



# Smart Attributes for Cyber-Physical Systems (CPS)

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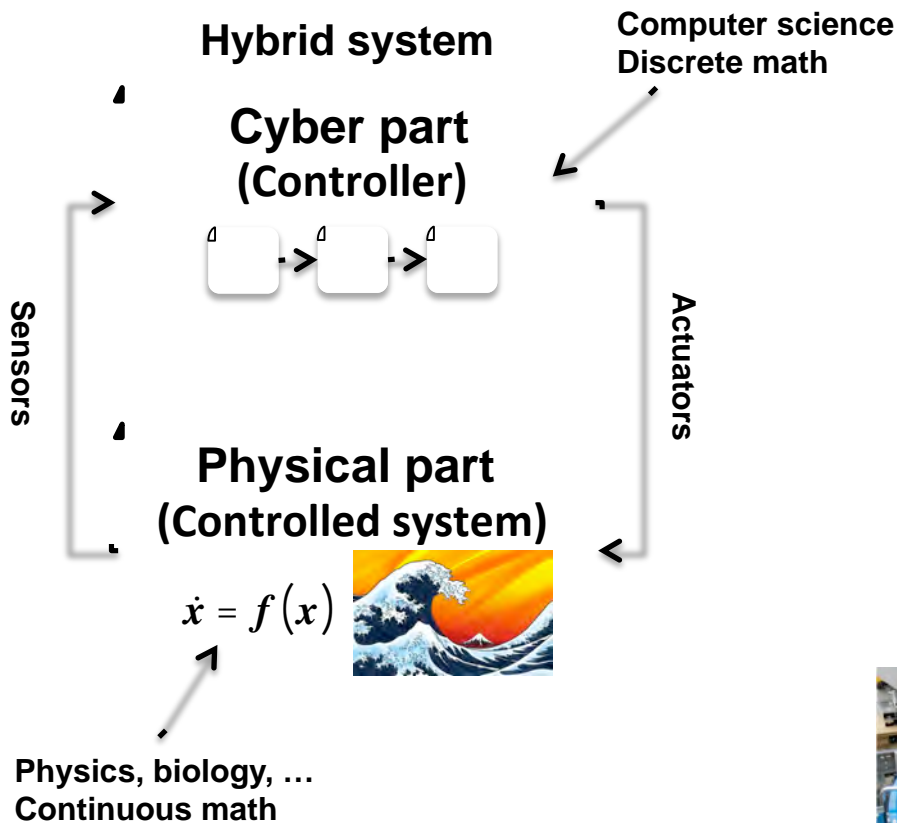
Institute of Computer Engineering



Cyber-Physical Systems Group

# Cyber-Physical Systems (CPS)

CPS are transforming how we interact with the physical world !



Amazon drone



Robotic Arm



Kiva robots



Conveyor Belt

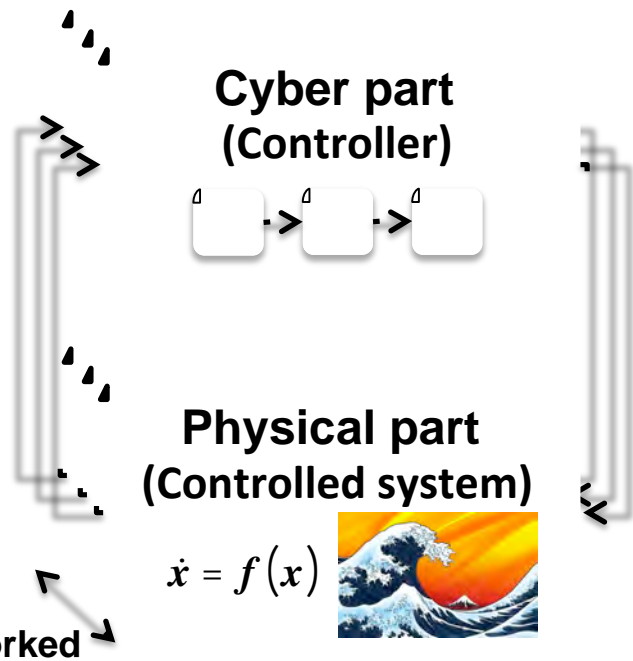


Gantry robots

# Cyber-Physical Systems (CPS)

CPS are transforming how we interact with the physical world !

Smart, Collaborative, Autonomous



Smart factory

**Common goal:** reach the highest customization of products with a very flexible (mass) –production

**But what does it mean to be smart ?**

## Open Hot Topics:

- Apply CS methods for optimization & control
- Predicting emergent behaviors
- Engineering safe/smart CPS

# Being Smart

We call ourselves *Homo Sapiens* = Wise Man

## Understanding human intelligence

- **How do we** perceive, understand, predict and manipulate
- **A world far larger** and more complicated than ourselves

## Building intelligent systems

- ***Originally:*** the aim of artificial intelligence
- ***Nowadays:*** control & decision theory, CPS, ...

# Being Smart

## The four possible goals in Artificial Intelligence

### Thinking Humanly

Building computers able to think like humans

Automation of all the activities with human thinking

### Thinking Rationally

Study the mental faculty using computational models

Computations allowing to perceive, act and reason

### Acting Humanly

Machines that perform actions requiring intelligence

Make computers do things at which we are currently better

### Acting Rationally

The study of the design of Intelligent agents

Concerned with intelligent behavior in artifacts

# Thinking Humanly

## Need to get inside the actual working of human minds

- **Introspection:** Try to catch our own thoughts
- **Psychological experiments:** Observing a person in action
- **Brain imaging:** Observing the brain in action

## Cognitive science brings together

- **Computer models:** From artificial intelligence
- **Experimental techniques:** From psychology
- **Goal:** Devise precise and testable theories

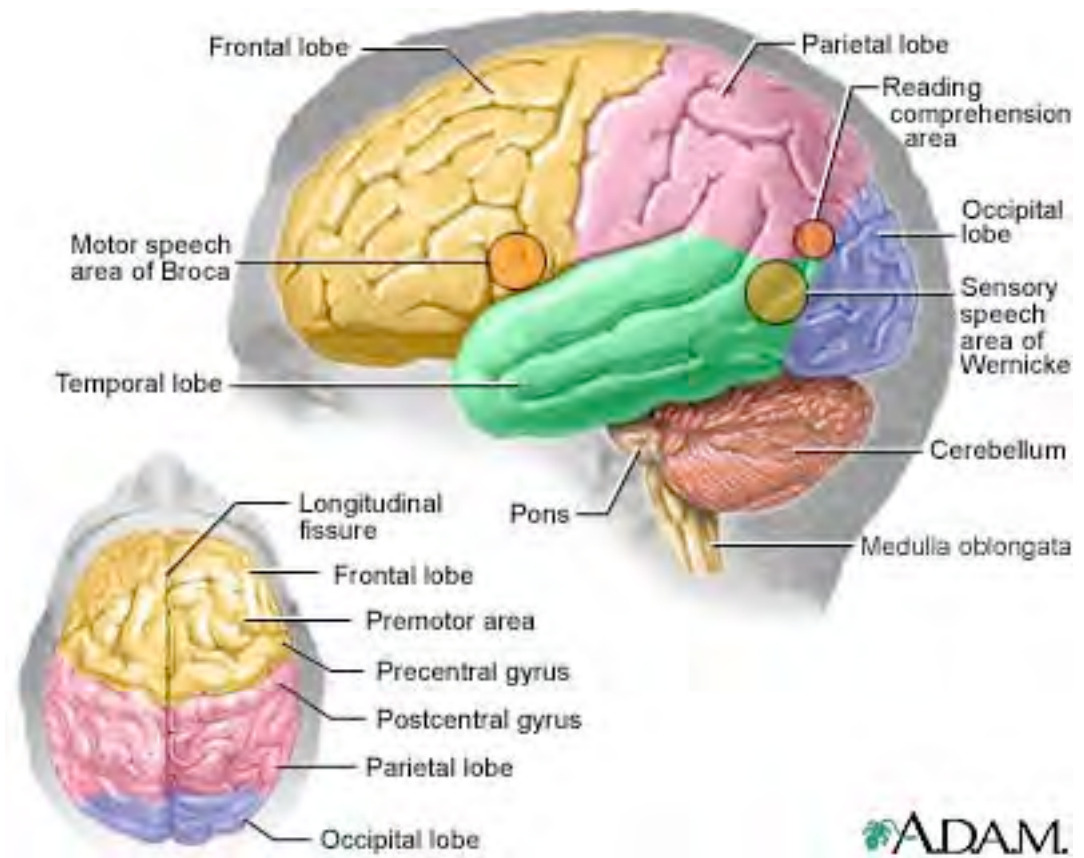


*René Descartes*



# Human Brain

- Human brains are very good at making rational decision (but not perfect)
- “Brains are to intelligence as wings are to flight”
- Brains aren't as modular as software
- Lessons learned, prediction and simulation are the key to decision making



# Thinking Rationally

## The syllogism of Greek philosopher Aristotle

- **Pattern for the right thinking:** Always yield correct conclusion
- **Main pattern:**  $A \wedge (A \rightarrow B) = A \wedge B = B \wedge (B \rightarrow A)$
- **Problem:** World is not black and white (qualitative)

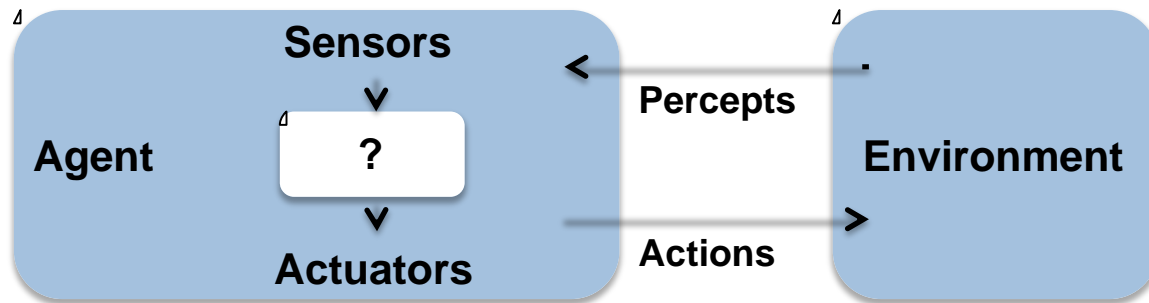
## The extension of syllogism to probability

- **Main pattern:**  $P(A)P(B|A) = P(A \wedge B) = P(B)P(A|B)$
- **Advantage:** Shades of gray (quantitative)





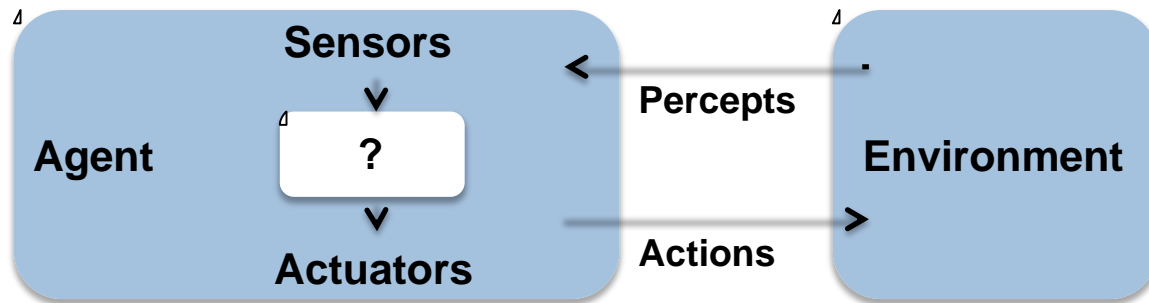
# Acting Rationally



## Computer Agent (Latin *agere* = doing)

- Operates autonomously and persist over long time
- Perceives, acts upon and adapts to its environment
- Creates and pursues its own goals

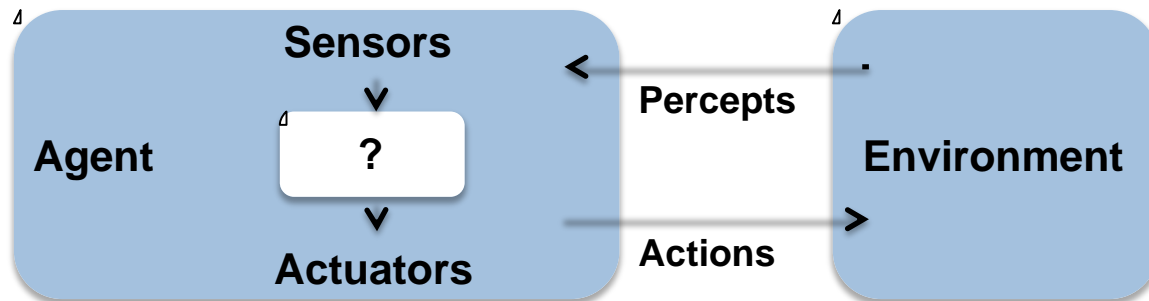
# Acting Rationally



## Rational Agent (Extension of Computer Agent)

- Acts so to **achieve the best outcome**, and when
- There is **uncertainty**, the **best expected outcome**

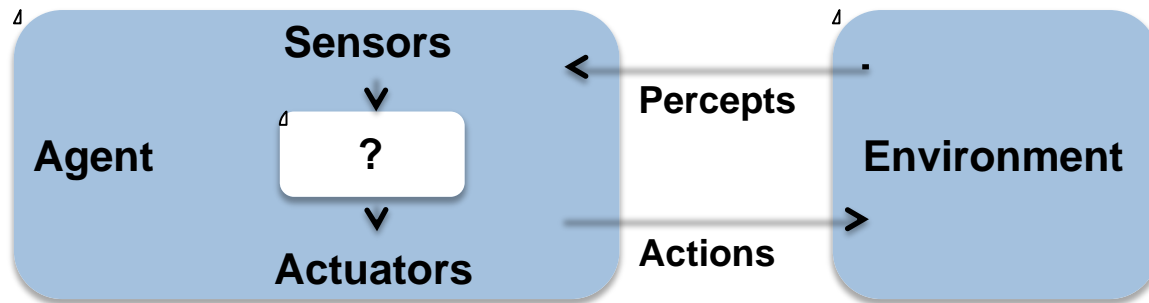
# Advantages of Rational Agents



## The rational-agent approach has two advantages

- It is more general than the laws-of-thought approach
  - ✓ Correct inference is just one way of achieving rationality
- It is more amenable to scientific development
  - ✓ Rationality is mathematically well defined and very general

# Rational Agent





# Rational Agent

## What is rational at any given time depends on

- **The performance measure** that defines success
- **The agent's prior knowledge** of the environment
- **The actions** that the agent **can perform**
- **The agent's percept sequence** to date

## For each percept sequence a RA 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*

# Acting Humanly

## Turing Test (Proposed in 1950)

- **After posing some written questions** a human interrogator
- **Cannot tell if the written responses** came from a computer

## A Computer Needs The Following Capabilities

- **Natural language processing:** To communicate
- **Knowledge representation:** To store what it knows
- **Automated reasoning:** To draw new conclusions
- **Machine learning:** To adapt new circumstances



# Acting Humanly

## Total Turing Test Contains in Addition

- **A video signal:** To test subject's perceptual abilities
- **A hatch:** To pass physical objects to the subject

## A Computer Needs Additional Capabilities

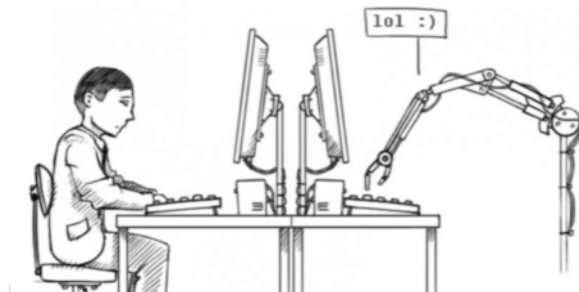
- **Computer vision:** To perceive objects
- **Robotics:** To manipulate objects and move



Robot-robot collaboration



Human-robot collaboration



# Research Agenda

**Vision:** Provide a framework to engineer smart, robust and resilient CPS

**Develop new highly scalable modeling and analysis techniques:**

- State-space of a CPS is generally exploding
- Open, physical part, uncertain and spatially distributed

**Build smart brain-inspired CPS:**

- Embedding neural decision structures in CPS hardware and software
- From Combinatorial Neural Networks to Deep (sequential) Neural Networks

**Guarantee a safe interaction between CPS and between CPS and humans:**

- CPS consists of several interconnected devices
- Only the interfaces are known

**Synthesis of Robust and Smart Controllers for CPS:**

- These controllers will encode all the valid behaviors within one stochastic program, whose adaptation to environment perturbations will merely prune away some of the previously valid behaviors.