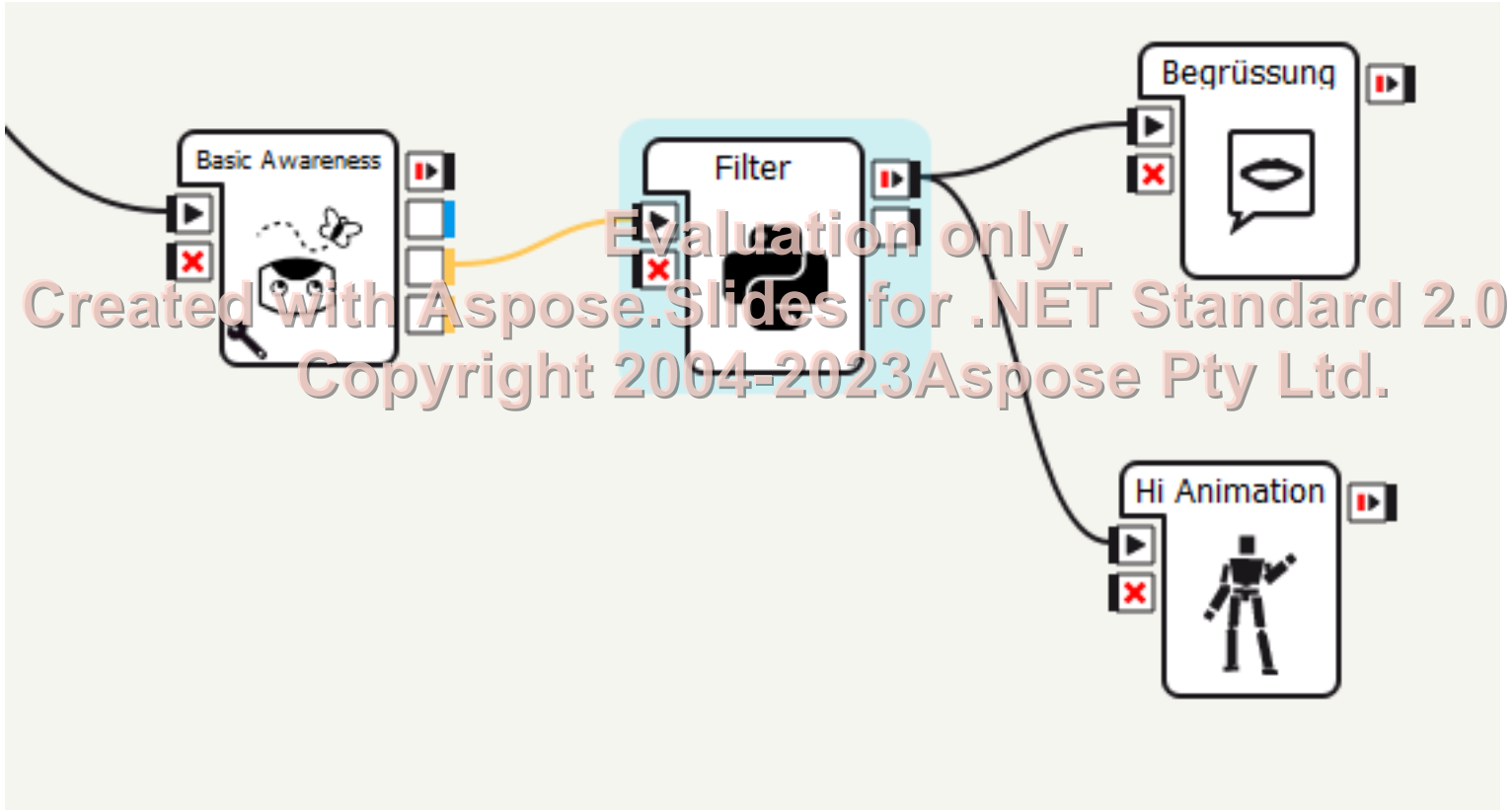
Model-based Reflexes in Pepper



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Model-based Pepper

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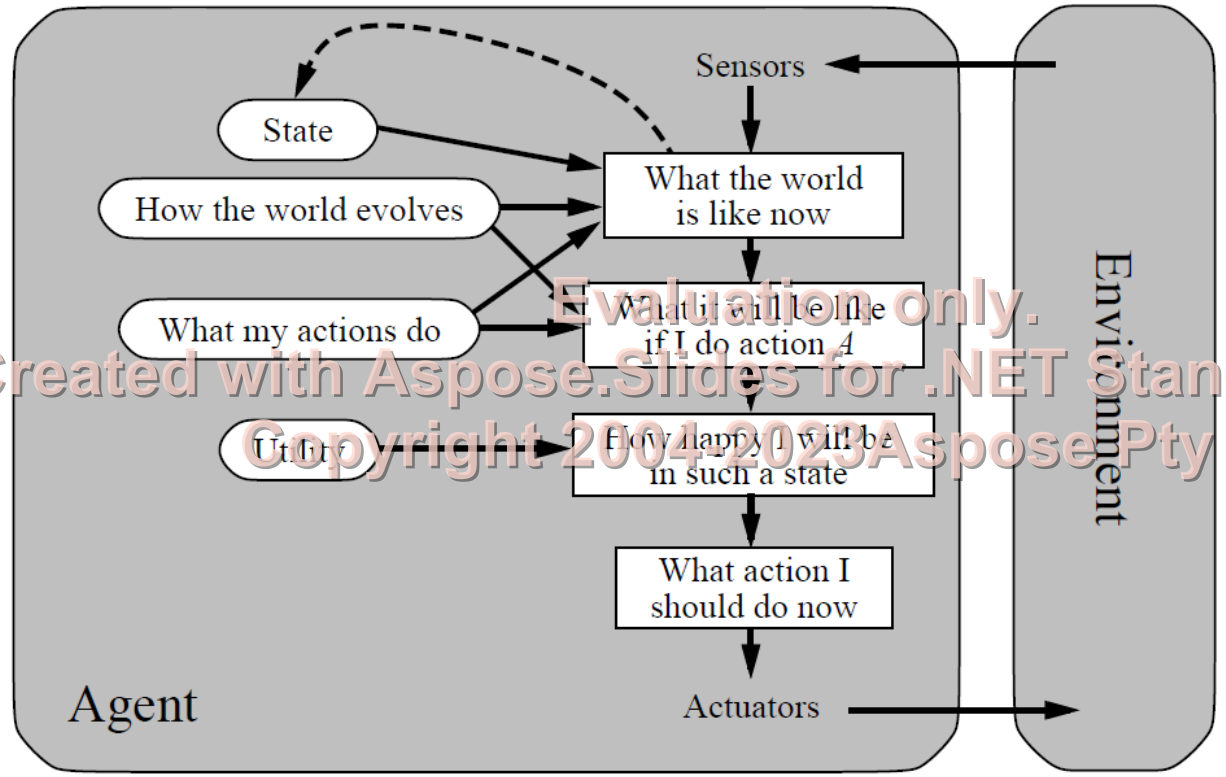
Utility-based Agent



Russell, S., & Norvig, P. (2010). Figure 2.14

- If several actions are possible in a state, this agent can evaluate their utility and make a deliberate choice

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Utility-based Pepper

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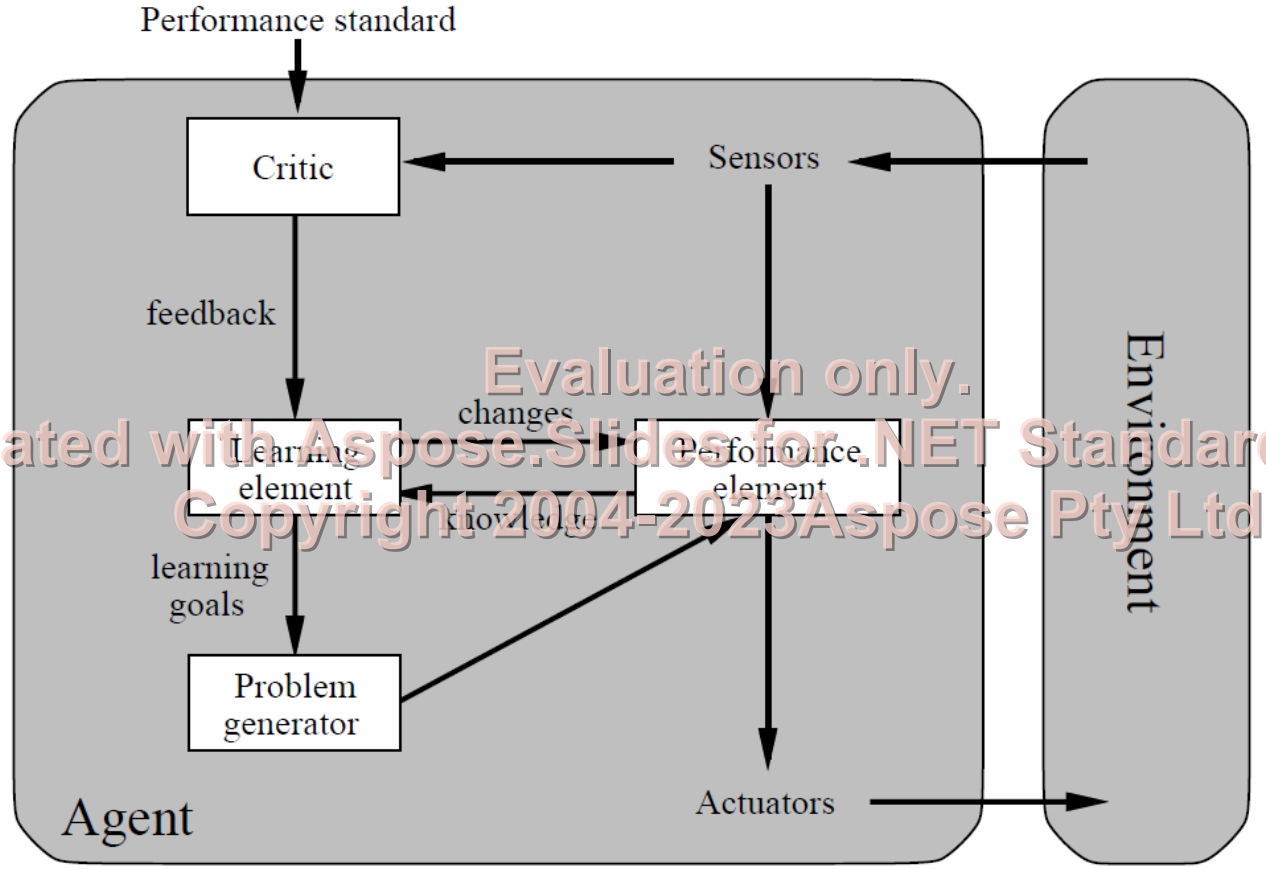
Learning Agent



Russell, S., & Norvig, P. (2010). Figure 2.15

- This agent can acquire new skills and reflect on its own performance to improve over time

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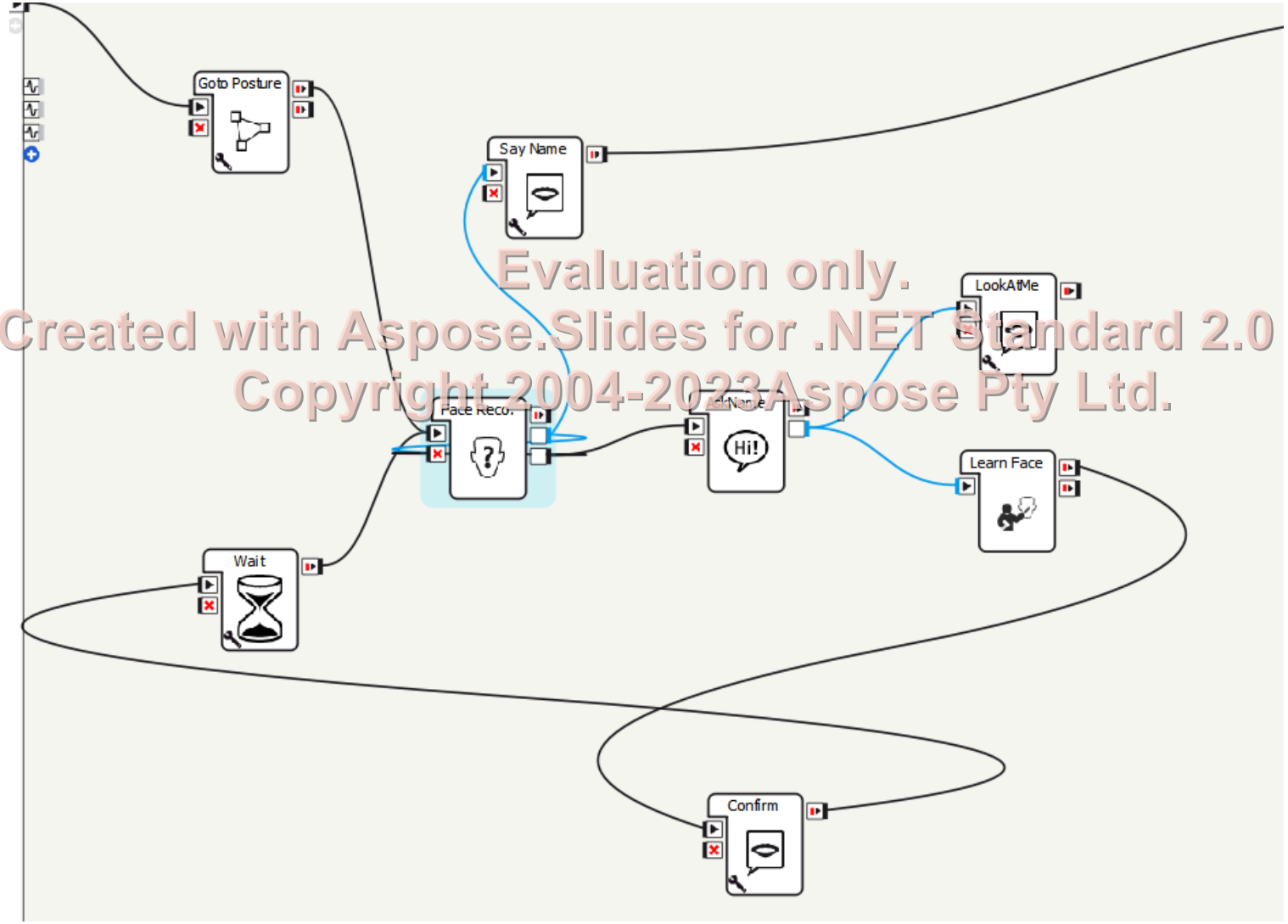
Learning Faces in Pepper



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(Simple) Learning Pepper

Watch videos about example agents in the CMS: Information > Materials > Videos

Learning Agent

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

- Responsibilities of its components
  - performance element: shows the agent how well it succeeded in the environment
  - learning element: improves the performance element because the agent learns how actions lead it to more states with higher utility
  - critic: evaluates the behavior of the agent based on its performance and gives the evaluation as feedback to the learning element
  - problem generator: suggests actions that will lead to informative experiences

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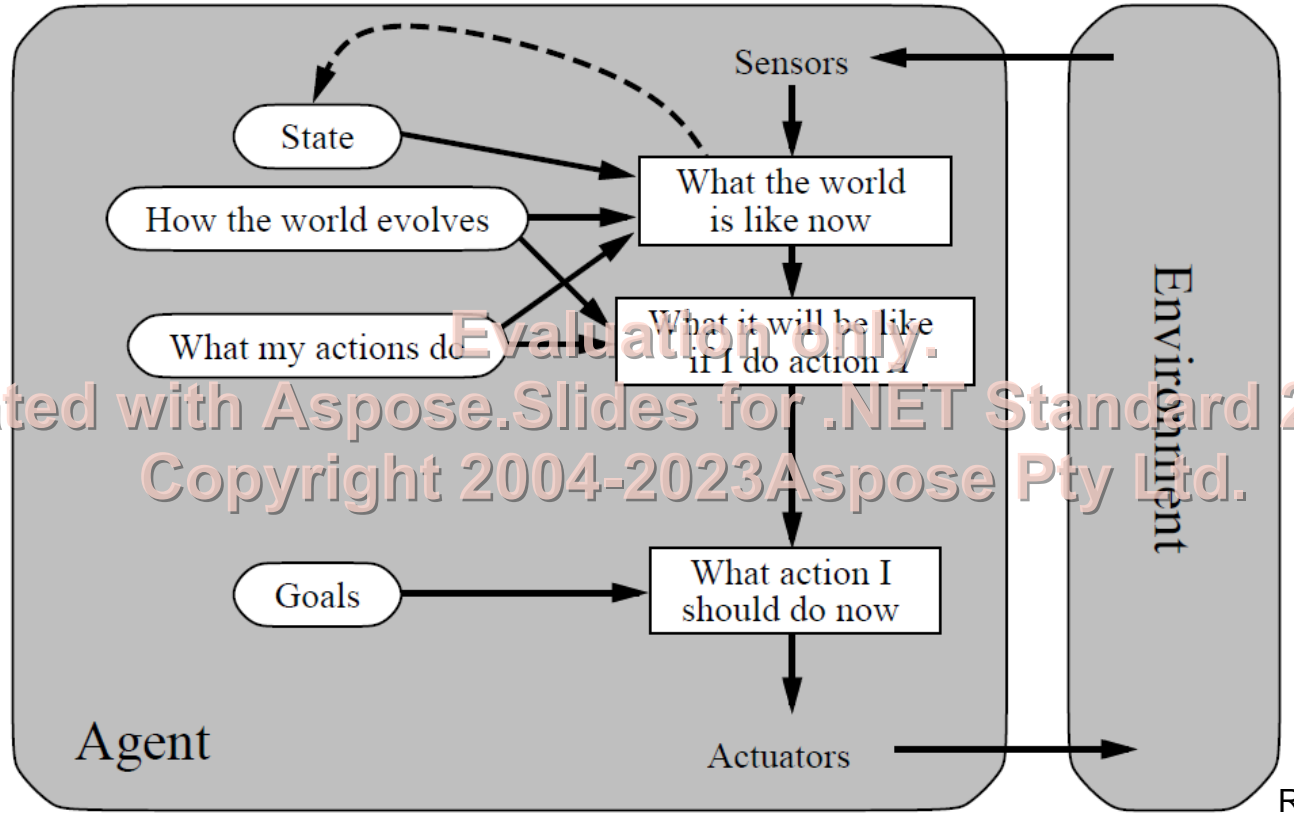
Goal-based Agent



Russell, S., & Norvig, P. (2010). Figure 2.13

- Builds a model of the world and uses an explicit representation of goals
- Considers effects of actions on the world model before selecting an action to achieve a goal state - to choose among competing actions/goals utility function is needed

Goal-Driven Spot

Guardian News (02.2018): New dog-like robot from Boston Dynamics can open doors. United States: The Guardian. Retrieved from https://www.youtube.com/watch?v=wXxrmussq4E (01.12.2020).

Summary

- AI research often assumes the metaphor of the rational agent, which maximizes expected outcome
- Humans are not rational agents and sacrifycing outcome for the benefit of other is important for the human society to work
- Understanding properties of the environment and the boundary between agent and environment is successful for building successful AI applications
- More complex environments usually require more complex agents, AI distinguishes different agent architectures
- Ethical and risk considerations are important when designing powerful agents, see, e.g., MIT Moral Machine Experiment http://moralmachine.mit.edu/

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Working Questions

1. What is a rational agent?
2. How can we characterize environments?
3. What is a PEAS description of an agent/environment pair?
4. What types of rational agents do we distinguish?
5. What agent type(s) do you need to build to achieve a certain behavior?