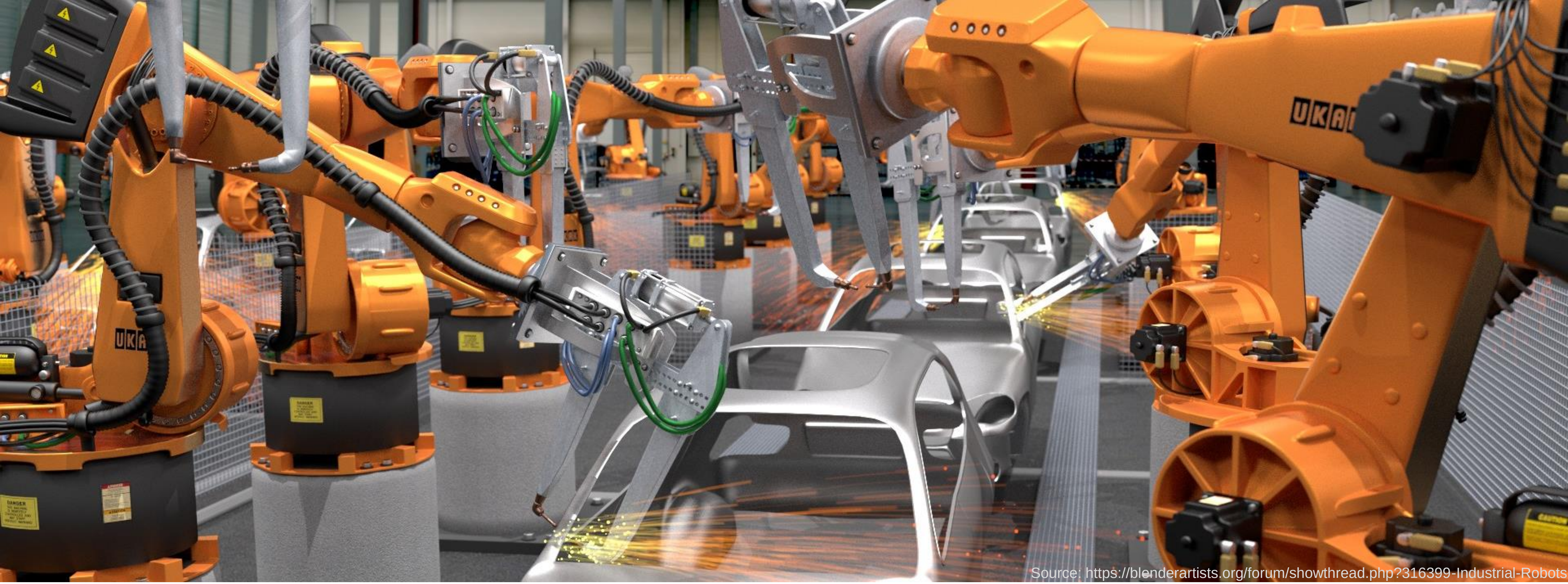


Source: https://blenderartists.org/forum/showthread.php?316399-Industrial-Robots

Robotics for Future Industrial Applications

Introduction to Industrial Robots & Challenges

Philipp Ennen, M.Sc.

IfU | IMA | ZLW | RWTH AACHEN UNIVERSITY

Content

Your Lecturers

Philipp Ennen, M.Sc.
PhD Candidate
„Robot Learning for Contact-Rich Assembly Tasks“

Coffee
Jazz
Wine

Haoming Zhang, M.Sc.
PhD Candidate
„Optimal Control, Machine Learning“

Big Bang Theory
Microcontroller

Organizational

<table>
<tr><th>Time</th><th>Sunday 13th August</th><th>Monday 14th August</th><th>Tuesday 15th August</th><th>Wednesday 16th August</th><th>Thursday 17th August</th><th>Friday 18th August</th><th>Saturday 19th August</th></tr>
<tr><td>9:00-9:30</td><td rowspan="26">Free Time for Excursions, Sight-Seeing and Self-Study</td><td rowspan="3">Introduction to Industrial Robots & Challenges</td><td rowspan="3">Fundamentals of Robot Learning and Control Theory</td><td rowspan="18">City Excursion to Cologne</td><td rowspan="3">Robot Learning with iterative Linear-Quadratic Regulator</td><td rowspan="6">Practical Unit: Robot Learning of an Assembly Task</td><td rowspan="26">Free Time for Excursions, Sight-Seeing and Self-Study</td></tr>
<tr><td>9:30-10:00</td></tr>
<tr><td>10:00-10:30</td></tr>
<tr><td>10:30-11:00</td><td rowspan="3">Motion Planning</td><td rowspan="3">Demonstration</td><td rowspan="3">Practical Unit: Robot Learning of an Assembly Task</td></tr>
<tr><td>11:00-11:30</td></tr>
<tr><td>11:30-12:00</td></tr>
<tr><td>12:00-12:30</td><td colspan="2" rowspan="4">Lunch Break at “Bistro Kerres”</td><td colspan="2" rowspan="4">Lunch Break at “Bistro Kerres”</td></tr>
<tr><td>12:30-13:00</td></tr>
<tr><td>13:00-13:30</td></tr>
<tr><td>13:30-14:00</td></tr>
<tr><td>14:00-14:30</td><td rowspan="6">Practical Unit: Introduction to Linux and Robot Operating System</td><td rowspan="3">Programming using Python</td><td rowspan="6">Practical Unit: Robot Learning of an Assembly Task</td><td rowspan="6">Show: Let the robot learn!</td></tr>
<tr><td>14:30-15:00</td></tr>
<tr><td>15:00-15:30</td></tr>
<tr><td>15:30-16:00</td><td rowspan="3">Practical Unit: Programming using Python</td></tr>
<tr><td>16:00-16:30</td></tr>
<tr><td>16:30-17:00</td></tr>
<tr><td>17:00-17:30</td><td rowspan="10"></td><td rowspan="6"></td><td rowspan="10"></td><td rowspan="5"></td></tr>
<tr><td>17:30-18:00</td></tr>
<tr><td>18:00-18:30</td><td rowspan="8"></td></tr>
<tr><td>18:30-19:00</td></tr>
<tr><td>19:00-19:30</td></tr>
<tr><td>19:30-20:00</td><td rowspan="5">„Karaoke Night“ with the Summer School Team and your Buddies</td></tr>
<tr><td>20:00-20:30</td><td rowspan="4">OPTIONAL International Tuesday with the INCAS Student Organisation</td></tr>
<tr><td>20:30-21:00</td></tr>
<tr><td>21:00-21:30</td></tr>
<tr><td>21:30-22:00</td></tr>
</table>

Organizational

Website and Wifi

- Website for this week: https://goo.gl/X5twgi

Home

Summerschool 2017: Intelligent Motion Planning

We (Haoming and Philipp) are glad to be organizing a seminar on intelligent motion planning for industrial robots. This seminar will be held in week two of the summer school "Robotics for Future Industrial Applications" at the Cybernetics Lab of the RWTH Aachen University (14. august - 18. august). 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 Haoming and Philipp

IfU IMA ZLW RWTH AACHEN UNIVERSITY

Day 1: Introduction

Lecture: Introduction to Industrial Robots and Challenges

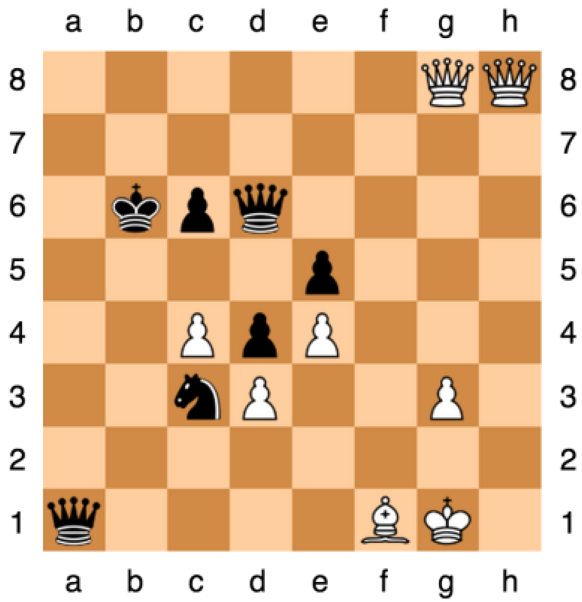
- Wifi-Access:
  - SSID: ariz
  - Password: ariz_ab12345!

Content

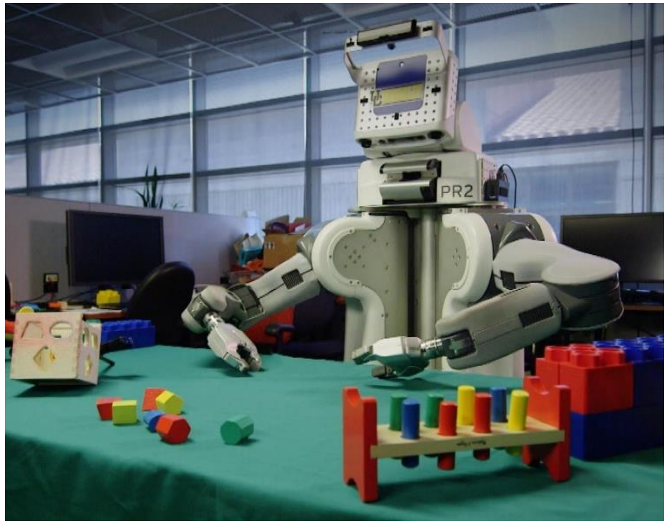
Introduction

„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 Garri Kasparow: **Easy**



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

The rise of **Robotics and AI**

Fueled by advances in computing power and connectivity, the fields of robotics and artificial intelligence have grown rapidly

1921
The term **robot** is first used by Czech writer Karel Capek

1939
Elektro, a humanoid robot, debuts at the World's Fair, smoking cigarettes and blowing up balloons

1941
Isaac Asimov formulates the
Three Laws of Robotics:
- **A robot may not injure a human being** or, through inaction, allow a human being to be harmed
- **A robot must obey orders** given it by human beings except where such orders would conflict with the First Law
- **A robot must protect its own existence** as long as such protection does not conflict with the First or Second Law

1948
William Grey Walter creates **the first autonomous robot with complex behavior**

1950
Alan Turing publishes paper about the possibility of machines that think, develops idea known as the
Turing's Test.
It tests a machine's ability to "think" by answering a series of questions. In essence, **the tester must think the machine's answers are coming from a human**

1951
Marvin Minsky builds the first neurocomputer, **SNARC**

1954
George Devol invents the first digitally operated and programmable robot

1956
Field of AI research founded at a conference at Dartmouth

1960
Frank Rosenblatt constructs **Mark I Perceptron,** a computer that learned new skills by trial and error

1961
GM installs Unimate robot to lift and stack hot pieces of metal

1968
Mobile robot "Shakey" is introduced. It's controlled by a computer the size of a room

1972
Stanford researcher develops PARRY, designed to simulate a paranoid schizophrenic.

How are you feeling today?

I have had enough of this.

1974
Intel produces its second-generation 8080 general-purpose chips

1979
SCARA, an articulated robot arm, is developed for assembly lines

1984
Doug Lenat and his team start **Cyc,** to codify millions of pieces knowledge that compose human common sense

1984
The RB5X, developed by General Robotics Corp., includes software enabling it to learn from its environment

1985
Jaron Lanier's VPL Research, Inc., sells first VR glasses and gloves; Lanier coins the phrase **virtual reality**

1986
Honda creates the E0, the first of a series of humanoid robots that walk on two feet

1988
Researchers launch Jabberwacky, an AI chatbot designed to learn through conversation

Nope, I'm human.

1988
The first HelpMate service robot begins work at Danbury Hospital

1956
IBM 305, the first hard disk drive
5MB

1970
IBM 1330
100MB
per pack

1985
IBM 0665, a 5.25" disk with
20-40MB

Minimize and maximize
Shrinking disk sizes and exponentially growing capacity help fuel robotics and AI

pwc

Robotics and AI charging forward

With technologies advancing at breakneck speeds, robotics and artificial intelligence are finding new applications in factories, businesses, and homes

1990
Tom Caudell coins the phrase **augmented reality**

1990
iRobot® Corporation is founded, producing domestic and military robots

1997
Deep Blue defeats Garry Kasparov in a game of chess

1997
NASA's Pathfinder lands on Mars

1998
Dr. Cynthia Breazeal creates **Kismet,** a robot that interacts emotionally with humans

2000
The UN estimates there are **742,500 industrial robots in use worldwide**

2005
Stanford robot **Stanley** drives autonomously for 131 miles

2006
IBM introduces Watson, a question-answering computer system that later defeated a Jeopardy! champion

2007
Fanuc develops an industrial **robot arm that can grab 120 items per minute**

2010
Google launches **a 3D version of its Street View**

2011
Siri is introduced

2012
Google introduces its Siri response: **Google Now,** which already has been rendered obsolete by Google Assistant

2012
An estimated **8.7 billion devices** are connected to the internet

2012
Baxter, created by Rodney Brooks, can do light repetitive tasks

2013
Google launches **Google Glass,** augmented reality glasses

2015
Amazon launches **Alexa,** a "virtual assistant" that helps communicate with connected devices in the home

2016
Amazon makes first drone delivery in UK

The FAA expects **7 million** drones to ship in the US, including 2.7 million commercial drones

2016
Sony PlayStation launches **PlayStation VR**

2016
Uber begins testing driverless cars in California and Arizona

2016
Companies utilize an estimated **1.8 million industrial robots**

2020
By 2020, the drone industry could be worth **$127 billion**

Growing capacities

As disk size has shrunk, capacity has grown exponentially since 2000

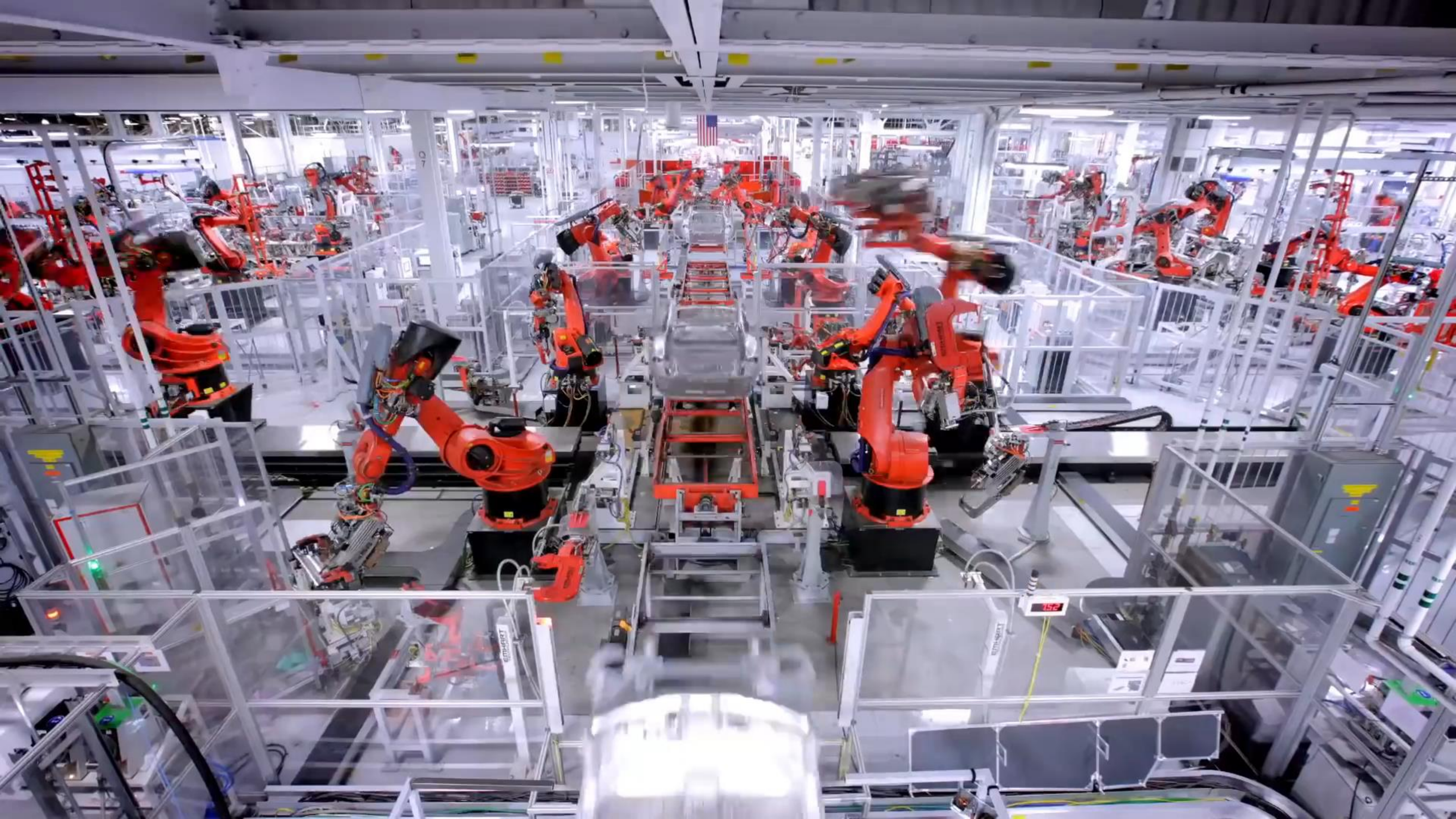
2004	2015	2025
Seagate ST1, 1" disk	Seagate Thin HDD, 2.5", 7mm thick	Even smaller
2.5-5GB	2 TB	100+ TB?

Industrial robots: looking forward

A common fixture in the factory, the industrial robot has reshaped the manufacturing landscape through the years by performing duties unsuitable for humans

2005	2016	2019	2034
Fewer than 1 million	1.8 million	2.6 million	Robotics and other computerization could replace 47 percent of U.S. jobs, according to a 2013 University of Oxford study

pwc



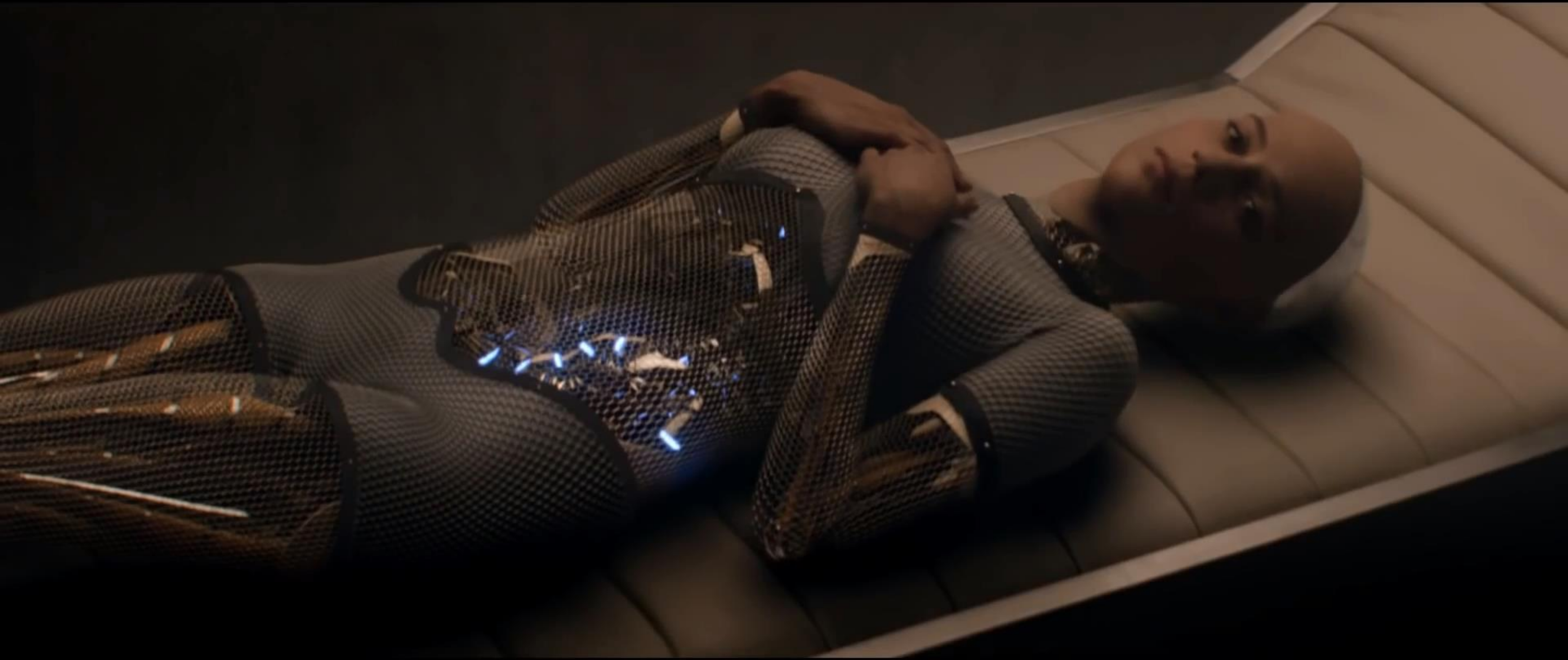
152

Introduction

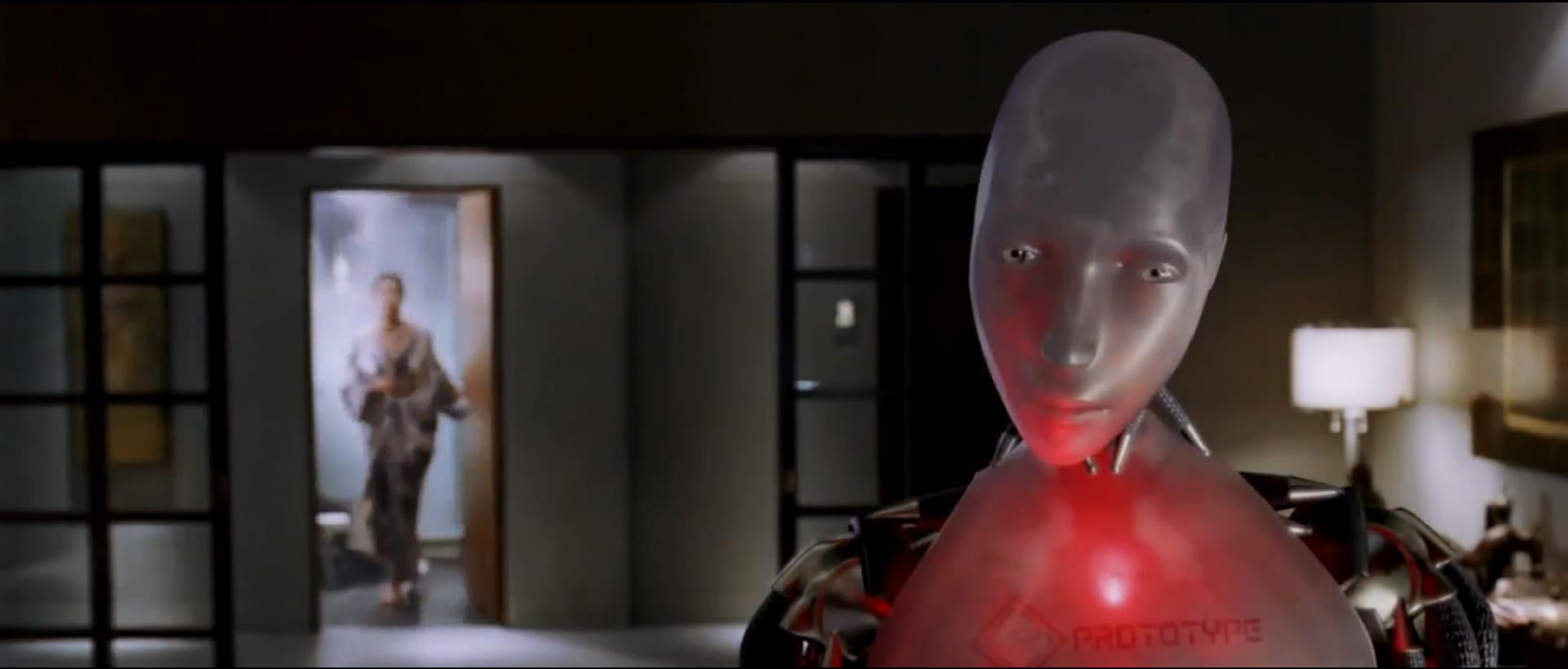
Traditional Industrial Robots

… high precision and velocity
… high programming effort (through experts)
… inflexible
… stationary
… high driven potential, protection fences necessary
… high integration/commissioning effort
… only isolated sensor integration, no environment detection

What do we really want?



What do we really want?



Robots getting smart!

- Adaptability
- Motion Ability

„Robotics 2020 Multi-Annual Roadmap“, For Robotics in Europe, SPARC, 2015

Robots getting smart!

- **Adaptability**
- Motion Ability

Adaptability for Industrial Robots

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

„Robotics 2020 Multi-Annual Roadmap“, For Robotics in Europe, SPARC, 2015

Robots getting smart!

- Adaptability
- **Motion Ability**

Motion Ability for Industrial Robots

Kinematics/Dynamics for advanced reconfigurable work cells

- Positioning
- Navigation

„Robotics 2020 Multi-Annual Roadmap“, For Robotics in Europe, SPARC, 2015

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 appropriate

„Robotics 2020 Multi-Annual Roadmap“, For Robotics in Europe, SPARC, 2015

Introduction

Robots getting smart!

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

Manipulation Ability for Industrial Robots

Handle material objects and tools

- Adaptability
- Robustness
- Accuracy
- Repeatability

„Robotics 2020 Multi-Annual Roadmap“, For Robotics in Europe, SPARC, 2015

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 Modility
- Efficent Signal and Data Analysis
- Generating Maximum Information Output from the Data
- Guaranteed Safe Perception

„Robotics 2020 Multi-Annual Roadmap“, For Robotics in Europe, SPARC, 2015

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 an adapt systems to new processes.”

„Robotics 2020 Multi-Annual Roadmap“, For Robotics in Europe, SPARC, 2015

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

„Robotics 2020 Multi-Annual Roadmap“, For Robotics in Europe, SPARC, 2015

Robots getting smart!

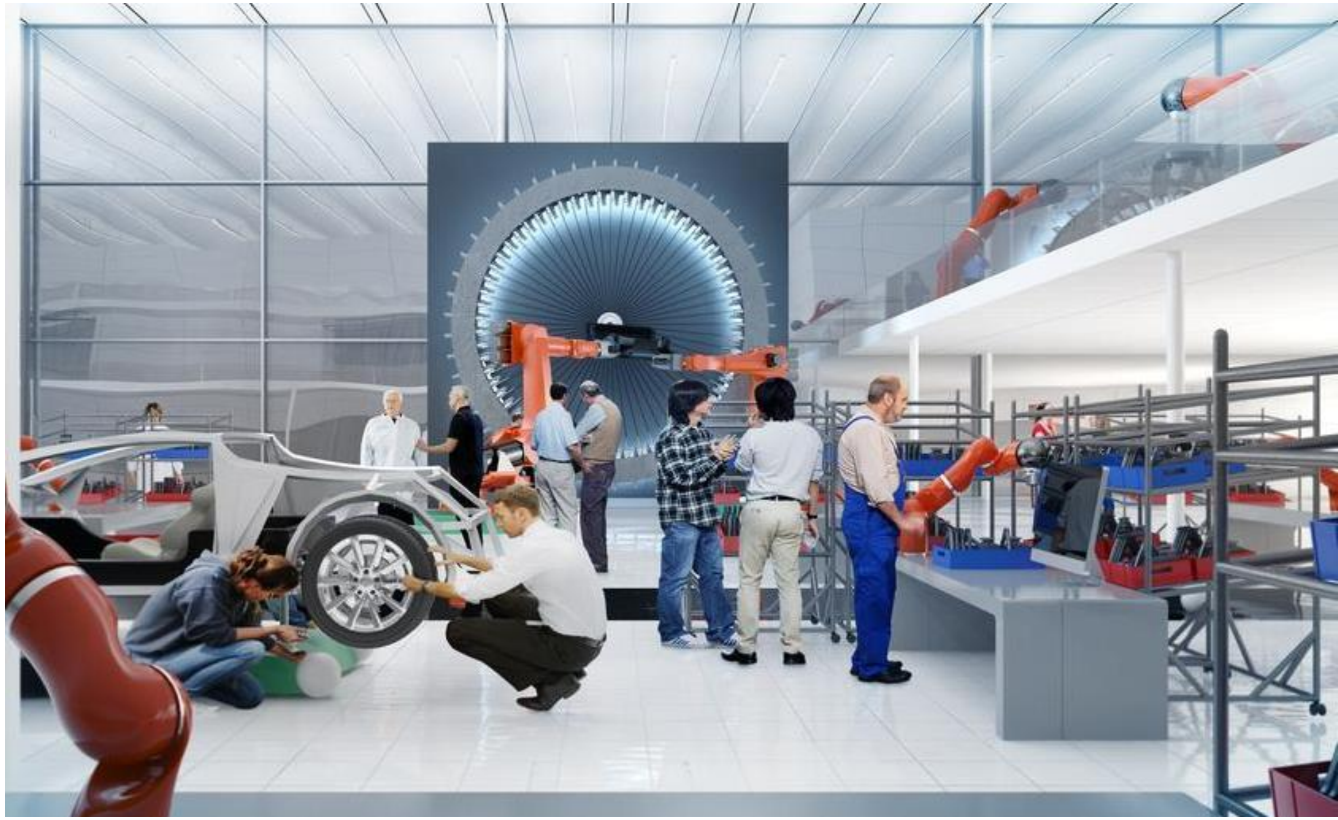



- Adaptability
- Motion Ability
- Interaction Ability
- Manipulation Ability
- Perception Ability
- Cognitive Abilities
- Decisional Autonomy

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

Industrial Robots of the Future

… work together with humans
… do not pose a risk to humans
… interact intuitively with humans (multimodal)
… are easy to program
… posses a wide range of sensory abilities
… are flexible to use
… have a high degree of autonomy



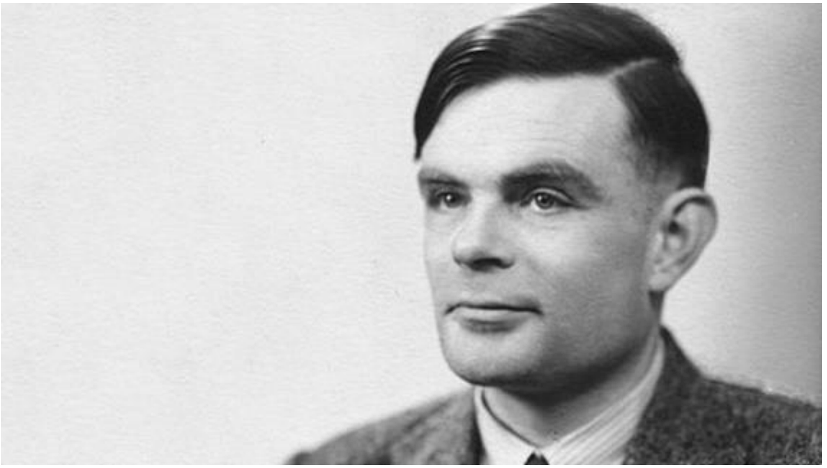
This week topic

How can we implement intelligence in industrials robots?

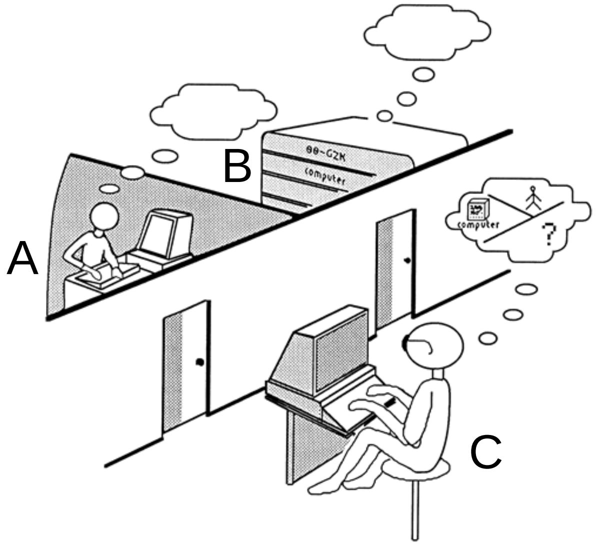
Content

What is Artificial Intelligence?

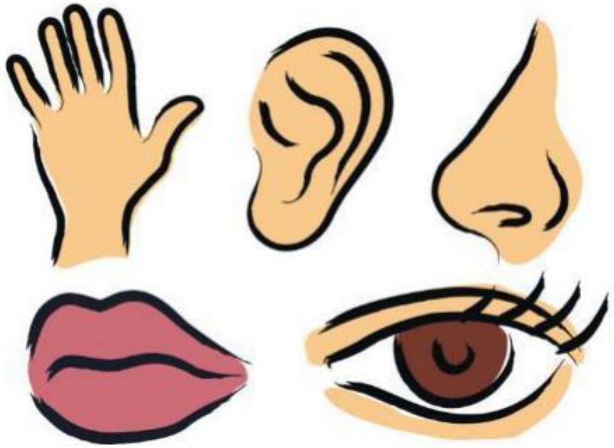
“Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's? If this were then subjected to an appropriate course of education one would obtain the adult brain.”, Alan Turing



- 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



What do we need for an intelligent machine?

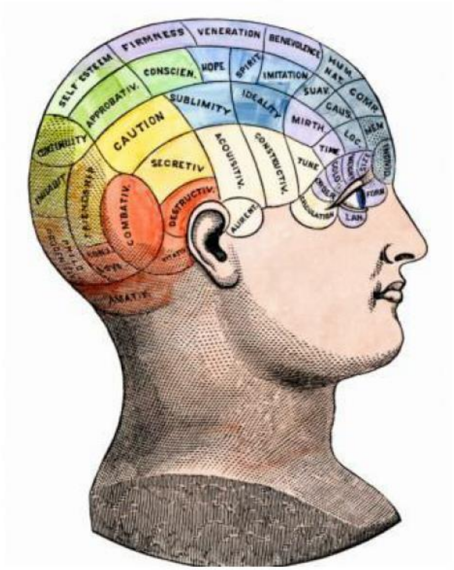


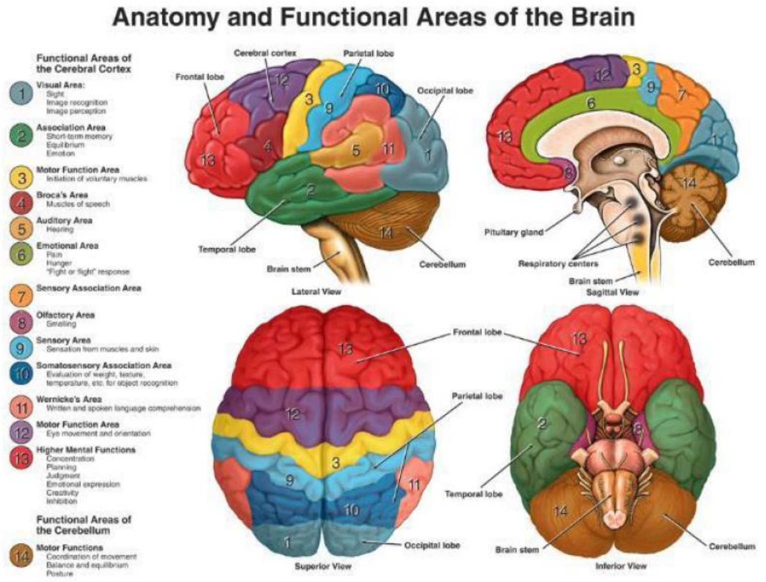
- Need for interpreting heterogeneous sensor values
  - (What das interpreting mean?)

- Need for choosing and acting complex actions

How would you start to build an intelligent machine?

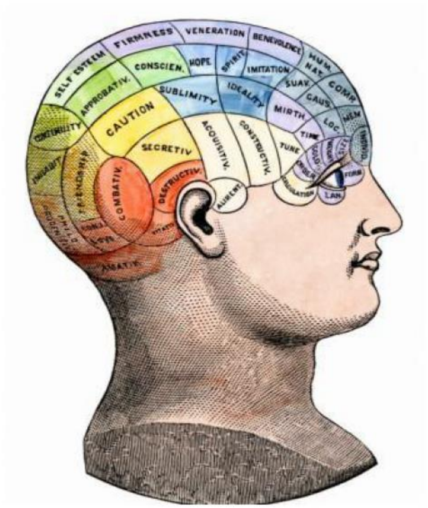
> *"We have a brain for one reason and one reason only: to produce adaptable and complex movements"*, Daniel Wolpert TED 2011 (Neuro-Scientist)



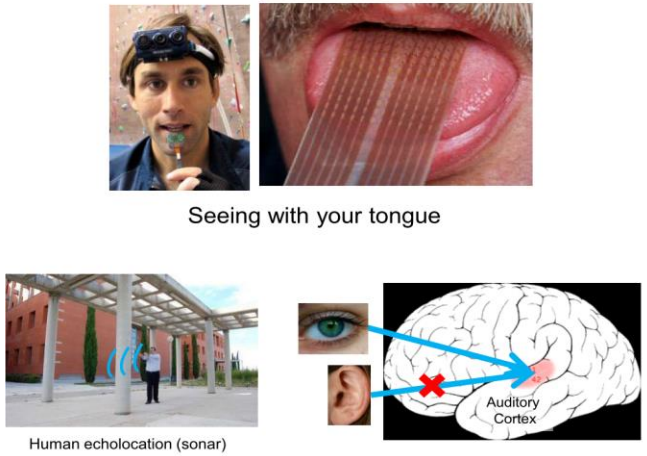


How would you start to build an intelligent machine?

An algorithm for each component in the brain?



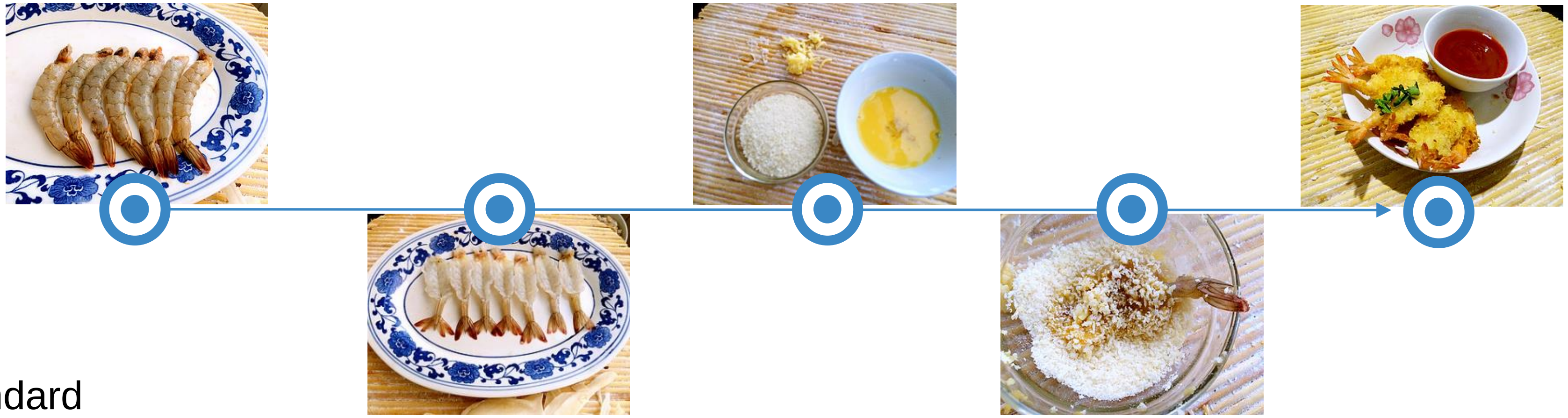
A single flexible algorithm?



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

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

Standard Cooking vs End-to-End Cooking



Standard

The central questions of robotics

What is it all about?

MOTION

The central questions of robotics

Three main question:

This weeks focus!

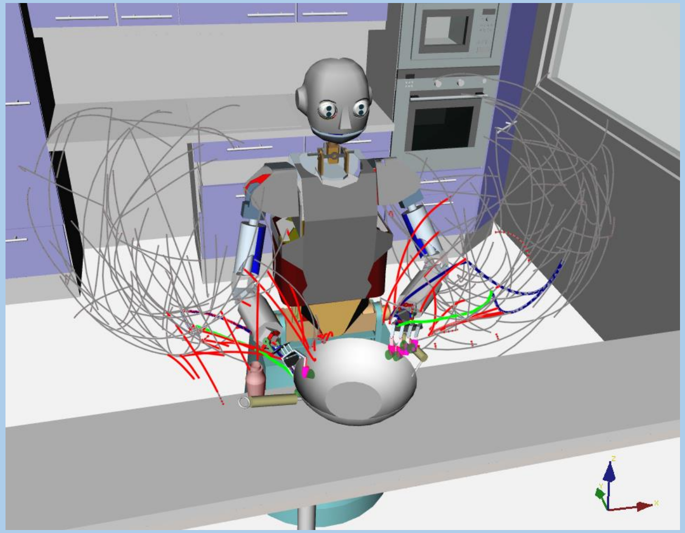
Where am I?

- Easy in Industrial Robotics
- Hard in Mobile Robotics

Where should I go?

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

How do I go there?

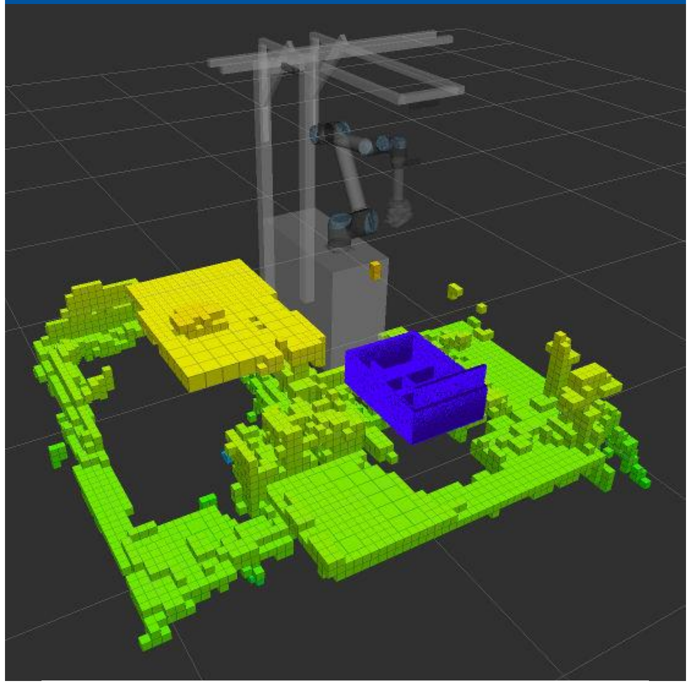


- Comparable Easy in Mobile Robotics
- Hard in Industrial Robotics

Robots as an Example for Intelligent Machines

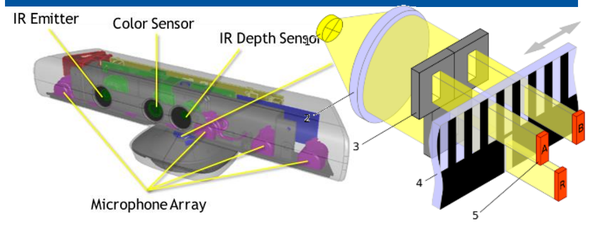
How do I (the robot) go there?

Model of the Robot and Environment



$$\begin{bmatrix}\dot{x}\\ \ddot{x}\\ \dot{\phi}\\ \ddot{\phi}\end{bmatrix} = \begin{bmatrix}1 & 0 & 0 & 0\\ 0 & \frac{-(I+ml^2)b}{I(M+m)+Mml^2} & \frac{m^2gl^2}{I(M+m)+Mml^2} & 0\\ 0 & 0 & 0 & 1\\ 0 & \frac{-mlb}{I(M+m)+Mml^2} & \frac{mgl(M+m)}{I(M+m)+Mml^2} & 0\end{bmatrix}\begin{bmatrix}x\\ \dot{x}\\ \phi\\ \dot{\phi}\end{bmatrix} + \begin{bmatrix}0\\ \frac{I+ml^2}{I(M+m)+Mml^2}\\ 0\\ \frac{ml}{I(M+m)+Mml^2}\end{bmatrix}u$$

Sensing



This weeks topic!

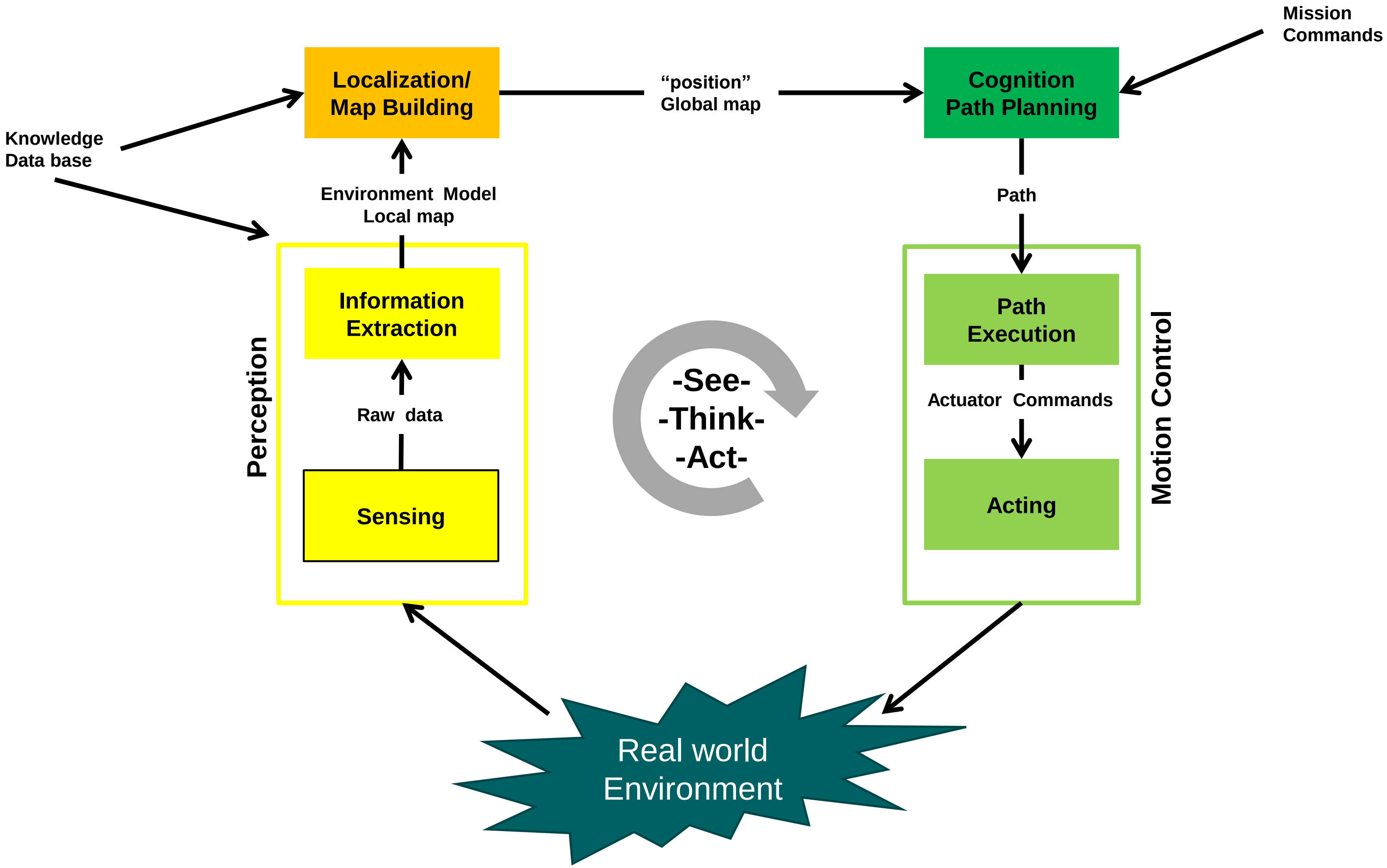
Motion Planning

Requires Goalstate:
- i.e. hand-engineered
- i.e. via a cost function

Motion Control and Execution

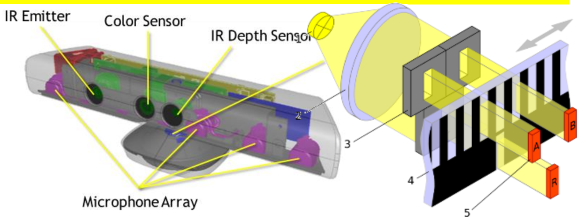
Robot-Architecture: See-Think-Act Cycle

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

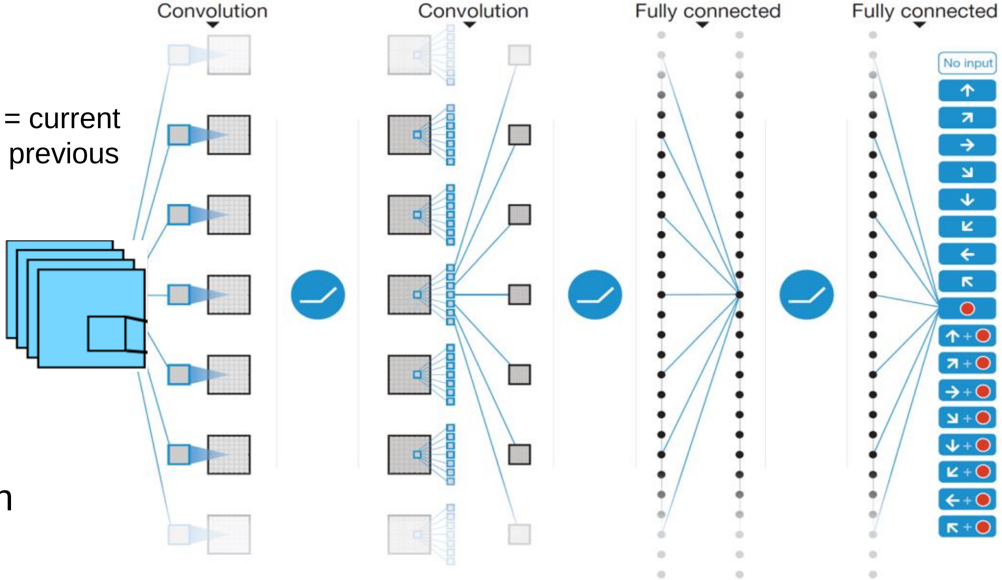


Robot-Architecture: End-To-End Control

Sensing → **Model** → **Motion Control and Execution**



1) Input:
4 images = current frame + 3 previous



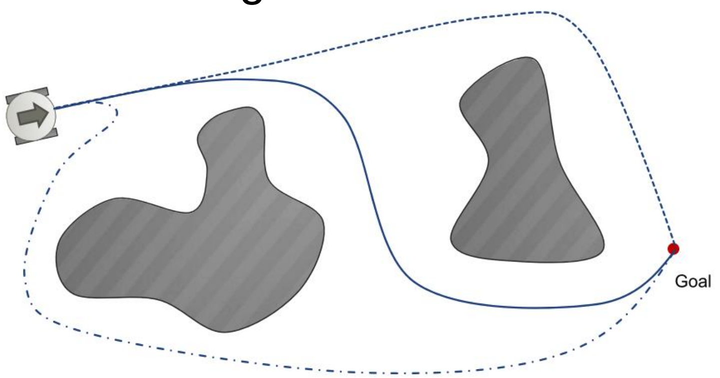
2) Output: $Q(s,a_i)$
$Q(s,a_1)$
$Q(s,a_2)$
$Q(s,a_3)$
.
.
.
.
.
.
.
.
.
$Q(s,a_{18})$

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

Mnih, Volodymyr, et al. "Human-level control through deep reinforcement learning." *Nature* 518.7540 (2015): 529-533.

Motion Planning

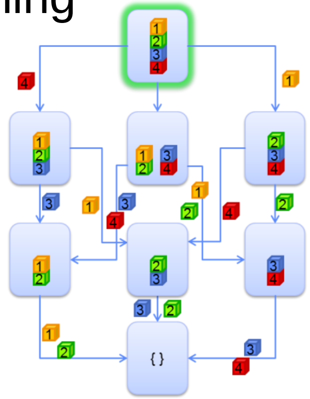
Path-Planning



Grasp-Planning

Task-Planning

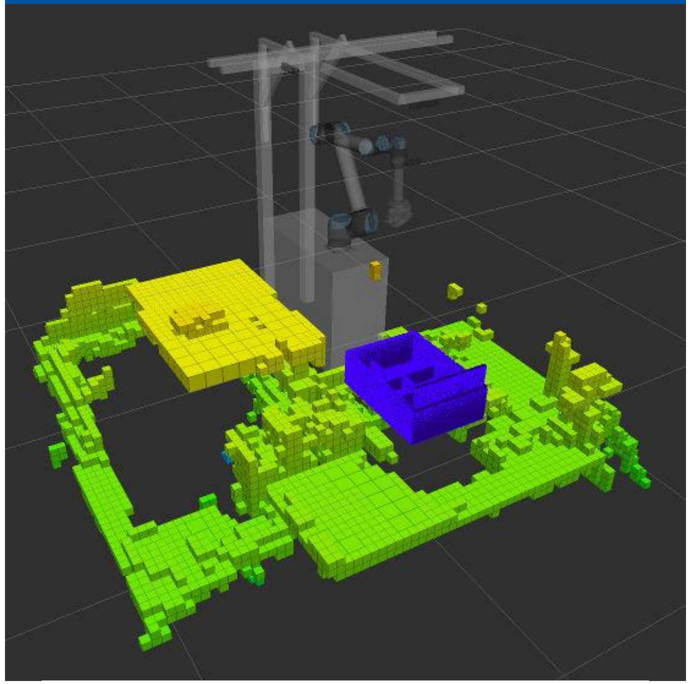
Assembly-Planning



Robots as an Example for Intelligent Machines

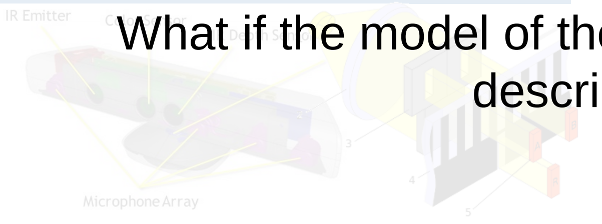
How do I (the robot) go there?

Model of the Robot and Environment



$$\begin{bmatrix} \dot{x} \\ \ddot{x} \\ \dot{\phi} \\ \ddot{\phi} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \frac{-(I+ml^2)b}{I(M+m)+Mml^2} & \frac{m^2gl^2}{I(M+m)+Mml^2} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \frac{-mlb}{I(M+m)+Mml^2} & \frac{mgl(M+m)}{I(M+m)+Mml^2} & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \phi \\ \dot{\phi} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{I+ml^2}{I(M+m)+Mml^2} \\ 0 \\ \frac{ml}{I(M+m)+Mml^2} \end{bmatrix} u$$

Sensing

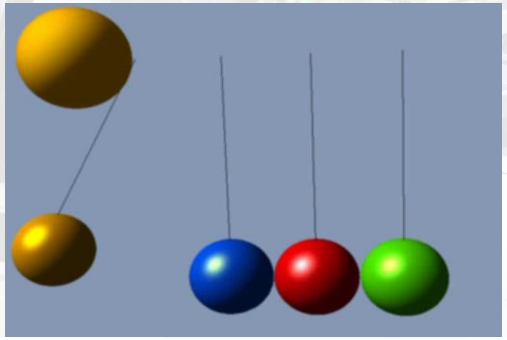


Motion Control and Execution

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

Think about flexible objects!

Think about contact-situations!

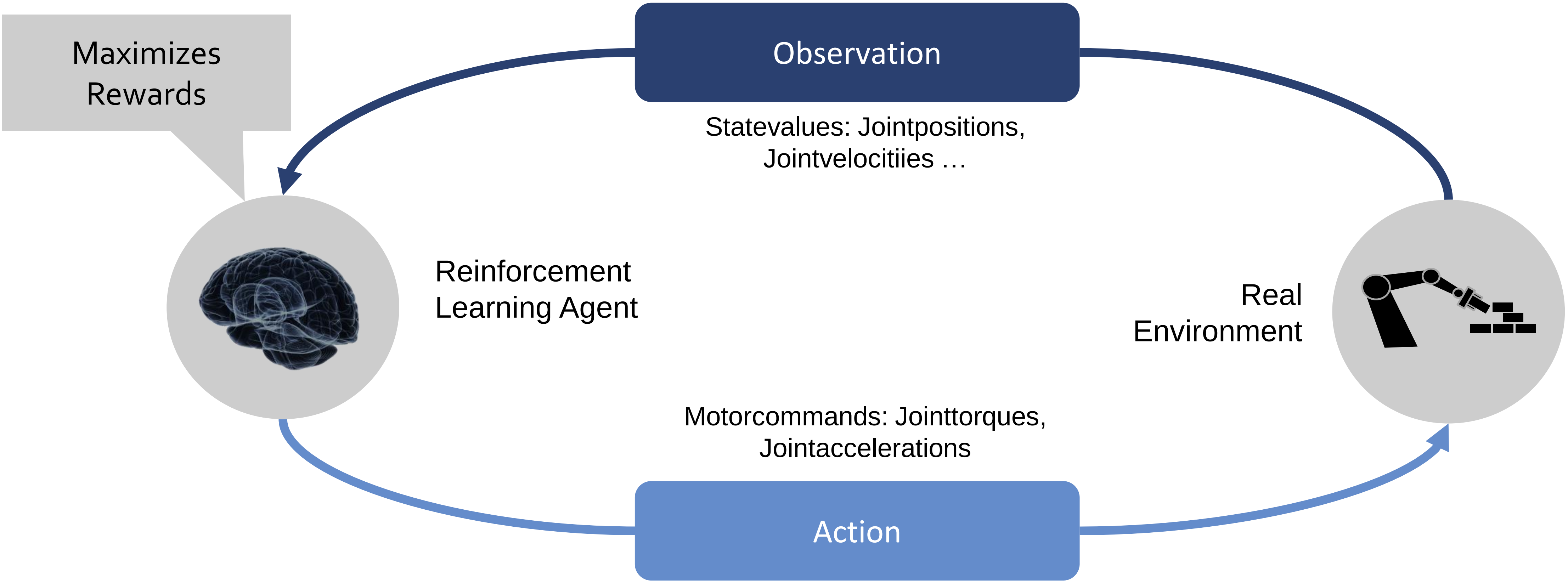


Requires Goalstate:
- i.e. hand-engineered
- i.e. via a cost function

Robots as an Example for Intelligent Machines

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

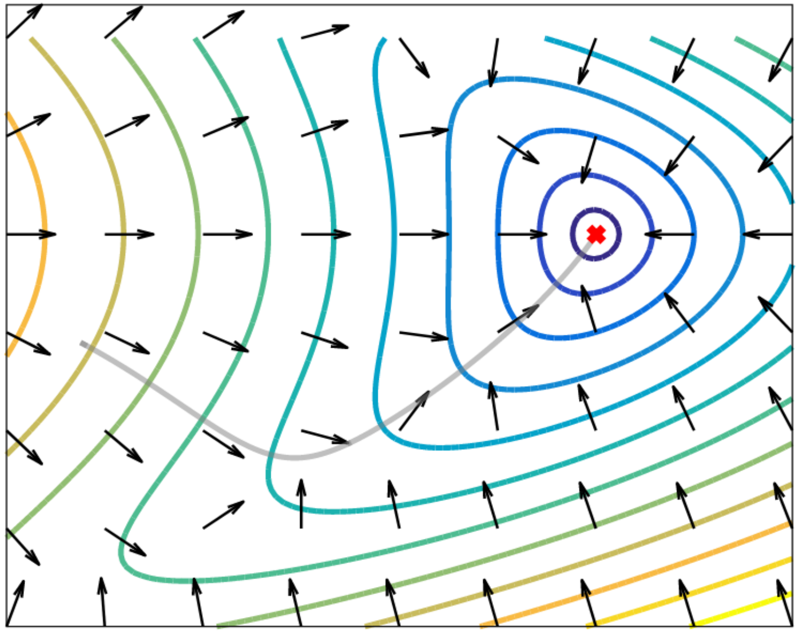
- Use an Reinforcement Learning Agent!



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

Closed-Loop

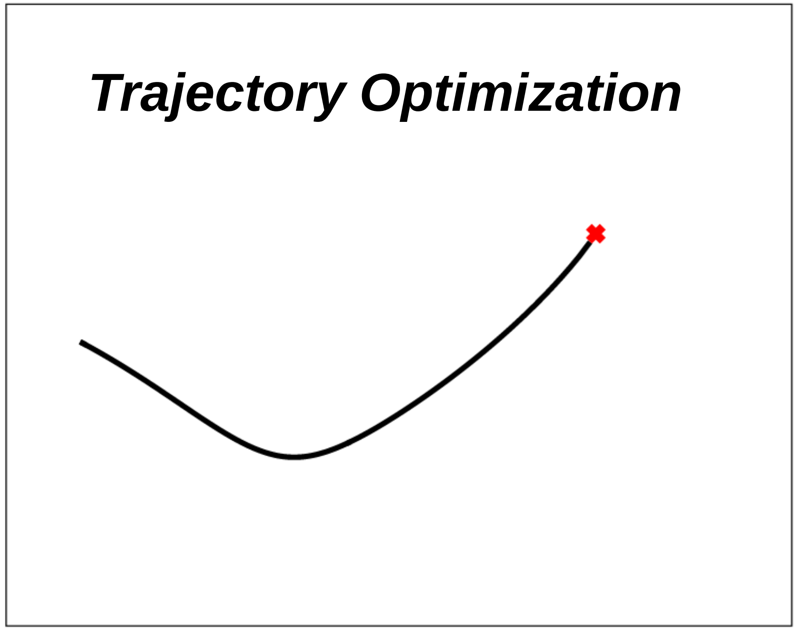
$u = u\,(x)$



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

Open-Loop

$u\,(t)$

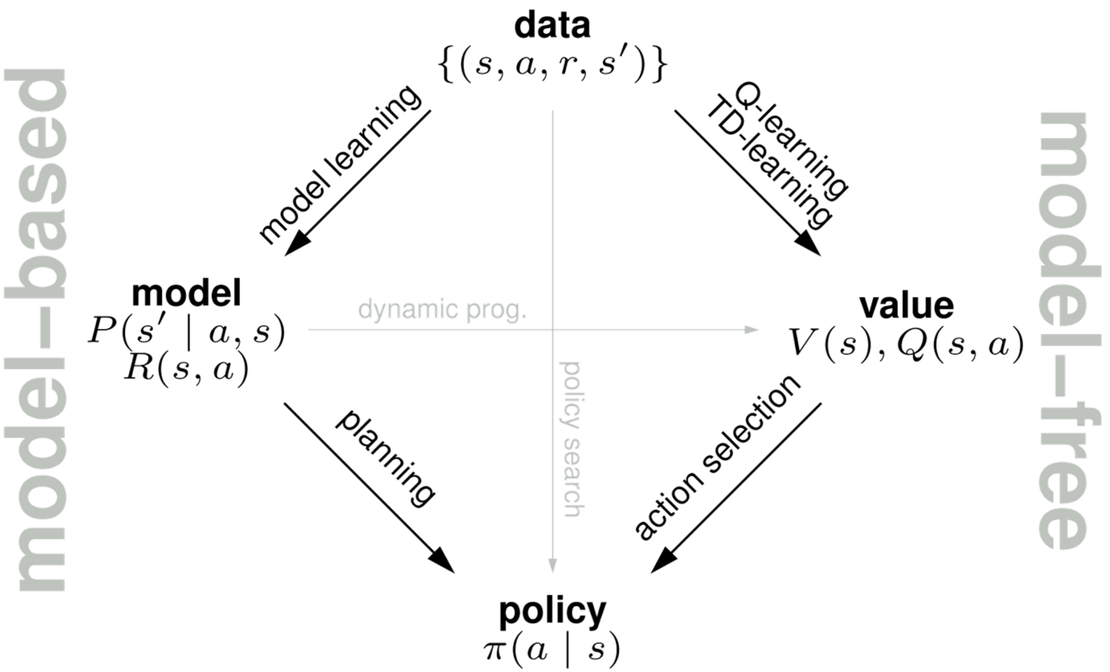


- Local motion strategy (a "**trajectory**")
- Only valid in a specific region

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

s: state
a: action
r: reward

Reinforcement Learning with End-to-End Technology

Sensing → **Model** → **Acting**

Organizational

<table>
<tr><th>Time</th><th>Sunday
13th August</th><th>Monday
14th August</th><th>Tuesday
15th August</th><th>Wednesday
16th August</th><th>Thursday
17th August</th><th>Friday
18th August</th><th>Saturday
19th August</th></tr>
<tr><td>9:00-9:30</td><td rowspan="26">Free Time for Excursions, Sight-Seeing and Self-Study</td><td rowspan="3">Introduction to Industrial Robots & Challenges</td><td rowspan="3">Fundamentals of Robot Learning and Control Theory</td><td rowspan="18">City Excursion to Cologne</td><td rowspan="3">Robot Learning with iterative Linear-Quadratic Regulator</td><td rowspan="6">Practical Unit: Robot Learning of an Assembly Task</td><td rowspan="26">Free Time for Excursions, Sight-Seeing and Self-Study</td></tr>
<tr><td>9:30-10:00</td></tr>
<tr><td>10:00-10:30</td></tr>
<tr><td>10:30-11:00</td><td rowspan="3">Motion Planning</td><td rowspan="3">Demonstration</td><td rowspan="3">Practical Unit: Robot Learning of an Assembly Task</td></tr>
<tr><td>11:00-11:30</td></tr>
<tr><td>11:30-12:00</td></tr>
<tr><td>12:00-12:30</td><td rowspan="4" colspan="2">Lunch Break at “Bistro Kerres”</td><td rowspan="4" colspan="2">Lunch Break at “Bistro Kerres”</td></tr>
<tr><td>12:30-13:00</td></tr>
<tr><td>13:00-13:30</td></tr>
<tr><td>13:30-14:00</td></tr>
<tr><td>14:00-14:30</td><td rowspan="6">Practical Unit: Introduction to Linux and Robot Operating System</td><td rowspan="3">Programming using Python</td><td rowspan="6">Practical Unit: Robot Learning of an Assembly Task</td><td rowspan="6">Show: Let the robot learn!</td></tr>
<tr><td>14:30-15:00</td></tr>
<tr><td>15:00-15:30</td></tr>
<tr><td>15:30-16:00</td><td rowspan="3">Practical Unit: Programming using Python</td></tr>
<tr><td>16:00-16:30</td></tr>
<tr><td>16:30-17:00</td></tr>
<tr><td>17:00-17:30</td><td rowspan="10"></td><td rowspan="6"></td><td rowspan="10"></td><td rowspan="5"></td></tr>
<tr><td>17:30-18:00</td></tr>
<tr><td>18:00-18:30</td><td rowspan="8"></td></tr>
<tr><td>18:30-19:00</td></tr>
<tr><td>19:00-19:30</td></tr>
<tr><td>19:30-20:00</td><td rowspan="5">„Karaoke Night“ with the Summer School Team and your Buddies</td></tr>
<tr><td>20:00-20:30</td><td rowspan="4">OPTIONAL International Tuesday with the INCAS Student Organisation</td></tr>
<tr><td>20:30-21:00</td></tr>
<tr><td>21:00-21:30</td></tr>
<tr><td>21:30-22:00</td></tr>
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