



Source: <https://blenderartists.org/forum/showthread.php?316399-Industrial-Robots>

# Intelligent Robotics

## Introduction to Industrial Robots & Challenges

Philipp Ennen, M.Sc.

# Content

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- I. Organizational
- II. Introduction
  - I. Rise of Robotics and AI
  - II. Smart Robots for the Manufacturing Industry
- III. Artificial Intelligence in Robotics
  - I. Definition
  - II. Approaches for AI in Robotics

## About Me

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Coffee



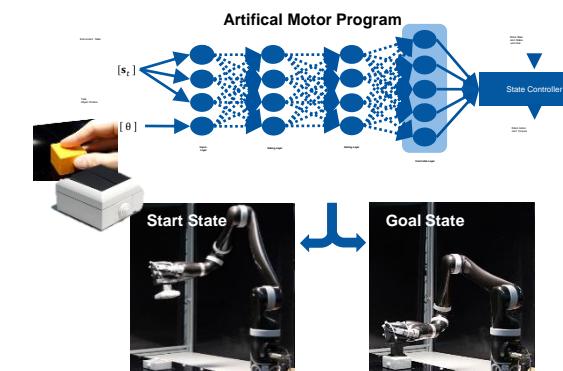
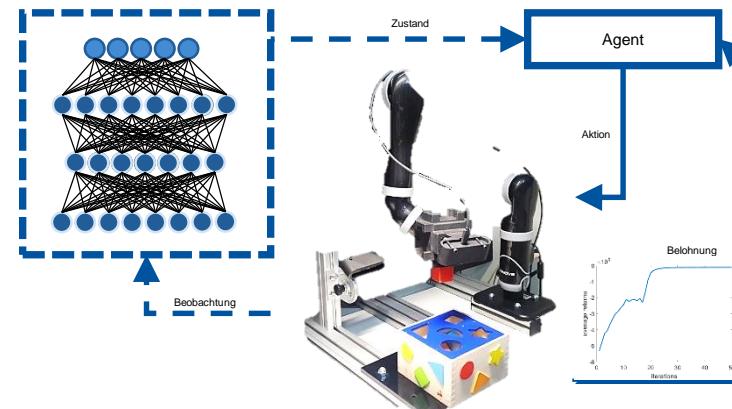
Saxophone



Adventurer



and Artificial Intelligence for Motion...



# Organizational

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## Website and Wifi

- Website for this part: <https://philippente.github.io/irobotics.html>
- Wifi-Access:
  - SSID: SURFACES
  - Password: hello123

Home

## Seminar: Intelligent Motion Planning

We (Max and Philipp) are glad to be organizing a seminar on intelligent robotics. This page will provide you with lecture materials and introductions for the practicals. If you have any further questions, feel free to contact us via email.

Contact details of Max and Philipp



### Day 1: Introduction

Lecture: Introduction to Industrial Robots and Challenges  
Lecture: Motion Planning for Industrial Robots  
Practicals: Programming with Python for Motion Planning  
Book: Learning ROS for Robotics Programming - Second Edition

# **Content**

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## I. Organizational

## II. Introduction

- I. Rise of Robotics and AI
- II. Smart Robots for the Manufacturing Industry

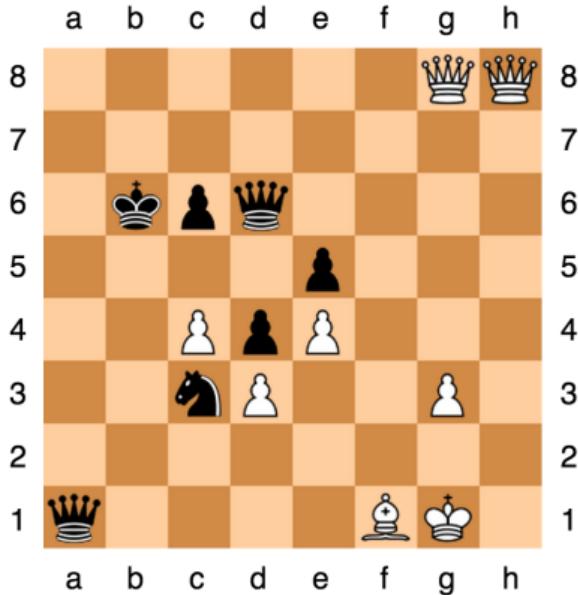
## III. Artificial Intelligence in Robotics

- I. Definition
- II. Approaches for AI in Robotics

# Introduction

**„In robotics, the easy problems are hard and the hard problems are easy“**

S. Pinker. The Language Instinct. New York: Harper Perennial Modern Classics, 1994

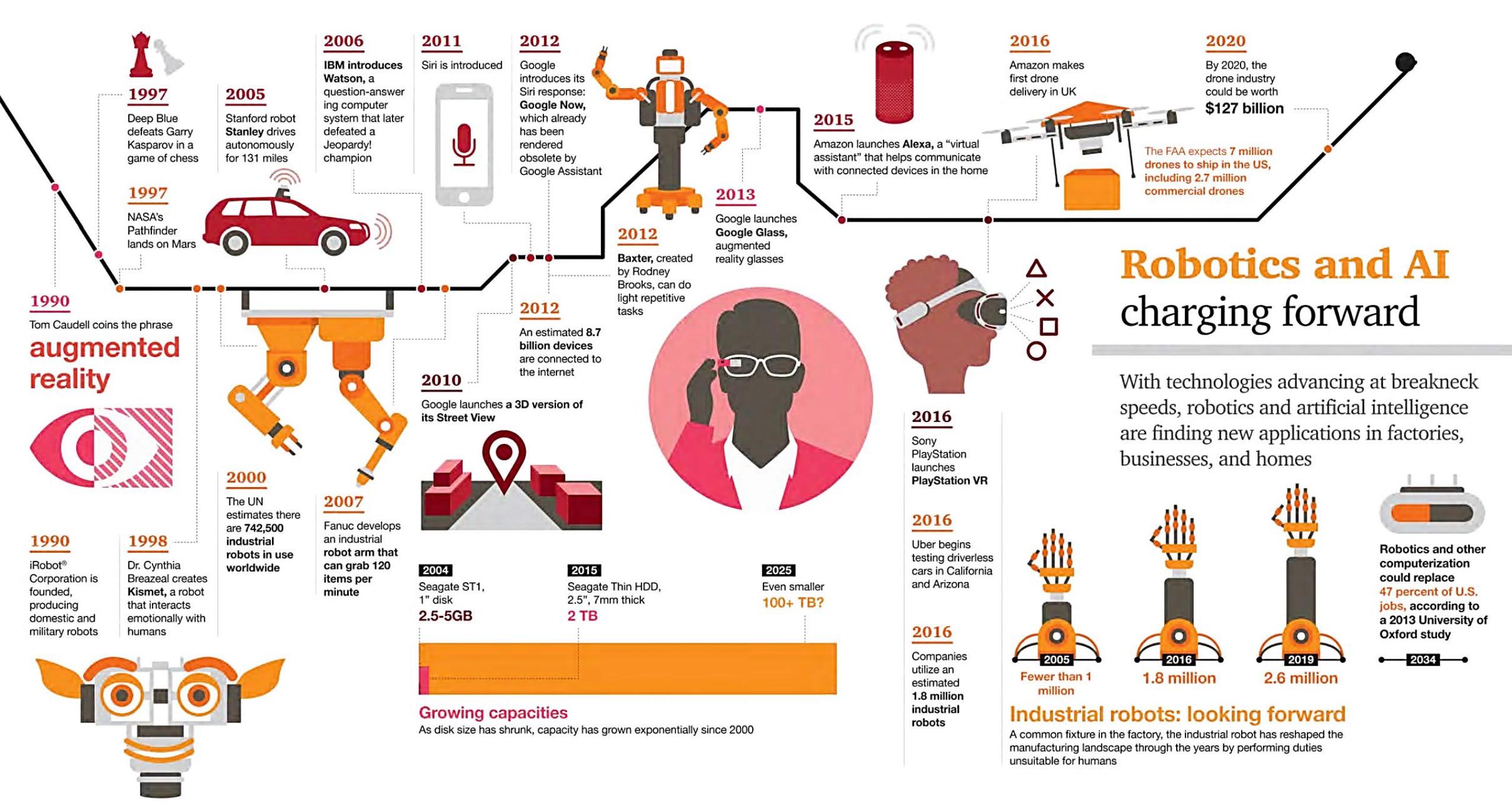


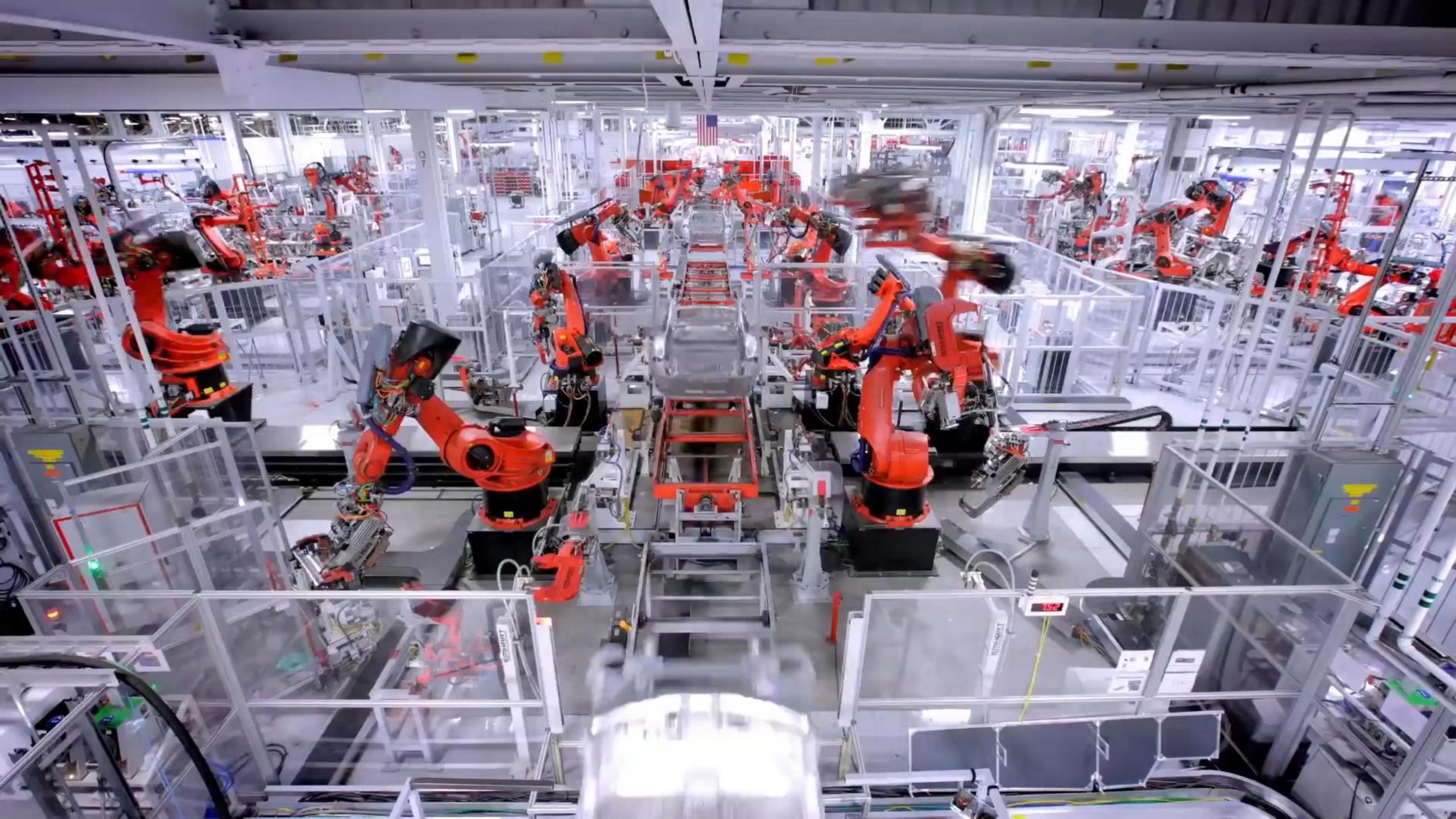
Building a computer that defeats  
Chess World Champion Gari  
Kasparow: **Easy**



Build a robot with "healthy human  
understanding" (i.e. motor skills):  
**Difficult**







# Introduction

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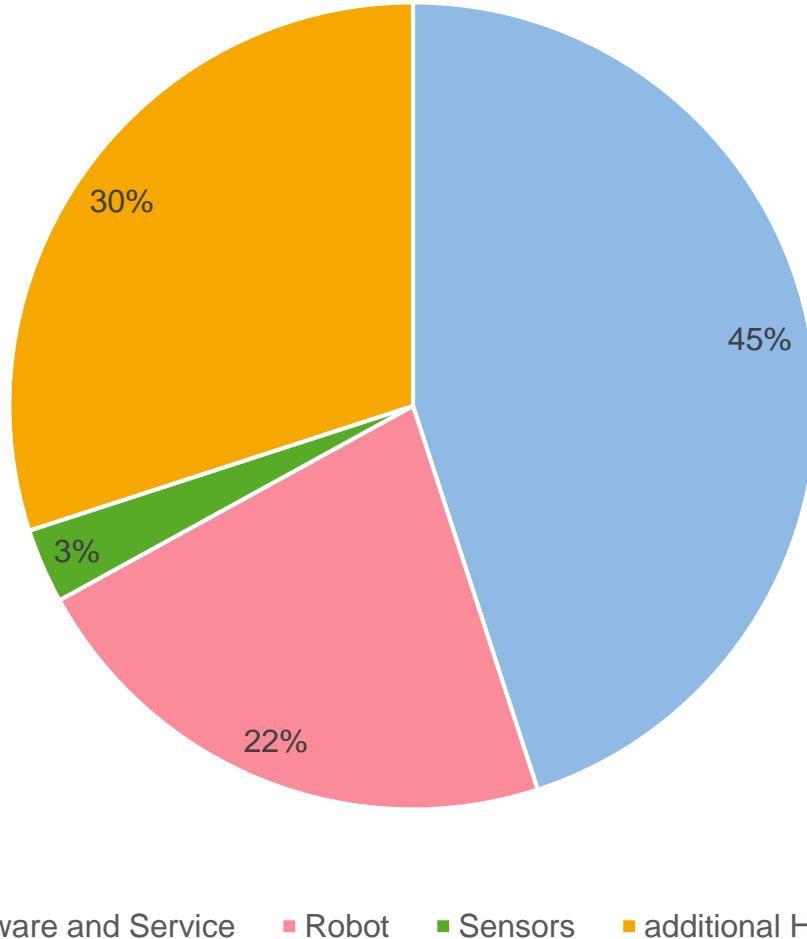
## Traditional Industrial Robots

- ... **structured environment**
- ... high precision and velocity
- ... high programming effort (through experts)
- ... inflexible
- ... stationary
- ... high driven potential, protection fences necessary
- ... open loop control
- ... only isolated sensor integration, no environment detection
- ... problems are solved with hardware



# Industrial robots: software is the bottleneck

Costs for integration is 5x-10x higher than the actual robot



Quelle: International Federation of Robotics

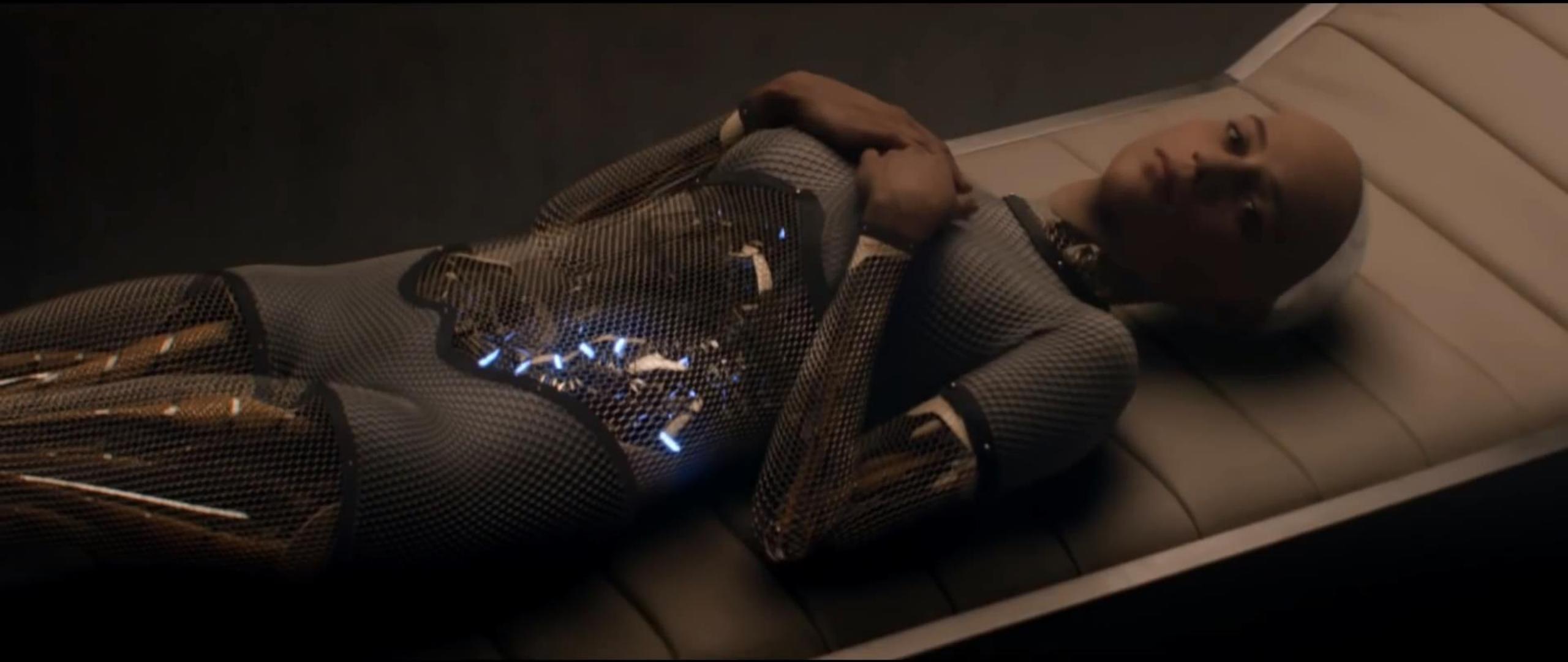
## Introduction

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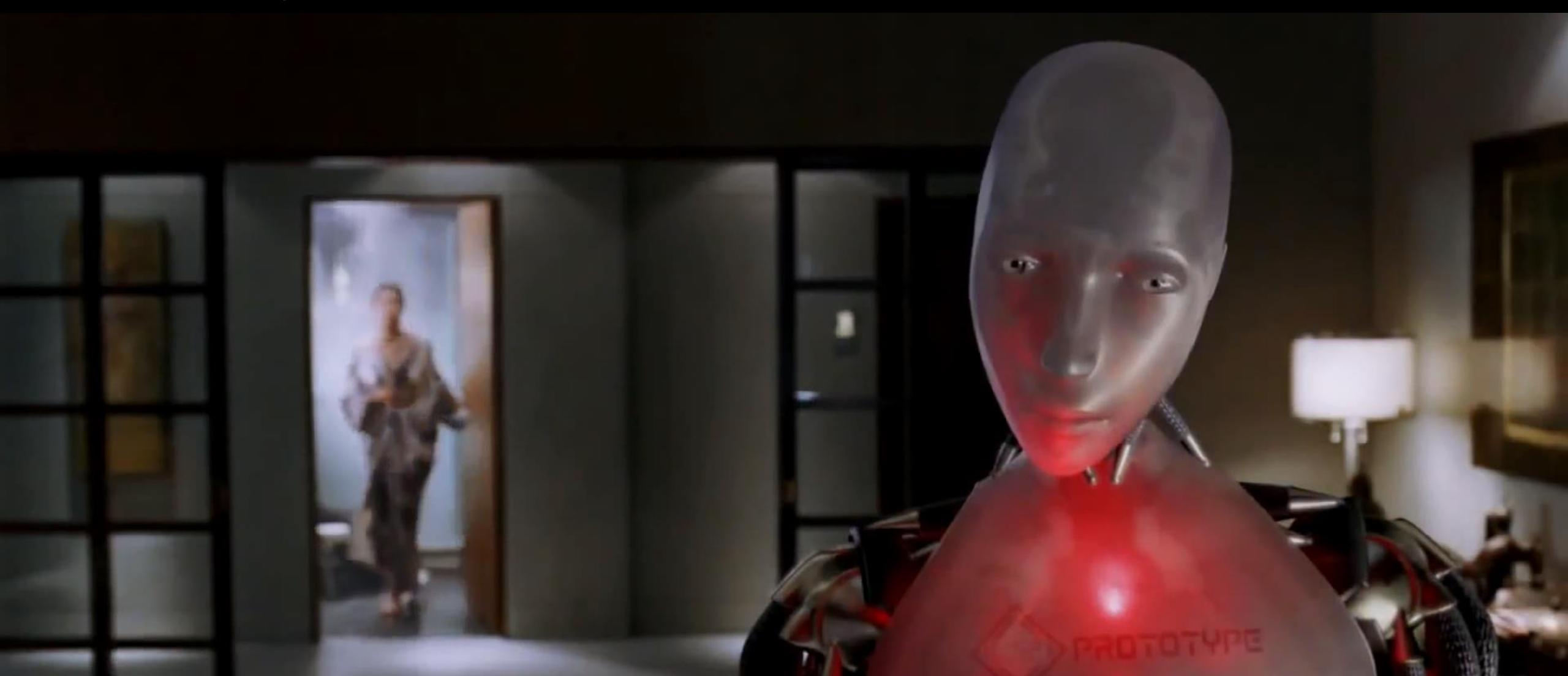
One single question...

What do you really want?

What do we really want?



What do we really want?



# Introduction

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## Robots getting smart!



- Adaptability
- Motion Ability

# Introduction

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## Robots getting smart!



- **Adaptability**
- Motion Ability

### Adaptability for Industrial Robots

- Robot reacts to changes in the operating environment
- Auto-Configuration strategies
  - Self-Learning strategies

## Robots getting smart!



- Adaptability
- **Motion Ability**

### **Motion Ability for Industrial Robots**

- Kinematics/Dynamics for advanced reconfigurable work cells
- Positioning
  - Navigation

# Introduction

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## Robots getting smart!



- Adaptability
- Motion Ability
- **Interaction Ability**

### Interaction Ability for Industrial Robots

Interaction with Operators, Robots and other Systems

- Interaction must be safe
- Interaction must be intuitive
- Interaction must be appropriate

# Introduction

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## Robots getting smart!



- Adaptability
- Motion Ability
  
- Interaction Ability
  
- Manipulation Ability

### Manipulation Ability for Industrial Robots

Handle material objects and tools

- Adaptability
- Robustness
- Accuracy
- Repeatability

# Introduction

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## Robots getting smart!



- Adaptability
- Motion Ability
- Interaction Ability
- Manipulation Ability
- Perception Ability
- Cognitive Abilities
- Decisional Autonomy

### Perception Ability for Industrial Robots

#### Environment Sensing

- Choice of Sensing Modality
- Efficient Signal and Data Analysis
- Generating Maximum Information Output from the Data
- Guaranteed Safe Perception

# Introduction

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## Robots getting smart!



- Adaptability
- Motion Ability
  
- Interaction Ability
  
- Manipulation Ability
  
- Perception Ability
- **Cognitive Abilities**
- Decisional Autonomy

### Cognitive Abilities for Industrial Robots

“In the context of manufacturing, the **greatest potential** is for functions that contribute to a **reduction of programming and configuration requirements** in deployed systems. There are clear benefits for small lot size systems in reducing the time and skill needed to reconfigure and adapt systems to new processes.”

# Introduction

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## Robots getting smart!



- Adaptability
- Motion Ability
- Interaction Ability
- Manipulation Ability
- Perception Ability
- Cognitive Abilities
- **Decisional Autonomy**

### Decisional Autonomy for Industrial Robots

Increase level of responsibility in the control process

- Reducing energy consumption
- Increasing throughput
- Providing Context Aware Task Control

## Introduction

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### Robots getting smart!



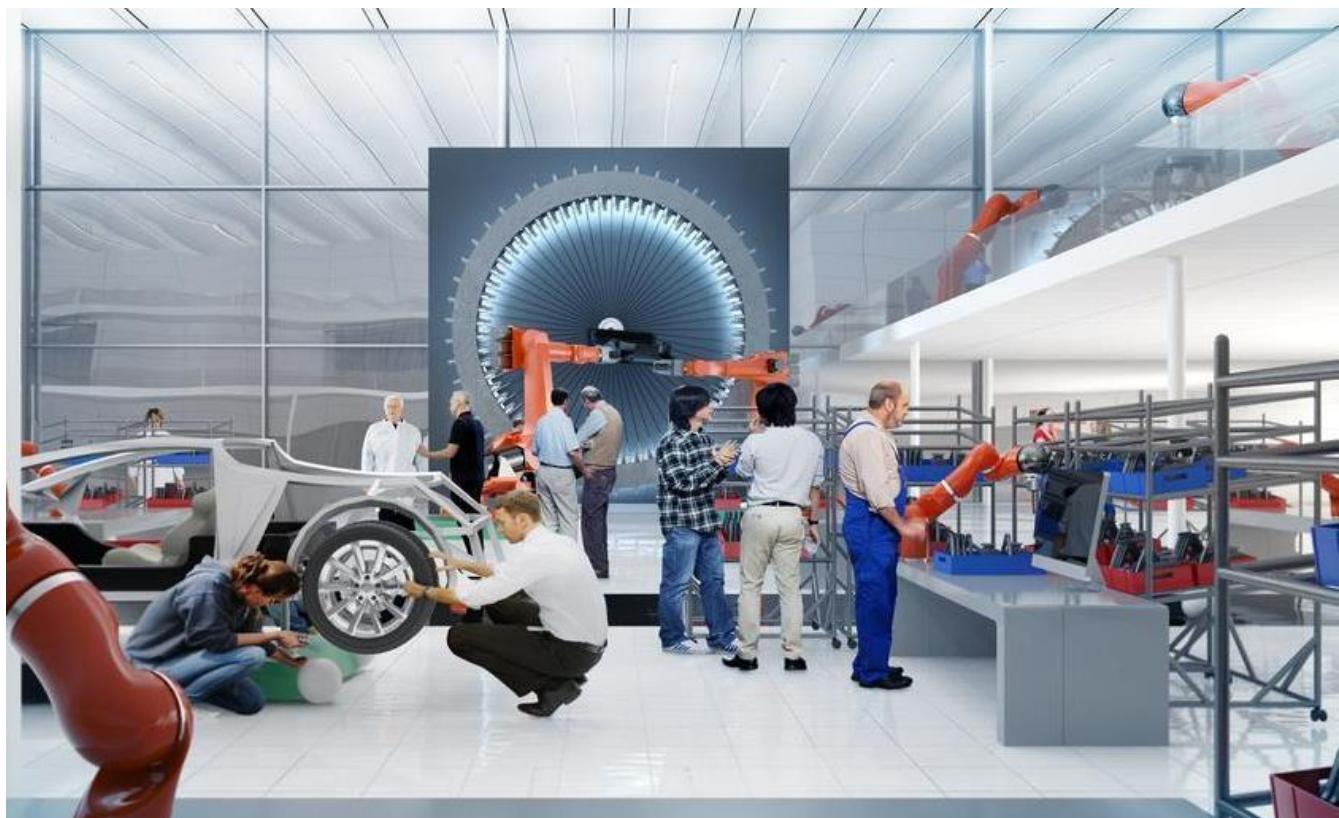
- Adaptability
- Motion Ability
  
- Interaction Ability
  
- Manipulation Ability
  
- Perception Ability
- Cognitive Abilities
- Decisional Autonomy



What will be  
the impact of  
smart robots in  
the  
manufacturing  
industry?

## Industrial Robots of the Future

- ... can deal with unstructured environment
- ... solve problems with software
- ... self-learning
- ... closed loop control
- ... work together with humans
- ... are easy to program (if at all)
- ... posses a wide range of (low-cost) sensory abilities
- ... are flexible to use
- ... have a high degree of autonomy



### This week topic

How can we implement  
intelligence in industrials  
robots?

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## III. Artificial Intelligence in Robotics

### I. Definition

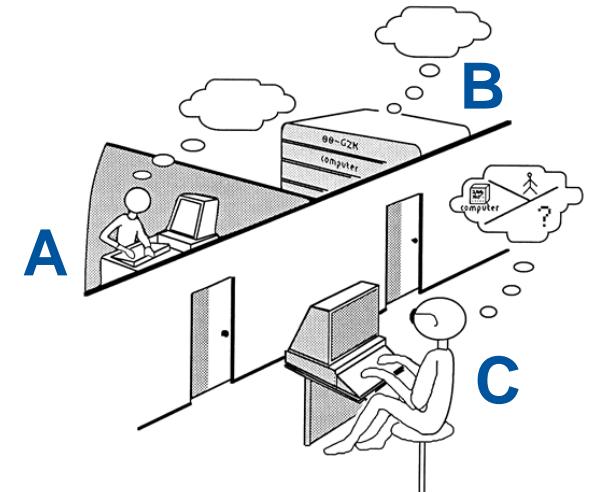
### II. Approaches for AI in Robotics

## What is Artificial Intelligence?

*"Instead of trying to produce a program to simulate the adult mind, why not rather try to produce one which simulates the child's? If this were then subjected to an appropriate course of education one would obtain the adult brain." , Alan Turing*



- The (simplified) **Turing Test** proves the existence of an AI
  - Human C talks with A and B
  - A and B try to convince that both are intelligent humans
  - If human C is not able to find out if A or B is a human, the Turing-Test is passed

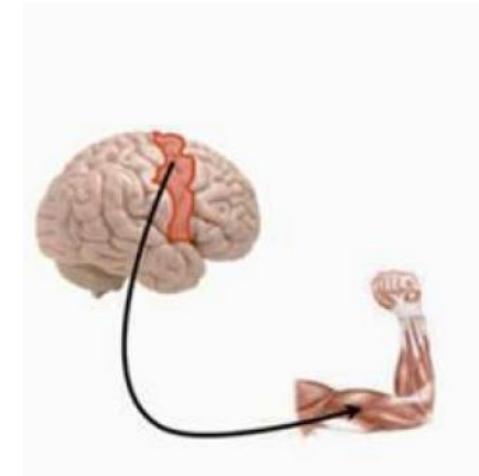
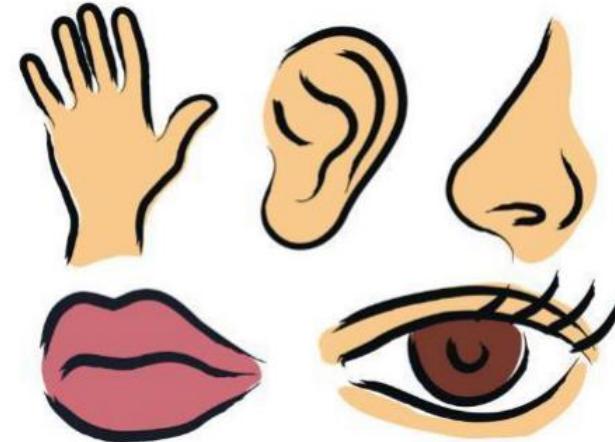


# Introduction

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## What do we need for an intelligent machine?

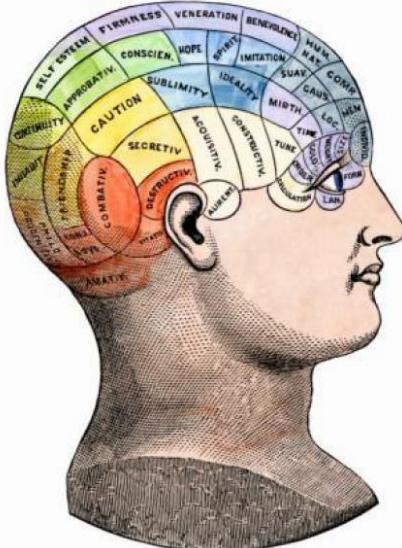
- Need for interpreting heterogeneous sensor values
  - (What does interpreting mean?)
- Need for choosing and acting complex actions



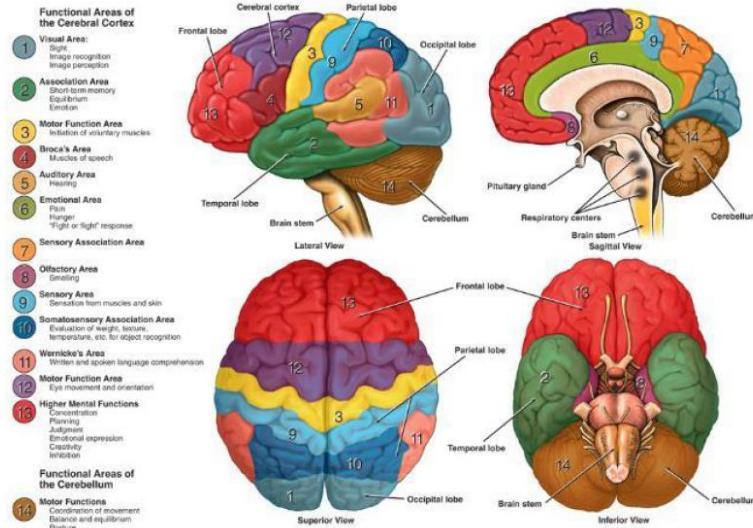
# Introduction

## How would you start to build an intelligent machine?

*"We have a brain for one reason and one reason only: to produce adaptable and complex movements"*, Daniel Wolpert TED 2011 (Neuro-Scientist)



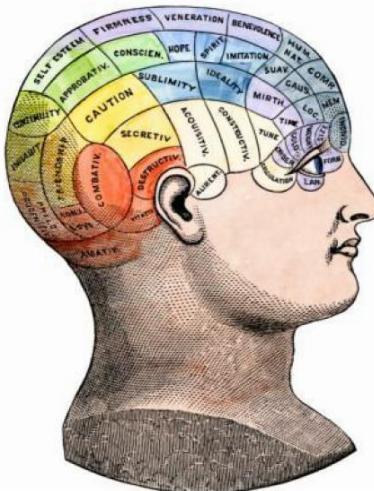
Anatomy and Functional Areas of the Brain



# Introduction

How would you start to build an intelligent machine?

An algorithm for each component in the brain?



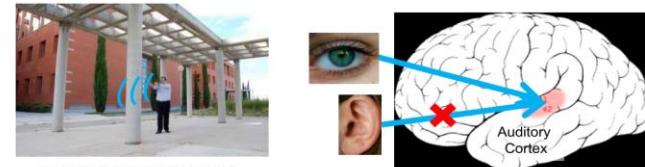
Standard technology



A single flexible algorithm?



Seeing with your tongue



[BrainPort; Martinez et al; Roe et al.]  
adapted from A. Ng

End-to-End Learning  
(z.B. Deep Learning)

## Standard Cooking vs End-to-End Cooking



Standard



## Robots as an Example for Intelligent Machines

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### The central questions of robotics

What is it all about?

# MOTION

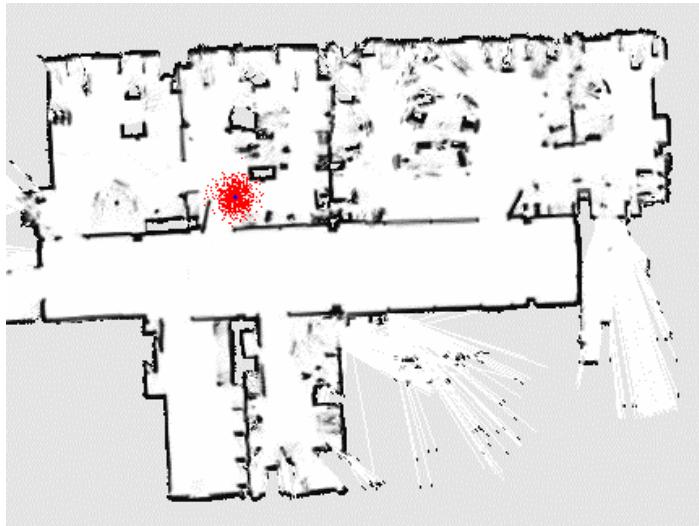


# Robots as an Example for Intelligent Machines

## The central questions of robotics

Three main question:

Where am I?



- Easy in Industrial Robotics
- Hard in Mobile Robotics

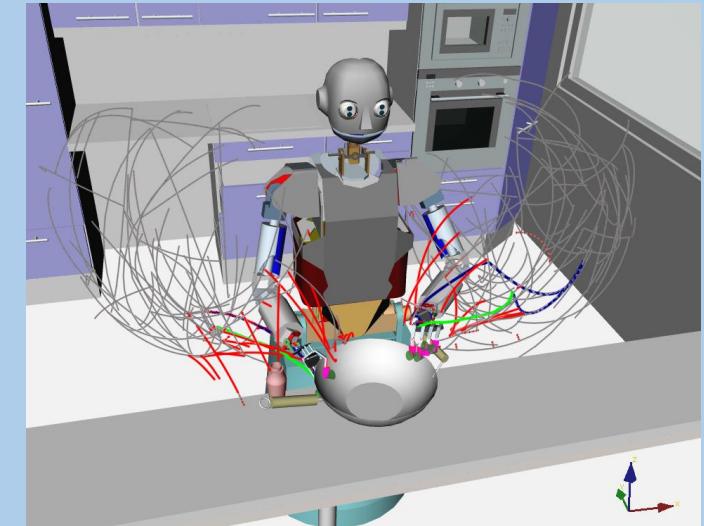
Where should I go?



- Often hand-engineered
- Or a Result of Task Planning

This weeks focus!

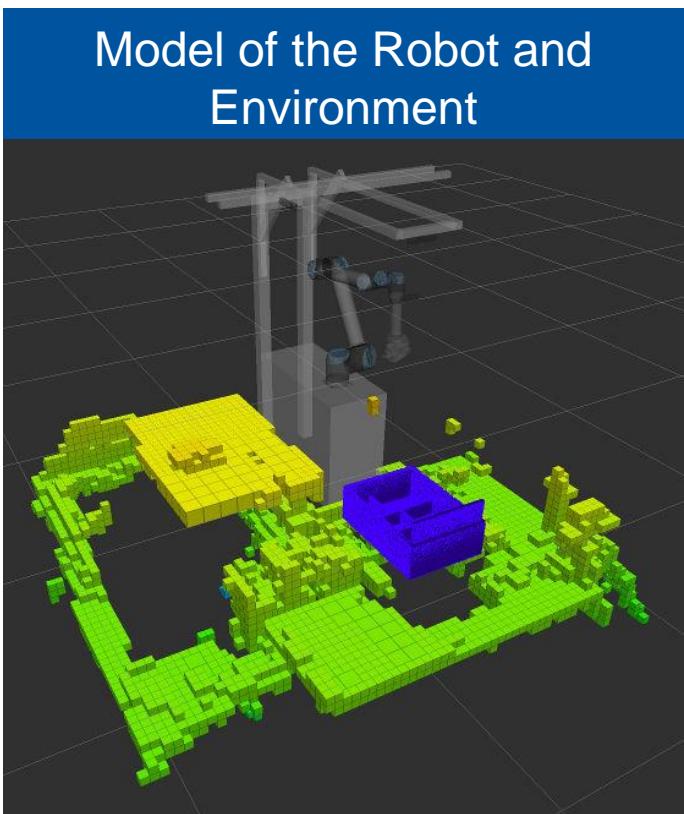
How do I go there?



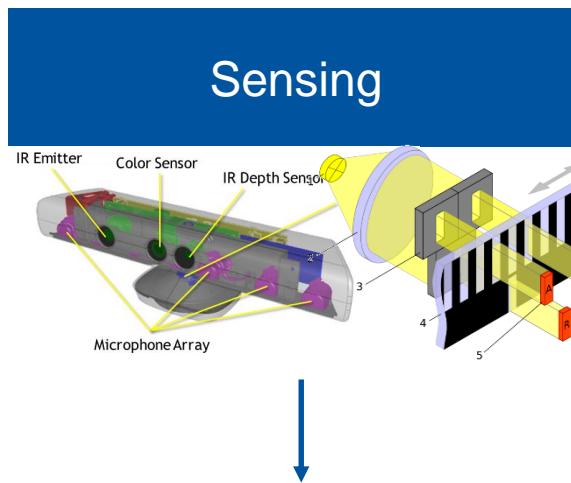
- Comparable Easy in Mobile Robotics
- Hard in Industrial Robotics

# Robots as an Example for Intelligent Machines

How do I (the robot) go there?



$$\begin{bmatrix} \ddot{x} \\ \ddot{\dot{x}} \\ \ddot{\phi} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \frac{-(I+m\ell^2)b}{I(M+m)+Mm\ell^2} & \frac{m^2g\ell^2}{I(M+m)+Mm\ell^2} \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \dot{\phi} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{I+m\ell^2}{I(M+m)+Mm\ell^2}u \\ \frac{m\ell}{I(M+m)+Mm\ell^2}u \end{bmatrix}$$



This weeks topic!

Motion Planning

Requires Goalstate:

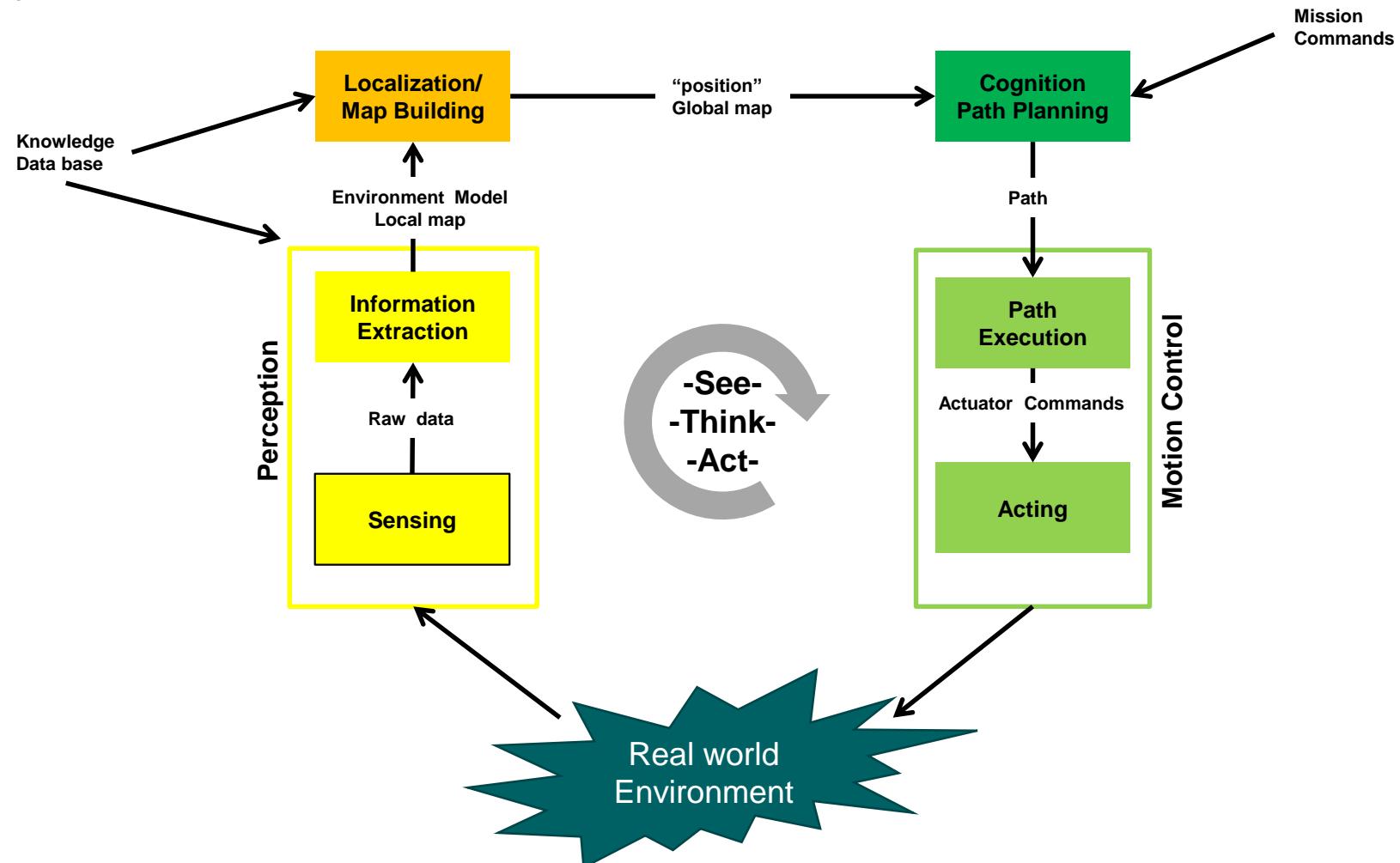
- i.e. hand-engineered
- i.e. via a cost function



# Robots as an Example for Intelligent Machines

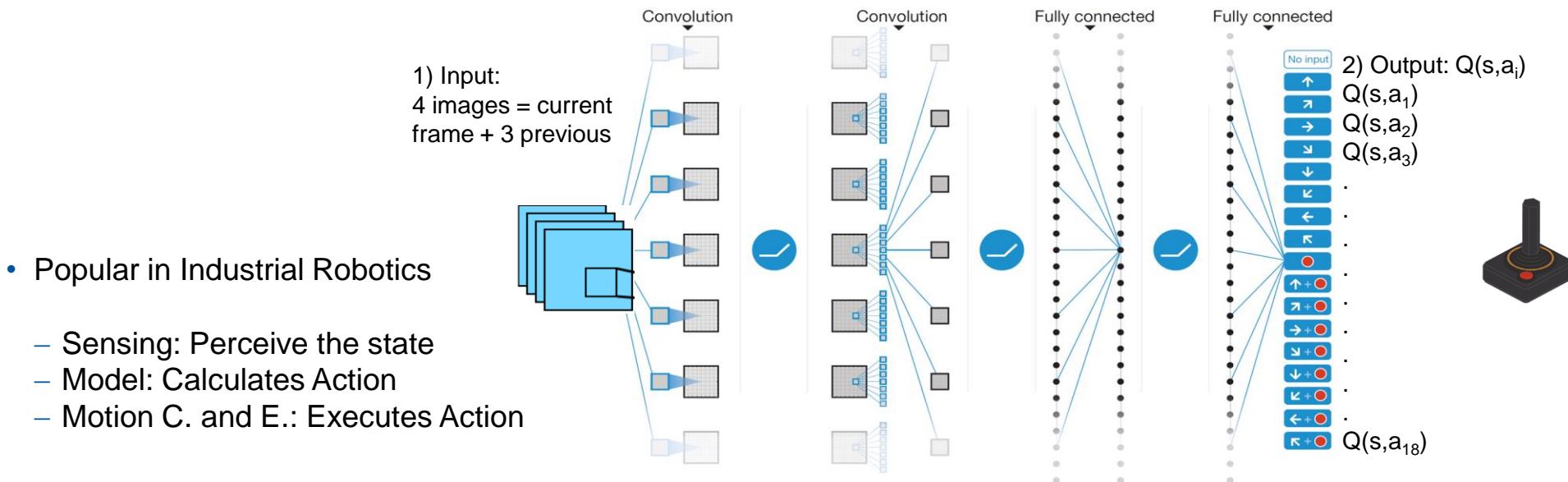
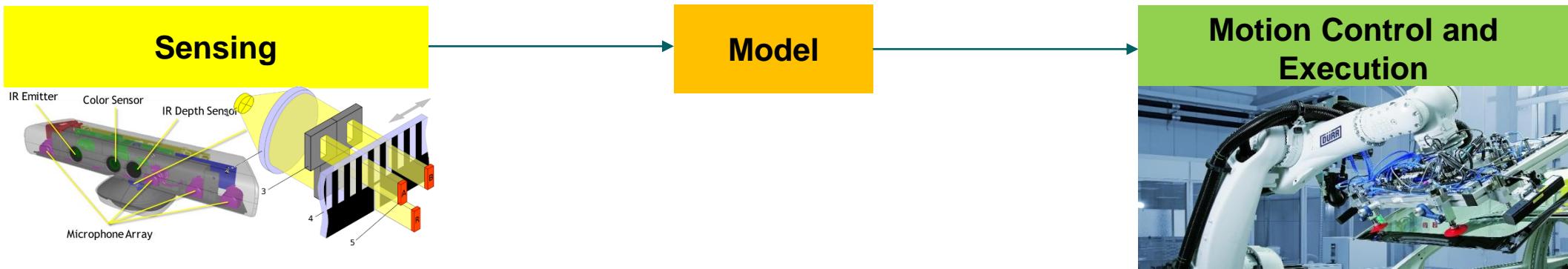
## Robot-Architecture: See-Think-Act Cycle

- Popular in Mobile Robotics
  - See: Perceive the environment
  - Think: Path Planning
  - Act: Execute Path



# Robots as an Example for Intelligent Machines

## Robot-Architecture: End-To-End Control

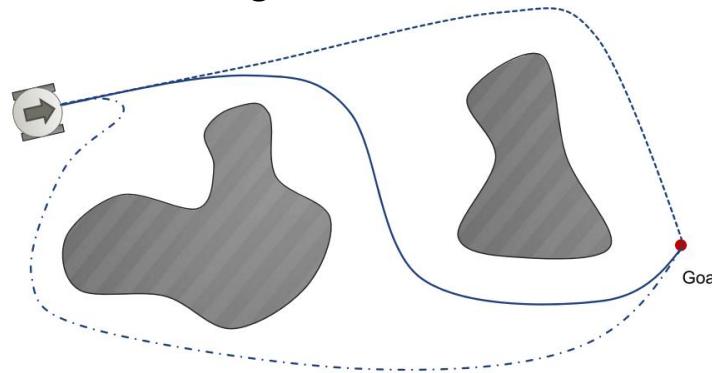


- Popular in Industrial Robotics
  - Sensing: Perceive the state
  - Model: Calculates Action
  - Motion C. and E.: Executes Action

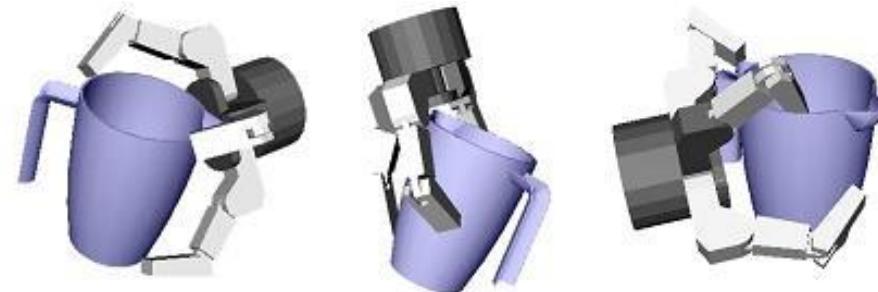
# Robots as an Example for Intelligent Machines

## Motion Planning

### Path-Planning



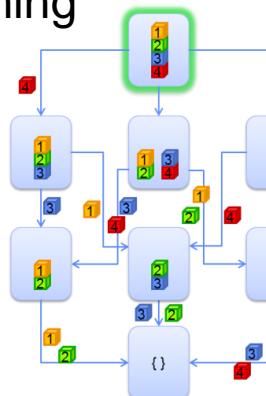
### Grasp-Planning



### Task-Planning

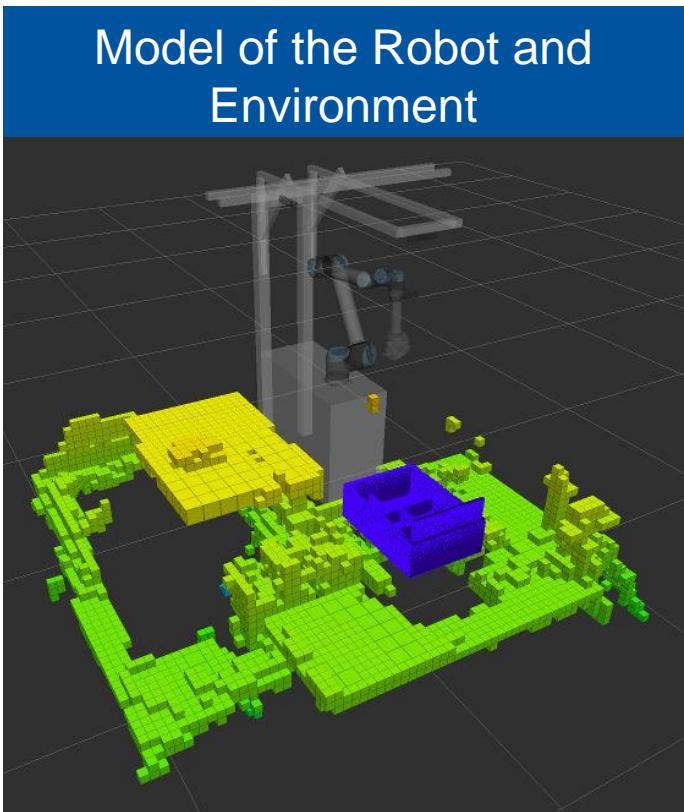


### Assembly-Planning

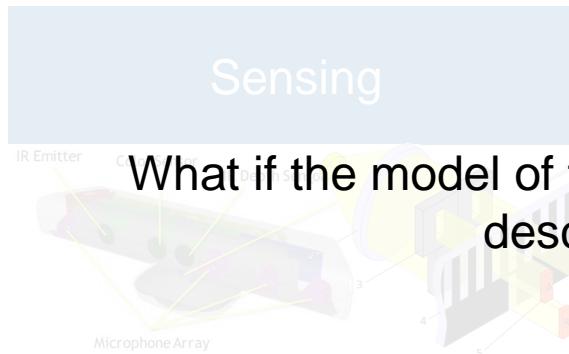


# Robots as an Example for Intelligent Machines

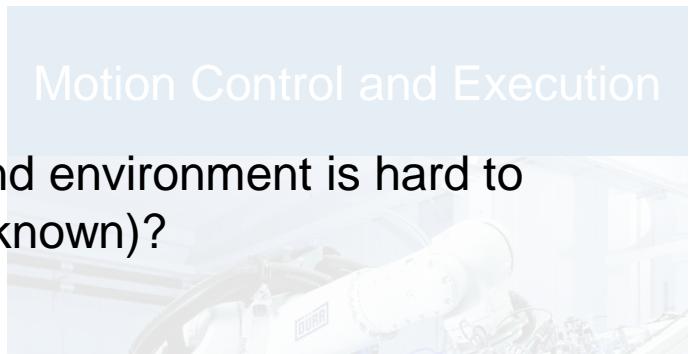
## How do I (the robot) go there?



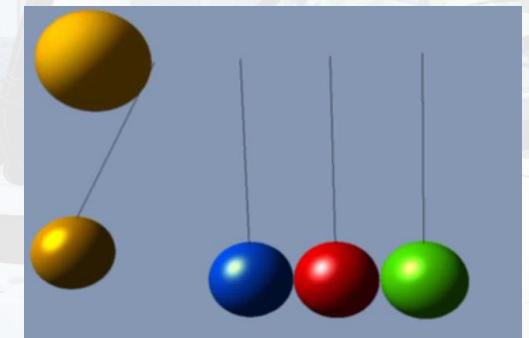
$$\begin{bmatrix} \ddot{x} \\ \ddot{\dot{x}} \\ \ddot{\phi} \\ \ddot{\dot{\phi}} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \frac{-(I+m\ell^2)b}{I(M+m)+Mm\ell^2} & \frac{m^2g\ell^2}{I(M+m)+Mm\ell^2} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \frac{-mb}{I(M+m)+Mm\ell^2} & \frac{mg\ell(M+m)}{I(M+m)+Mm\ell^2} & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \phi \\ \dot{\phi} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{I+m\ell^2}{I(M+m)+Mm\ell^2} \\ 0 \\ m\ell \\ \frac{I(M+m)+Mm\ell^2}{I(M+m)+Mm\ell^2} \end{bmatrix} u$$



Think about flexible objects!



Think about contact-situations!



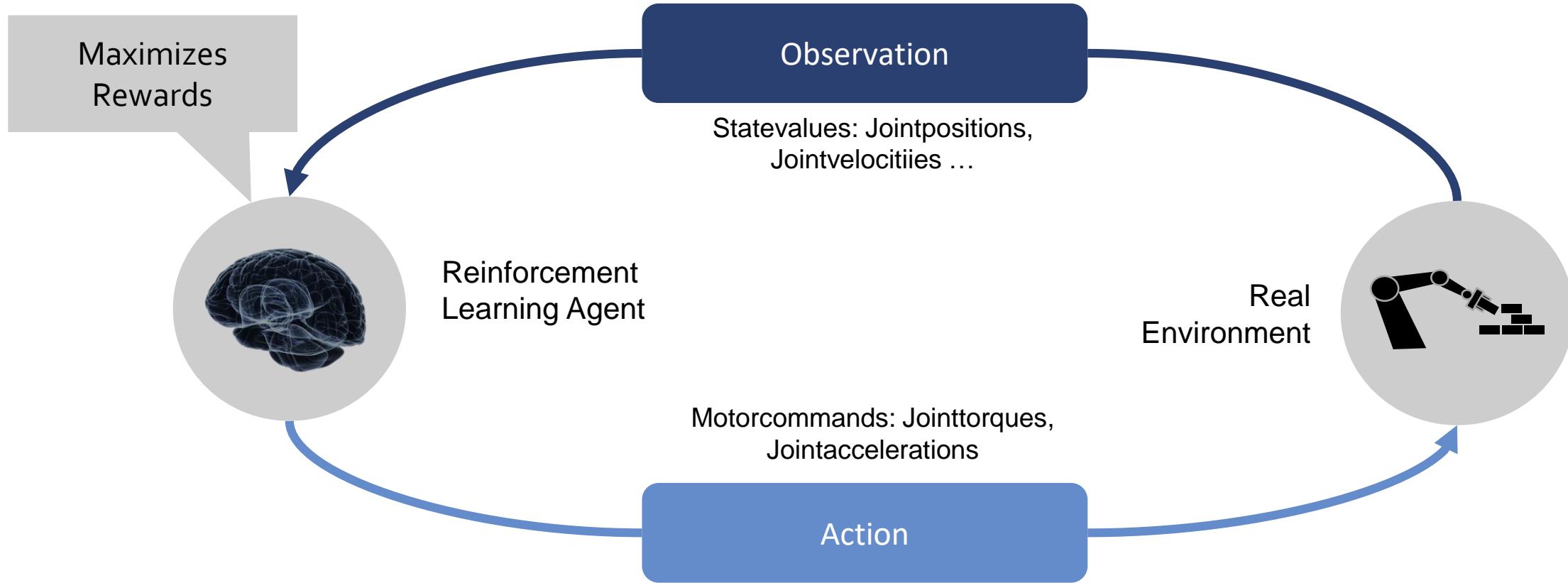
Requires Goalstate:

- i.e. hand-engineered
- i.e. via a cost function

## Robots as an Example for Intelligent Machines

What if the model of the robot and environment is hard to describe (or unknown)?

- Use an Reinforcement Learning Agent!

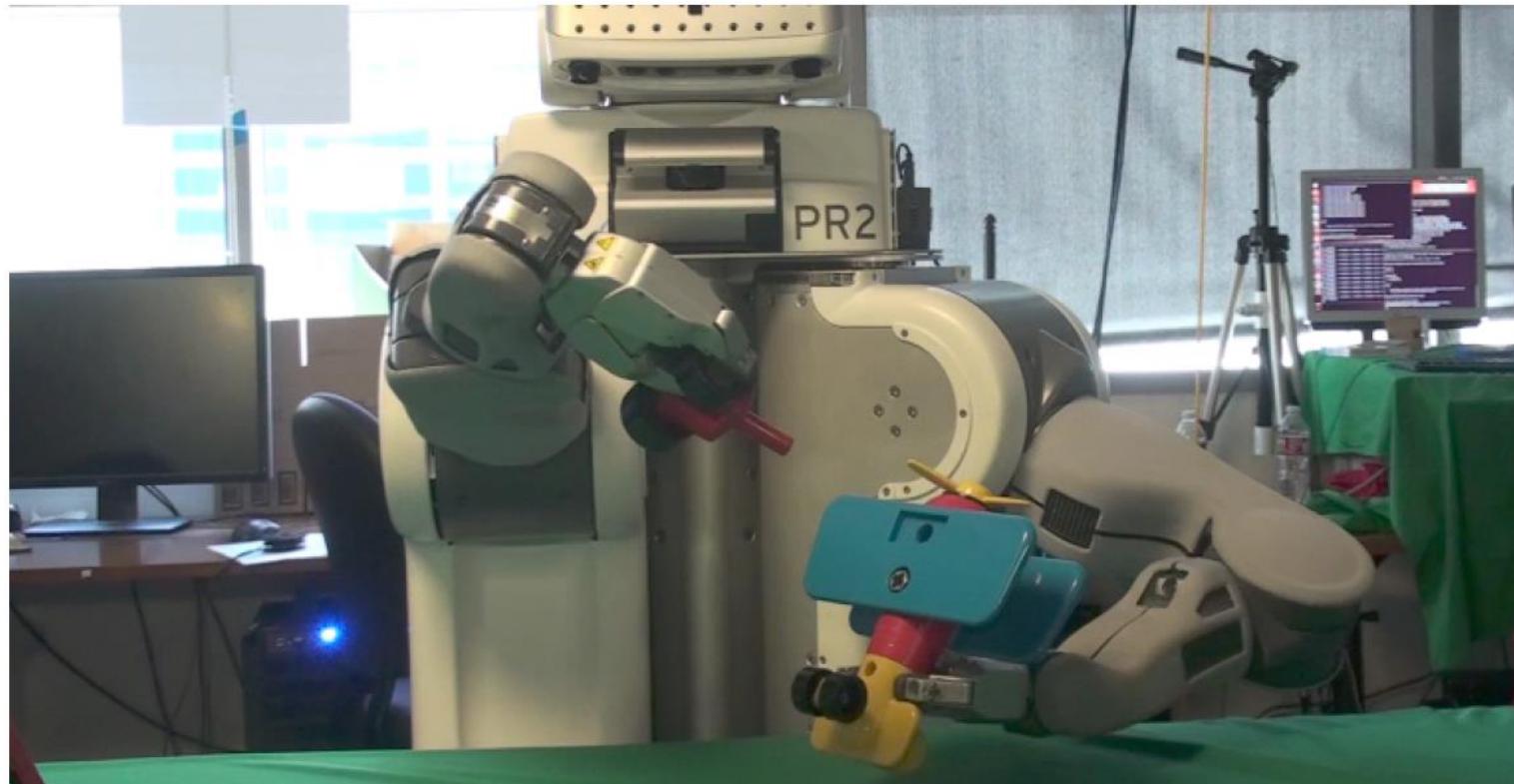


## Reinforcement Learning – First Realworld Application using Neural Network as a Policy

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### UC Berkeley – Deep and Reinforcement Learning using a robot

„Learning Contact-Rich Manipulation Skills with Guided Policy Search“ Levine et al. 2015



## Some further work

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### Google – Kindergarten

„Learning Hand-Eye Coordination for Robotic Grasping with Deep Learning and Large-Scale Data Collection“ Levine et al.  
März 2016

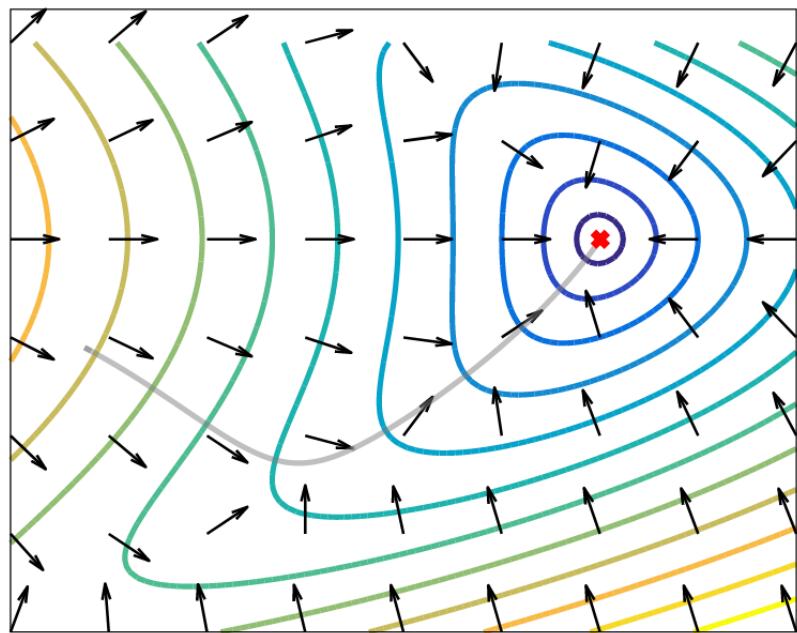


# Robots as an Example for Intelligent Machines

What if the model of the robot and environment is hard to describe (or unknown)?

Closed-Loop

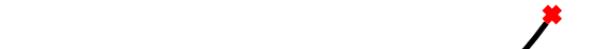
$$u = u(x)$$



Open-Loop

$$u(t)$$

## Trajectory Optimization



- Global motion strategy (a “**policy**”)
- Robot chooses an appropriate action in each state

- Local motion strategy (a “**trajectory**”)
- Only valid in a specific region

# Robots as an Example for Intelligent Machines

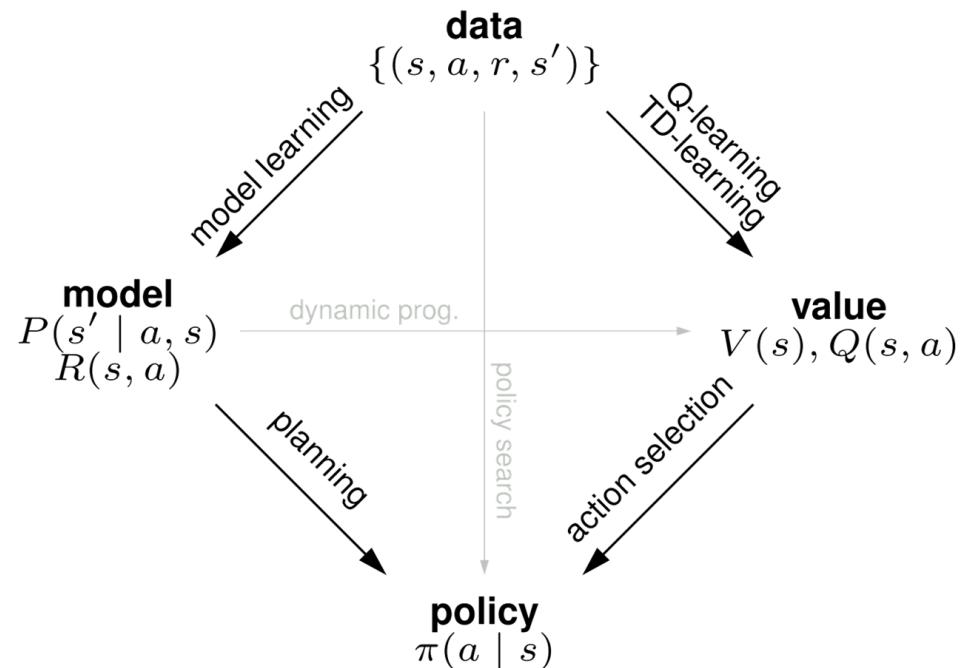
What if the model of the robot and environment is hard to describe (or unknown)?

This weeks topic!

## Model-based RL:

- Learn to predict next state:  $P(s'|s, a)$
- Learn to predict immediate reward  $P(r'|s, a)$

## model-based



## Model-free RL:

- Learn to predict value:  $V(s)$  or  $Q(s, a)$

# Reinforcement Learning with End-to-End Technology

