Robotics II: Humanoid Robotics

Tamim Asfour

High Performance Humanoid Technologies (H²T)

http://www.humanoids.kit.edu

http://h2t.anthropomatik.kit.edu

KIT-Department of Informatics - Institute for Anthropomatics and Robotics - High Performance Humanoid Technologies (H²T)

Lecturer and teaching assistants

Tamim Asfour
Prof. Dr.-Ing.

IAR-H2T
Geb. 50.20
Raum 017
asfour@kit.edu

Fabian Paus
M. Sc.

IAR-H2T
Geb. 50.20
Raum 334
Tel.: 608 – 47126
paus@kit.edu

You Zhou
M. Sc.

IAR-H2T
Geb. 50.20
Raum 333
Tel.: 608 – 47110
You.zhou@kit.edu

H²T: Geb. 50.20

Sprechstunde:

Mittwochs 10:00 – 12:00 Uhr im Adenauerring 2, EG, Raum 017 oder nach Vereinbarung per E-Mail

Lecture related information

- Lecture dates: **Monday, 09:45 - 11:15 Uhr, HS -101 (Geb. 50.34)**

- KIT **ILIAS-Portal:** https://ilias.studium.kit.edu
  - Password for ILIAS: **armar@kit**
  - Lecture slides will be available after each lecture

- Access ILIAS:
  - Login
  - Search course: „Robotik II – Humanoide Robotik“
  - Join the course using the password
  - Now you can access the slides and additional material

Exam, ECTS, …

- Written exam; date will be announced
- 3 ECTS

Lehrveranstaltungen @ H2T

WS | SS | WS & SS

Robotik I – Einführung in die Robotik
Stammmodul (6 ECTS)

Vorlesungen

- Mechano-Informatik in der Robotik (4 ECTS)
- Rechnerorganisation (6 ECTS)
- Digitaltechnik (6 ECTS)
- **Robotik II: Humanoide Robotik (3 ECTS)**
- Anziehbare Robotertechnologien (4 ECTS)
- Robotik III: Sensoren in der Robotik (3 ECTS)

Praktika

- Lego Mindstorms (3 ECTS)
- Humanoide Roboter (3 ECTS)
- Roboterpraktikum (6 ECTS)
- Basispraktikum Mobile Roboter (4 ECTS)

Seminare

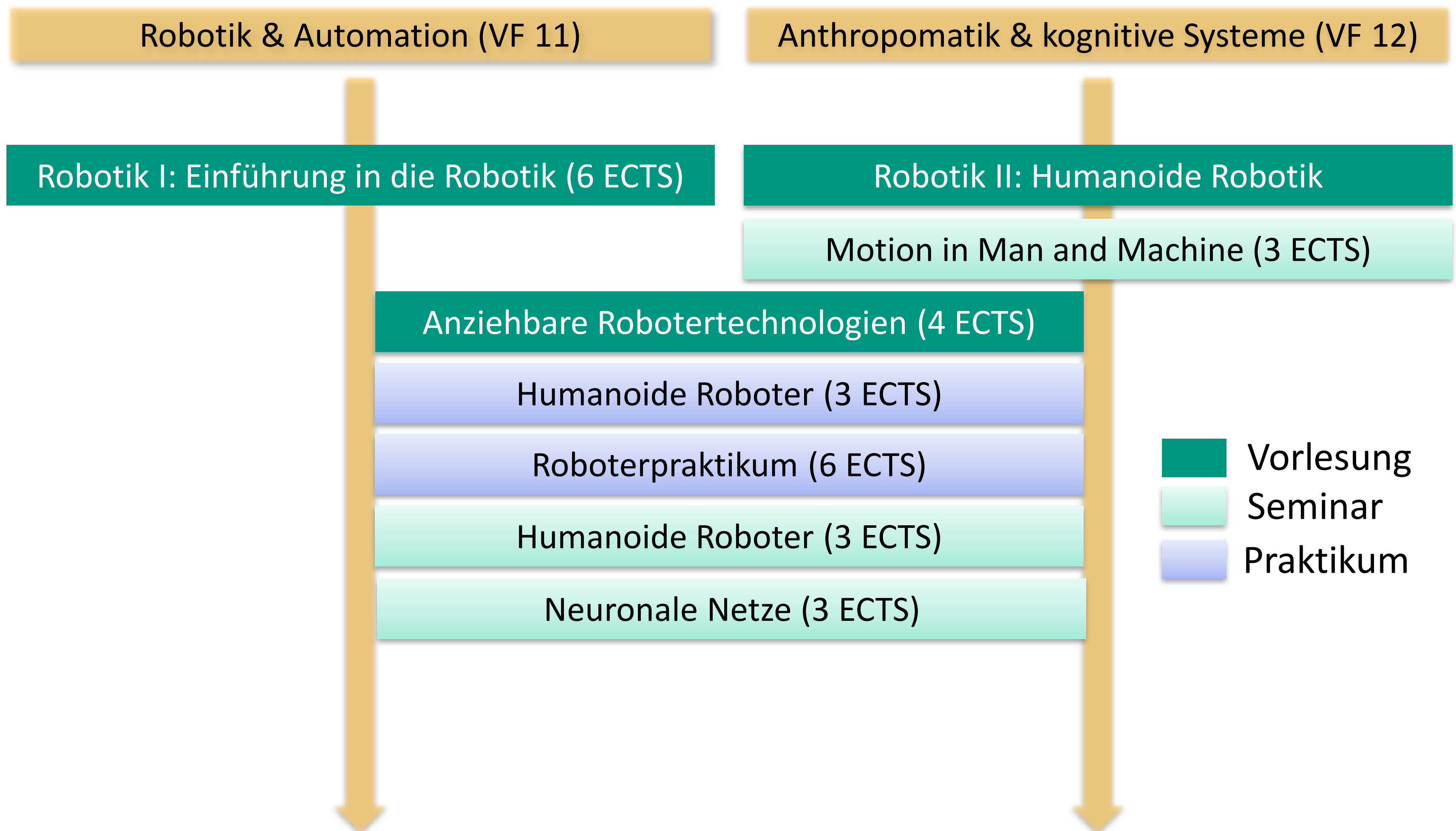
- Humanoide Roboter (3 ECTS)
- Neuronale Netze (3 ECTS)
- Motion in Man and Machine (3 ECTS)

Praxis der Softwareentwicklung (6+2 ECTS)

Praxis der Forschung (24 ECTS)

Robotik: Informatik zum Anfassen (Schüler AG am Goethe Gymnasium)

Lehrveranstaltungen @ H2T - Vertiefung



Institute for Anthropomatics and Robotics (IAR)

10 Labs, approx. 150 members

- High Performance Humanoid Technologies

Asfour

- Vision and Fusion

Beyerer

- Humanoids and Intelligence Systems

Dillmann

- Intelligent-Sensor-Actuator Systems

Hanebeck

- Intelligent Industrial Robotics

Hein

- Intelligent Process Control and Robotics

Kröger

- Computer Vision for Human Computer Interaction

Stiefelhagen

- Interactive Systems

Waibel

- Autonomous Learning Robots

N.N.

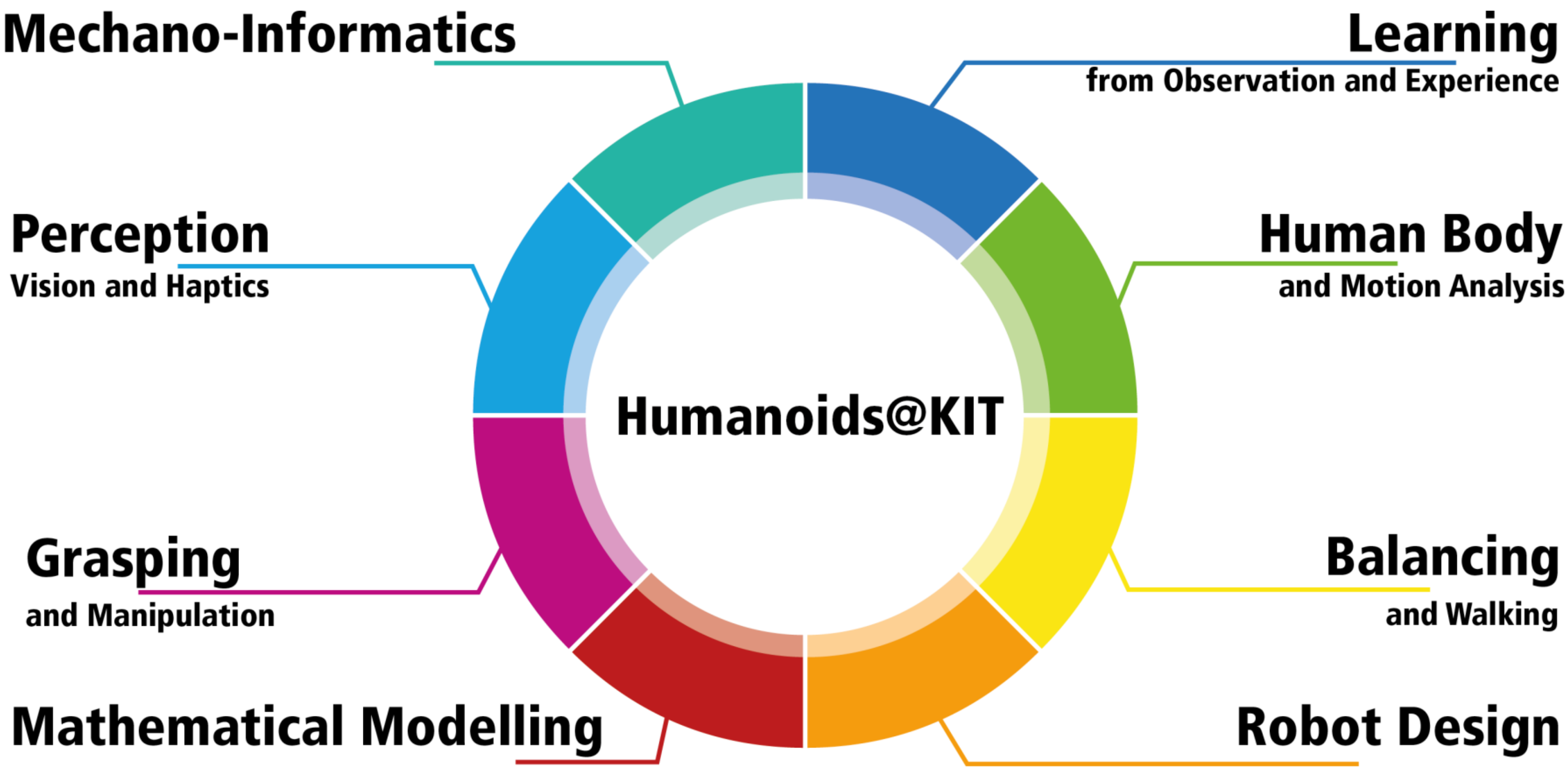
- Medical Robotics

N.N.

H²T team

Humanoids@KIT

H^{2}T Research Topics



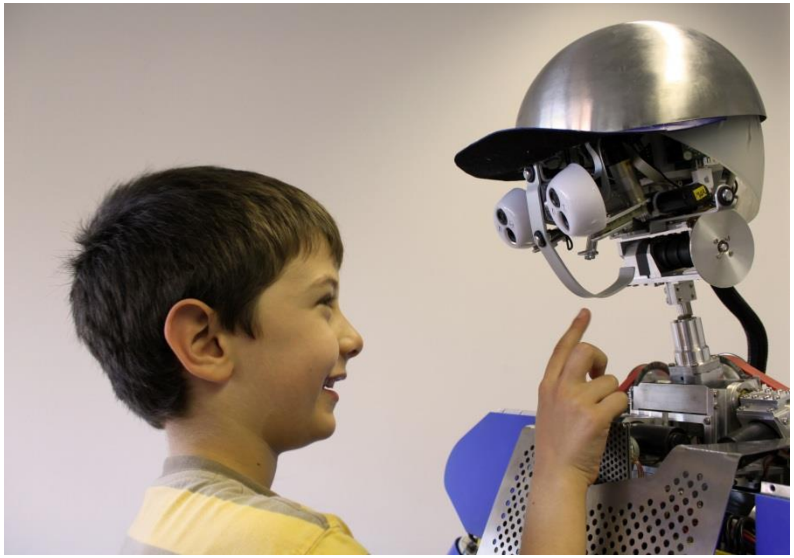
This lecture: Robotics II – Humanoid Robotics

- Interactive lecture
- Selected topics related to **perception, action, learning, artificial intelligence and cognition** will be discussed to extend the theoretical and practical knowledge in the area of humanoid robotics.
- Current state of the art of research
- **Material: selected publications**

WHAT IS ANTHROPOMATICS?

Anthropomatics is …

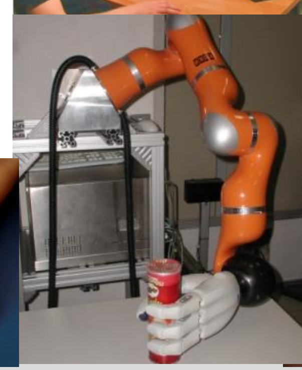
… the science of the symbioses between human and machine



KIT-Focus: Anthropomatics and Robotics

Anthropomatics is…

… the science of the symbioses between human and machine



Research topics

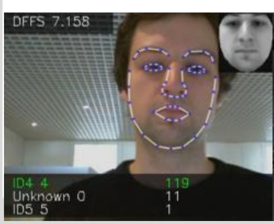
- Multimodal Human-Machine Interaction
- Image and Speech Understanding
- Learning through Experience and Interaction
- Biosignal Processing
- Cognitive Information Processing
- Human-Machine Interfaces

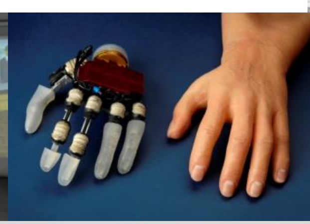
Robotics is…

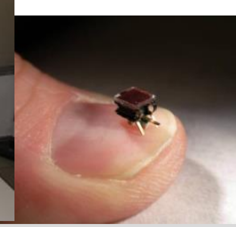
… the science of automatic handling, services for humans and manufacturing

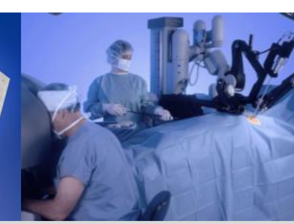
Research topics

- Humanoid Robotics
- Service Robotics
- Industrial Robotics
- Medical Robotics
- Micro Robotics
- Swarm Robotics









Strategic Goal and Mission

Design, implement and evaluate anthropomatic systems to improve humans' quality of life

- Understanding of humans in terms of anatomy, motor skills, perception, behavior and information processing
- Building systems and technologies that coexist with humans as assistants and companions at different ages, in different situations, different environments and with varying activities
- Technology transfer to different industries

Research Topics

MI – Machine Intelligence
- Representations
- Memory Structures
- Machine Learning
- Cognitive Architectures

HCR – Human-Centered Robotics
- Humanoid and Service Robotics
- Prosthetics and Orthotics
- Medical Robotics
- Sensor-Actuator Networks

MIC – Multimodal Interaction and Communication
- Speech Processing and Translation
- Robot and Computer Vision
- Biosignal Processing
- Multimodal Perception

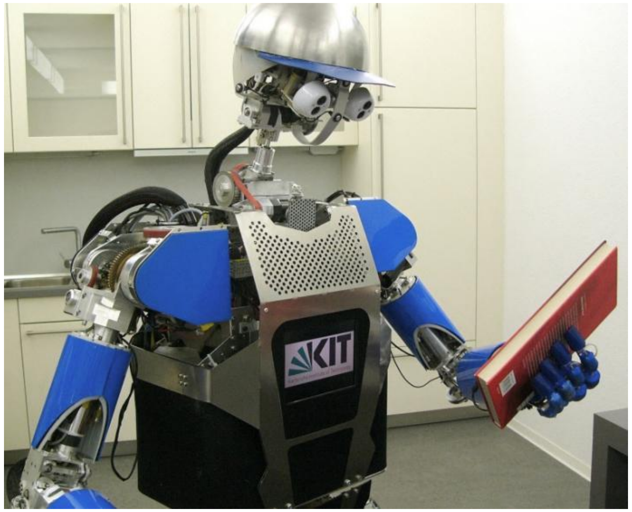
RT – Robot Technologies
- Mechatronics and Control
- Lightweight Design
- Sensors and Actuators
- Embedded Systems

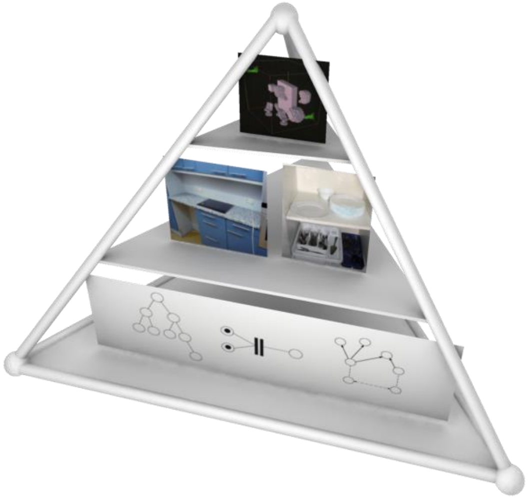
IR – Industrial Robotics
- Manufacturing
- Automation
- Industrial Vision Processing
- Supervision

TT – Technology Transfer

Machine Intelligence

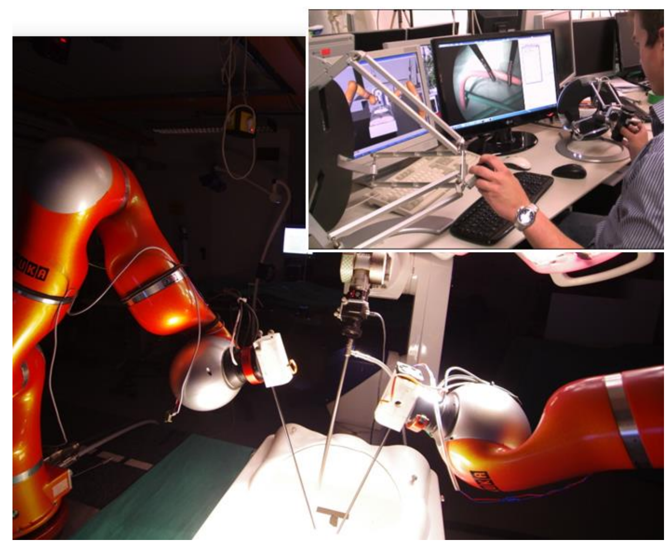
- How to implement intelligence in technical systems?
- How can robots learn from humans?
- How can knowledge be represented at different levels of abstraction?
- How can memory structures and cognitive architectures be realized in technical systems?





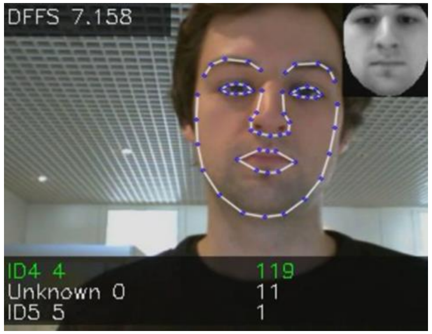
Human Centered Robotics

- Humanoid robots that act and interact in the real world to perform a wide variety of tasks
- Prosthetic and orthotic devices
- Intelligent systems for medical assistance in the diagnosis and treatment
- Robot-assisted and robot-guided surgery



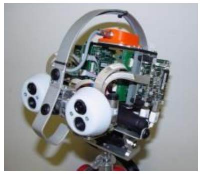
Multimodal Interaction and Communication

- Systems for automatic speech recognition, translation and syntheses
- Applications: Simultaneous translation of lectures and debates in Parliament
- Biosignal analysis for salient Speech
- Face recognition, facial expressions and gaze direction detection for the development of better Human-Machine Interfaces



Robot Technologies

- Mechatronics for anthropomatic Systems such as humanoid and service robots
- Light-weight and energy efficient robot components
- Microrobot for the handling of objects in micro- and nano-scale

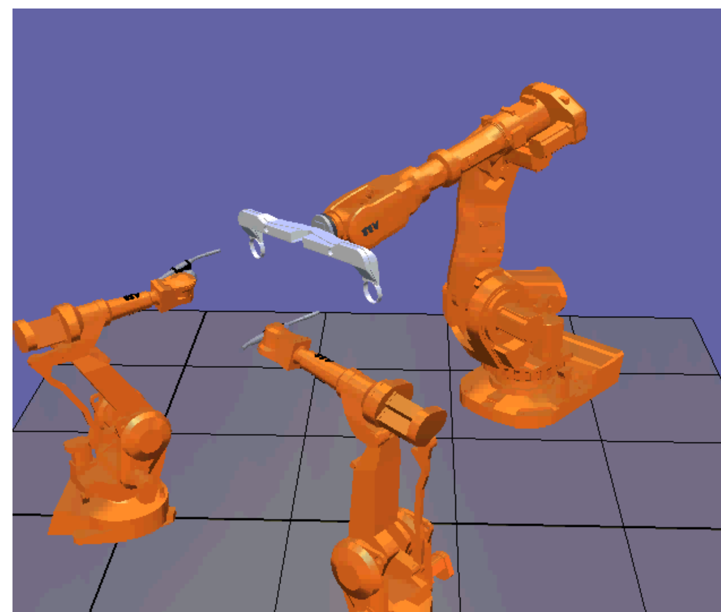


Industrial Robotics

- Novel Man-Machine Interfaces for programming of and interaction with industrial robots

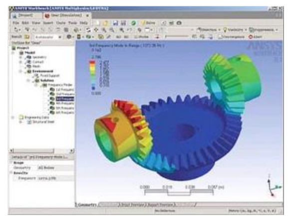
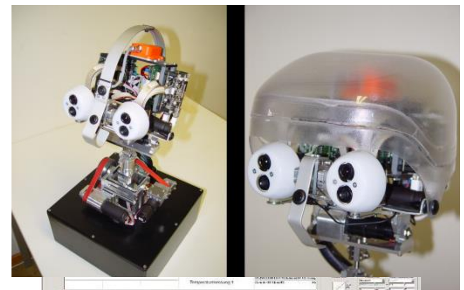
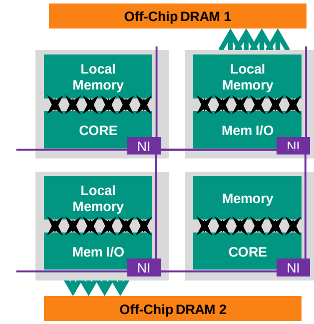
- New sensor technologies and user interfaces for enhanced safety

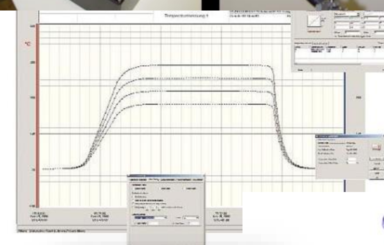
- Sensor-based control of robotic systems in tasks, such as assembly, handling, inspection and testing

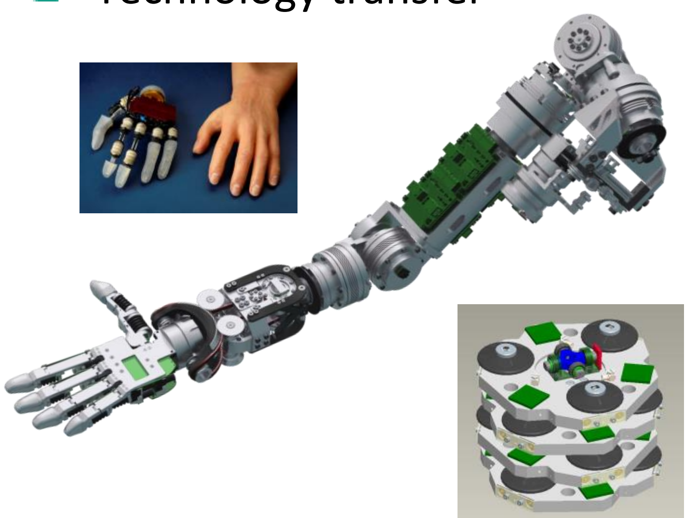


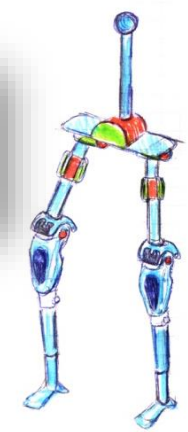
KIT Robot Design Atelier

- Provide infrastructure for design, control, programming and testing of anthropomatics and robotics components
  - CAD
  - Mechatronics
  - Embedded Systems
  - Control
  - Software
  - Technology transfer






WHY HUMANOIDS?

Why humanoids?

- **Versatility:** We need robots which …
  - are **versatile,** i.e. can perform a wide variety of tasks
  - can act and interact in **made-for-human environments**
  - can use **made-for-human tools**

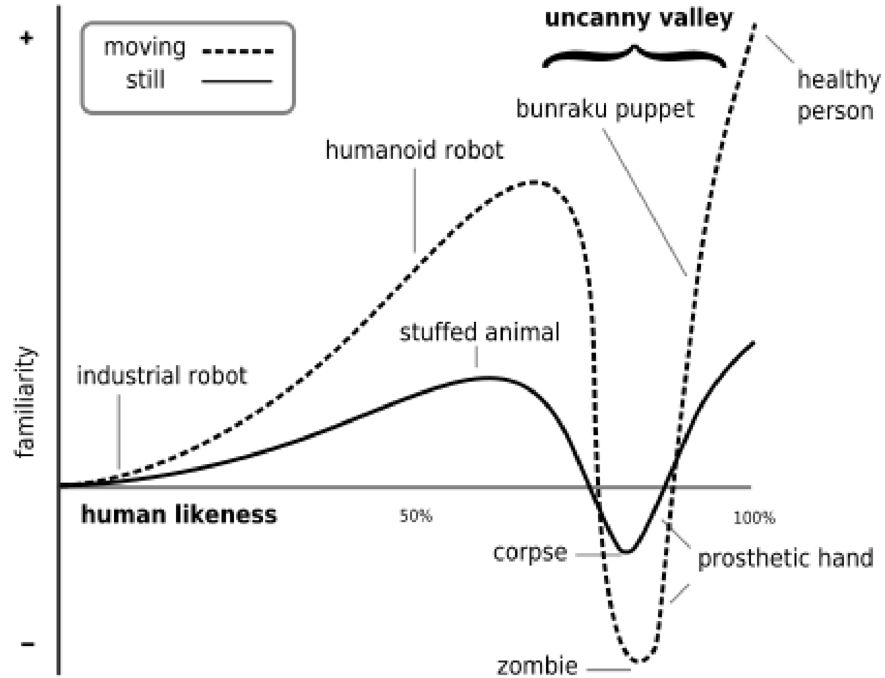
  Human body is the best morphology we know so far!

- **Better Prediction of robot actions**
  - Motion behavior of robots with human-like morphology, i.e. humanoid robots, allows humans to better **predict** the robot actions which leads to intuitive and fluent human-robot interaction

- **Acceptance**
  - Human-like appearance may support **acceptance and intuitive human-robot interaction** but the **Uncanny Valley** tells us something different!

The Uncanny Valley

- The uncanny valley is the region of negative emotional response towards robots that seem "almost" human. Movement amplifies the emotional response



https://de.wikipedia.org/wiki/Uncanny_Valley

Japanischen Robotiker **Masahiro Mori:** The Uncanny Valley, Phänomen des unheimlichen Tals, jap. 不気味の谷現象 bukimi no tani genshō, 1970

Why Humanoids? Impact of humanoids

Building Humanoids = Building Human-Centered Technologies



- Versatile systems that act and interact in made-for-human environments and use made-for-human tools
- Versatile assistants and companions that provide help for people in different ages, situations, and environments and improve human's quality of life
- Key technologies for future robotic systems
- Experimental platforms "bodies" to study theories about humans

My inspiration

- Biology

- Science Fiction

Human performance

Roger Federer

Johanna Quaas - oldest active Gymnast of the World!
86 years, Halle, Germany

Human performance

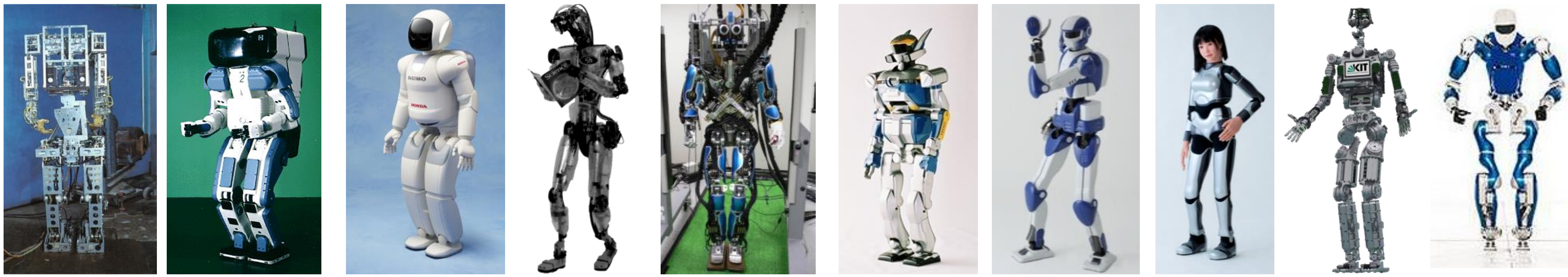
- … in-hand manipulation (e.g. pen spinning)

Major goals in humanoid research

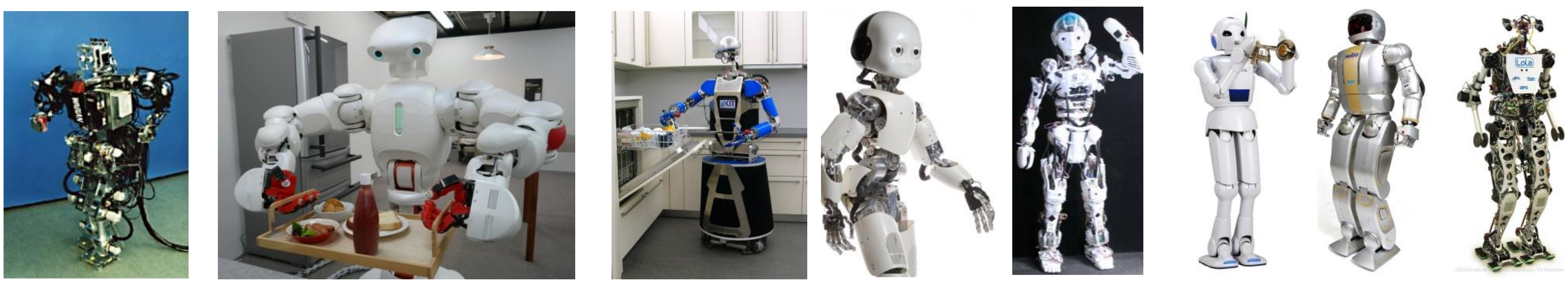
- Advanced human-like mechatronics/mechanoinformatics systems

- Tools to study humans

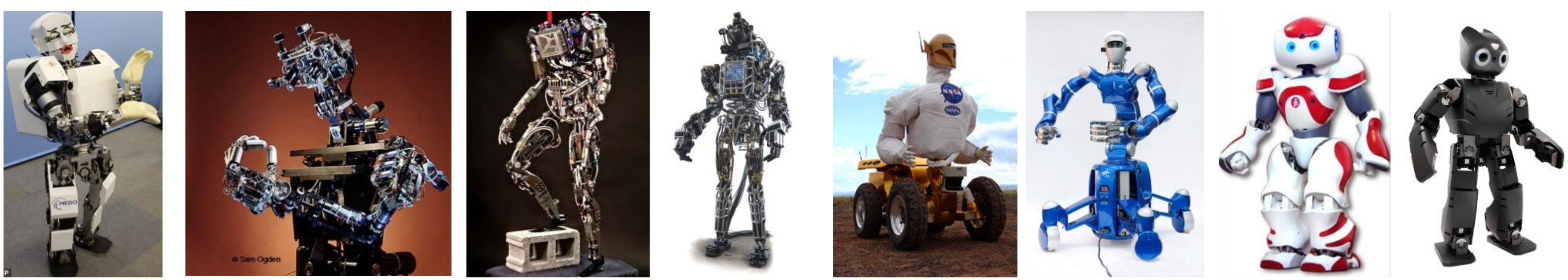
Humanoid robotics has made progress !



WABOT-1 | P2 | ASIMO | DB | CB | HRP-2 | HRP-4 | HRP-4C | ARMAR-IV | Toro



WABIAN | Twendy-one | ARMAR-III | iCub | kojiro | Partner Robot | HUBO | Lola



KOBIAN | Cog | Petman | Atlas | Robonaut | Justin | NAO | DARwIN-OP

Ambitious goals have been set for humanoid robotics

- Companions and assistants for humans in daily life
- Helpers in man-made and natural disasters
- Winners against the winner of the most recent World Cup in 2050
- DARPA Robotics Challenge

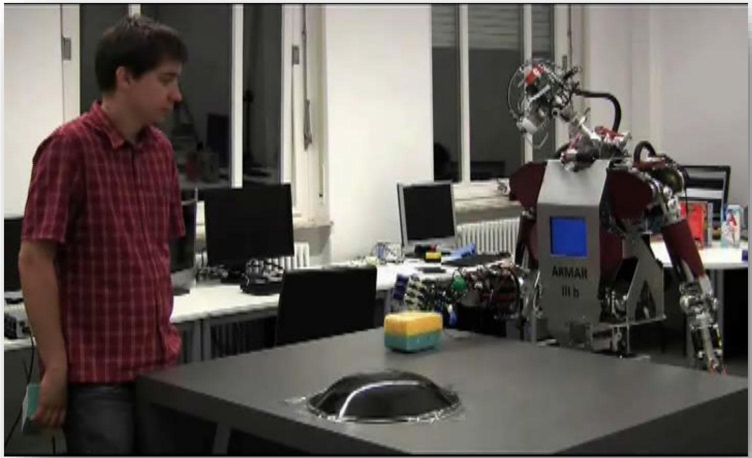
Image: DARPA

Some examples

ASIMO, Honda, Japan

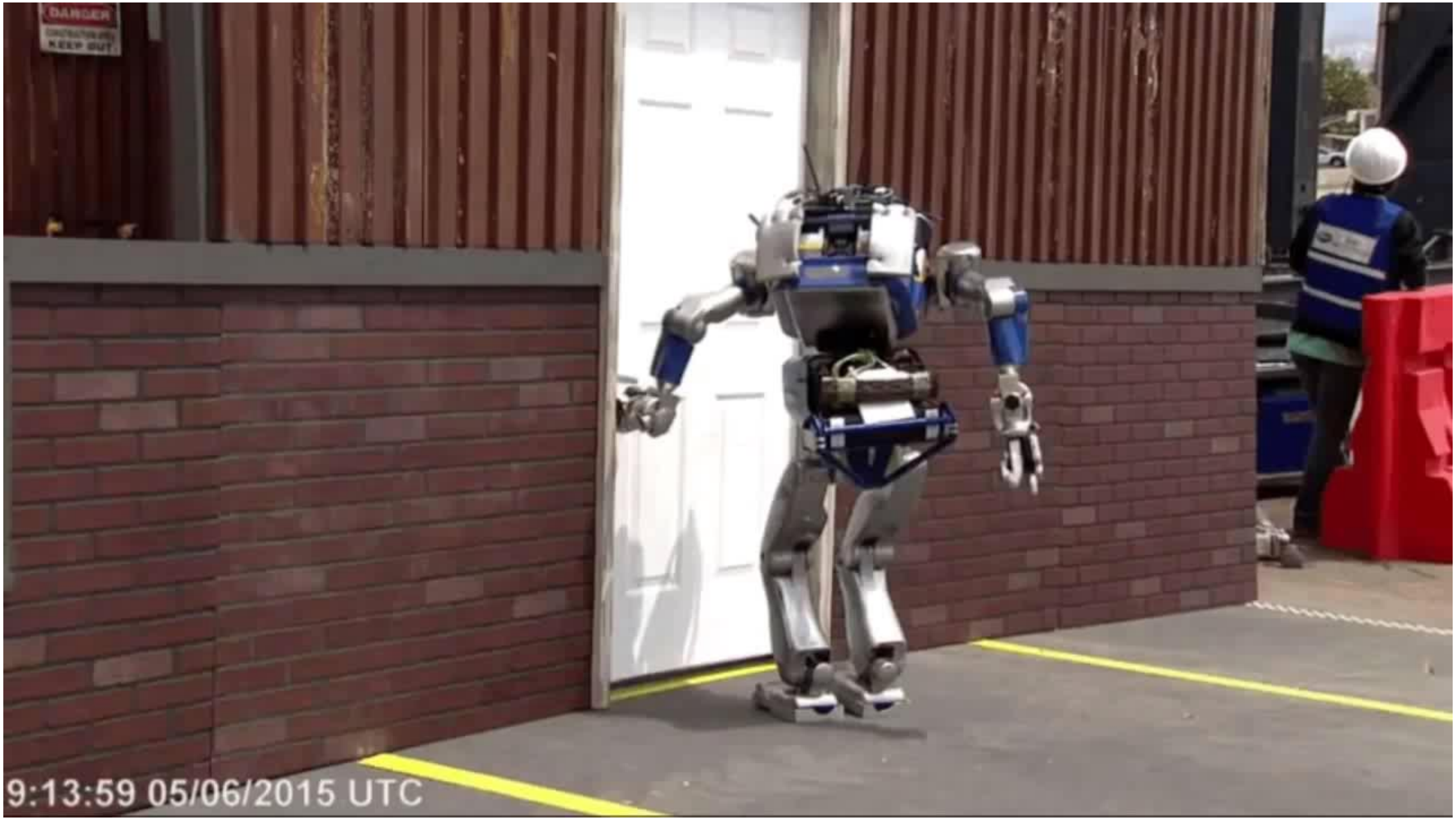
HRP-4C, AIST, Tsukuba, Japan

Atlas, Boston Dynamics, USA



ARMAR, KIT, Germany

Humanoids vs. Doors



Boston Dynamics Atlas (Feb. 2016)

Boston Dynamics Handle (Feb. 2017)

Schaft Robots – DRC (2013)

Schaft Robots – Google

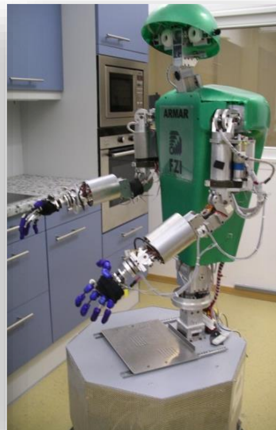
Humanoids in the real world

- Engineering Humanoids
- Grasping and manipulation
- Learning for human observation
- Natural Interaction and communication

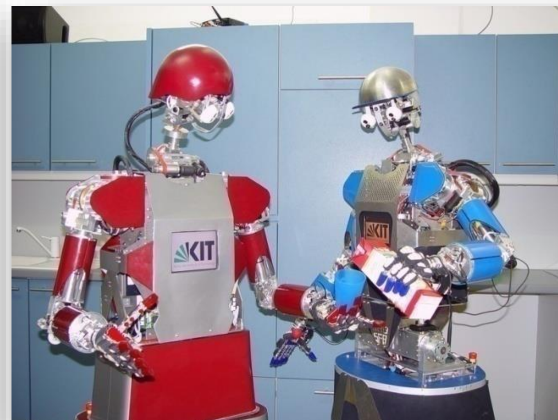
Humanoid Robots @ KIT

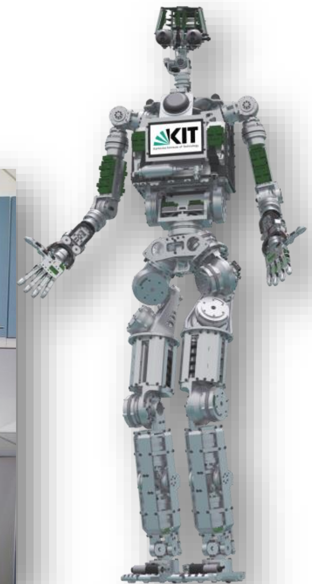
Deutsche Forschungsgemeinschaft


ARMAR, 2000


ARMAR-II, 2002

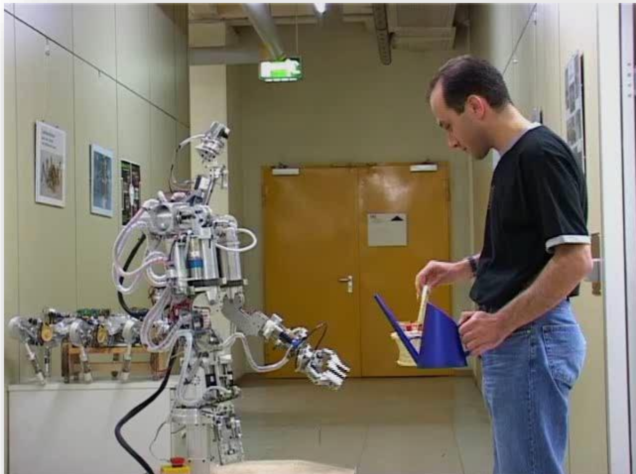

ARMAR-IIIa, 2006

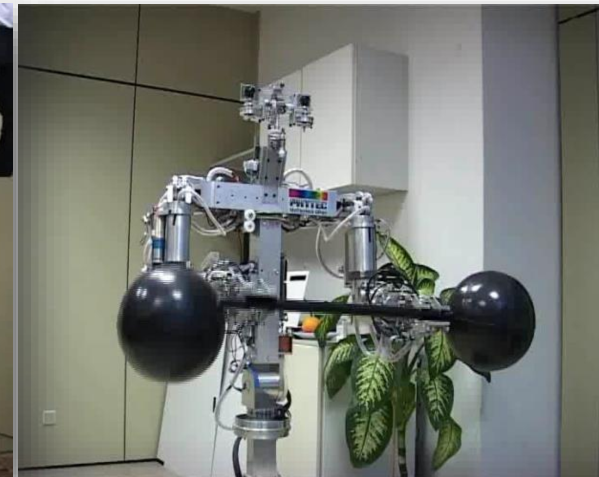

ARMAR-IIIb, 2008


ARMAR-IV, 2011

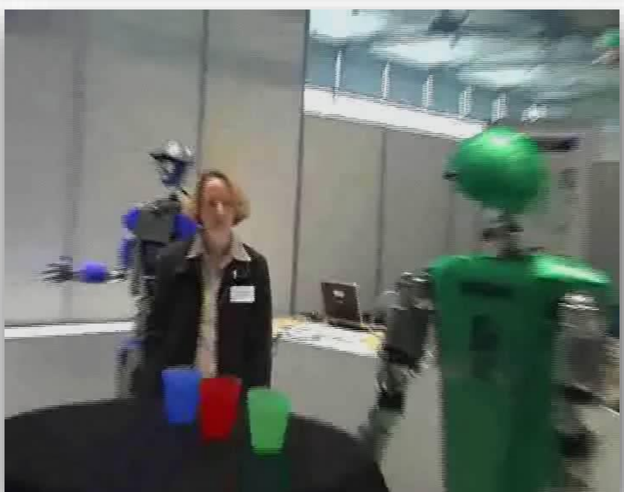
- Collaborative Research Center 588: Humanoid Robots - Learning and Cooperating Multimodal Robots (SFB 588)
  - Funded by the German Research Foundation (DFG: Deutsche Forschungsgemeinschaft)
  - 2001 – 2012
  - http://www.sfb588.uni-karlsruhe.de/

ARMAR-I (1999) and ARMAR-II (2003)





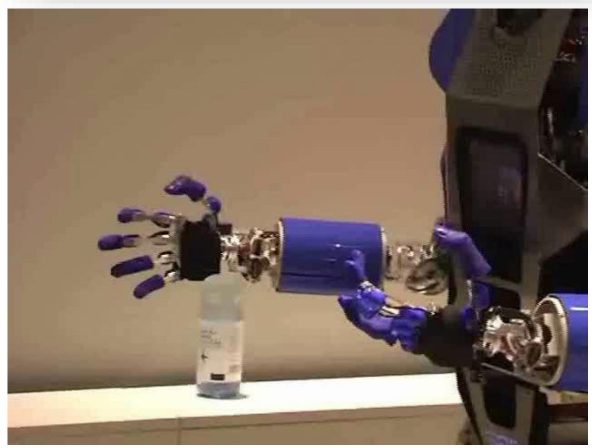
First demonstrator of the SFB 588



Demo at CEBIT 2006

ARMAR-IIIa (2006) and ARMAR-IIIb (2008)

- 7 DOF head with foveated vision
  - 2 cameras in each eye
  - 6 microphones
- 7-DOF arms
  - Position, velocity and torque sensors
  - 6D FT-Sensors
  - Sensitive Skin
- 8-DOF Hands
  - Pneumatic actuators
  - Weight 250g
  - Holding force 2,5 kg
- 3 DOF torso
  - 2 Embedded PCs
  - 10 DSP/FPGA Units
- Holonomic mobile platform
  - 3 laser scanner
  - 3 Embedded PCs
  - 2 Batteries
- Weight: 150 kg



Fully integrated humanoid system

ARMAR-4 (2013)

- Torque controlled
- 3 on-board embedded PCs
- 76 Microcontroller
- 6 CAN Buses

- 63 DOF
  - 41 electrically-driven
  - 22 pneumatically-driven (Hand)

- 238 Sensors
  - 4 Cameras
  - 6 Microphones
  - 4 6D-force-torque sensors
  - 2 IMUs
  - 128 position (incremental and absolute), torque and temperature sensors in arm, leg and hip joints
  - 18 position (incremental and absolute) sensors in head joints
  - 14 load cells in the feet
  - 22 encoders in hand joints
  - 20 pressure sensors in hand actuators
  - …

More than mechatronics

ARMAR-IV

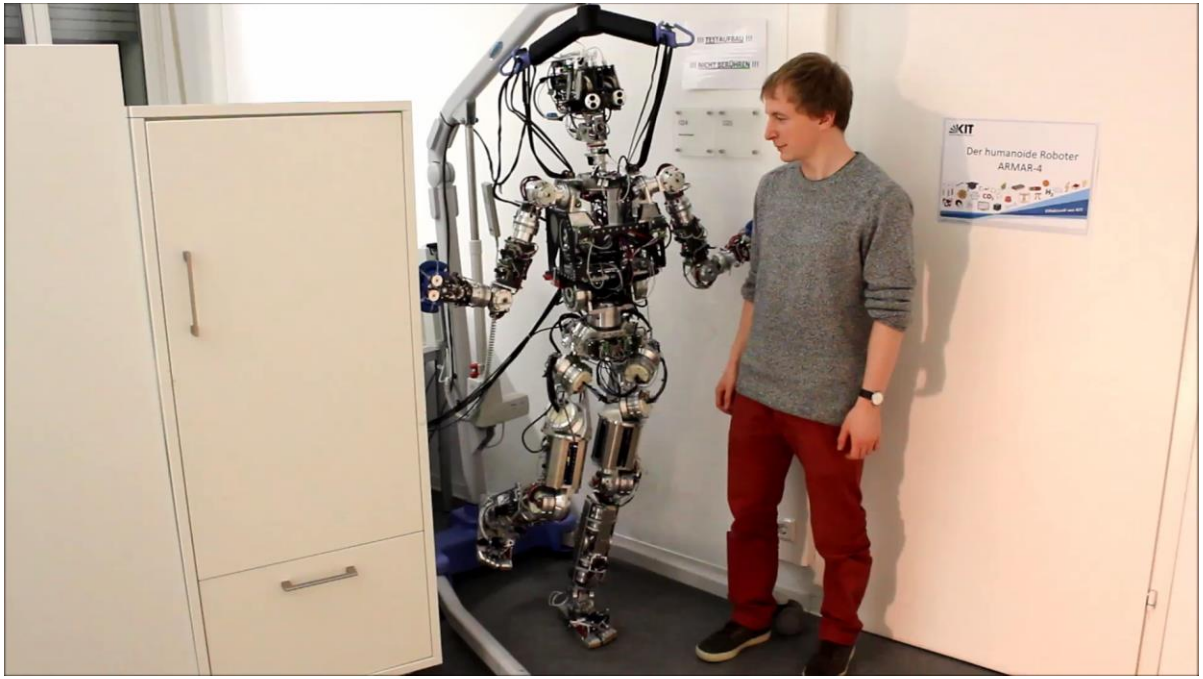
made@KIT

70 kg

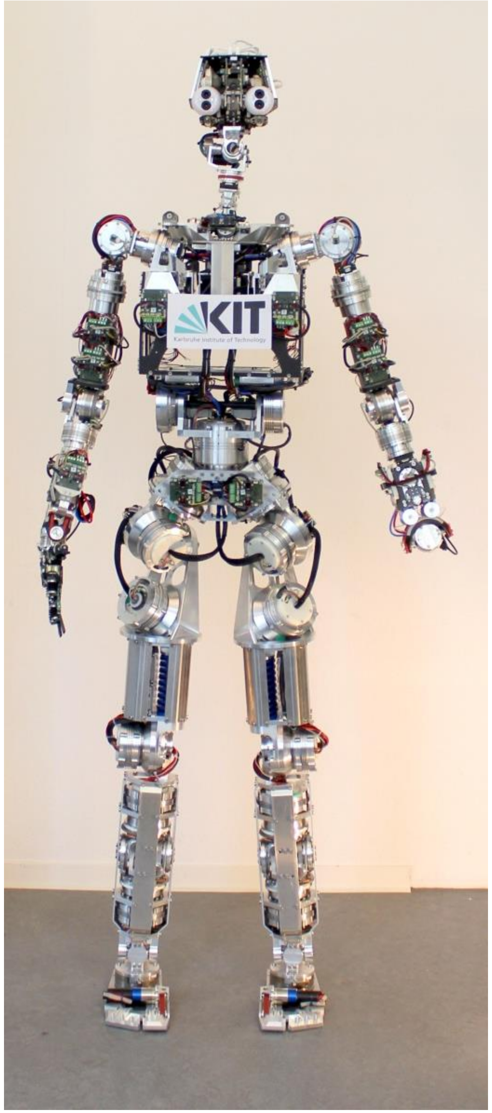
170 cm

ARMAR-4

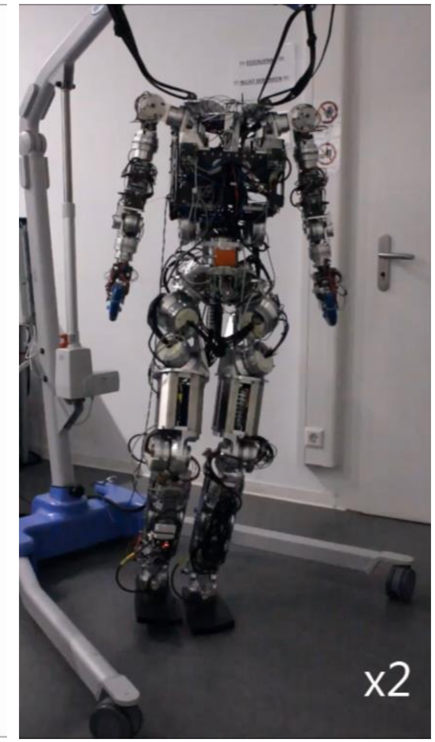
- 63 DOF
- Torque-controlled!



Multi-contact active compliance balancing controller



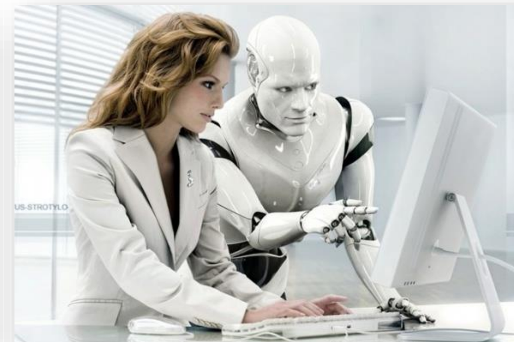
Learning to balance from human observation



ARMAR-5: Humanoids for Human Augmentation

- Humanoid robots with **multiple functions** and for **multiple use**

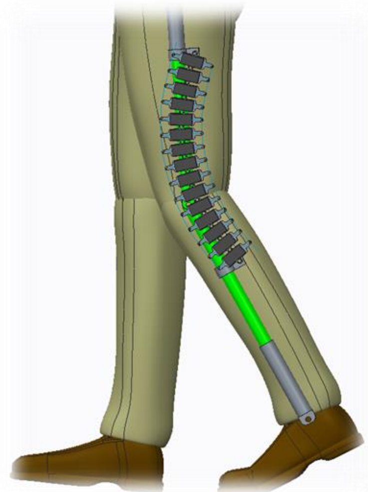
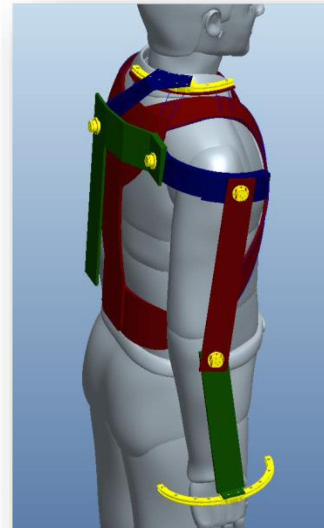
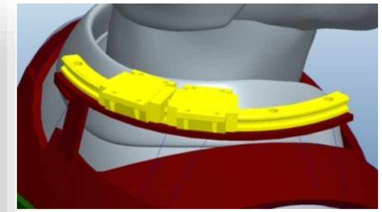
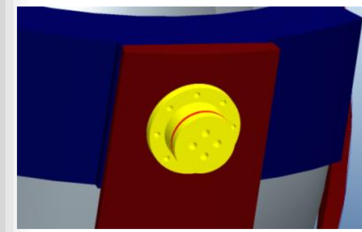
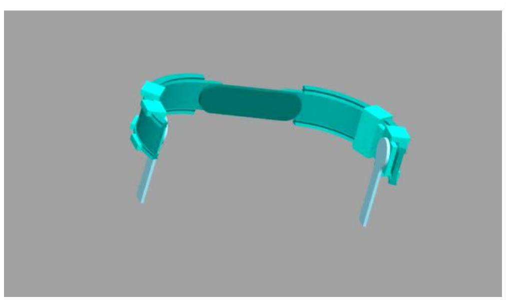
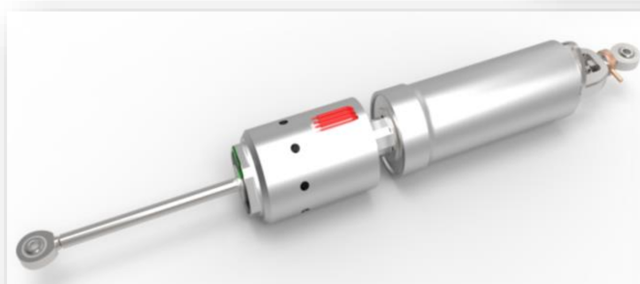
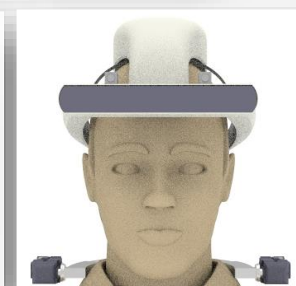
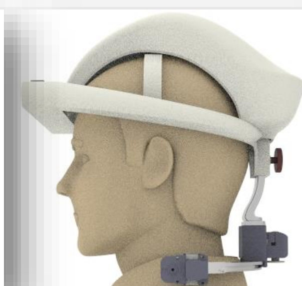
Helper, Assistant and Companion



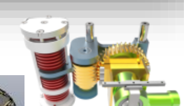
Wearable Humanoid „Body Suit“

ARMAR-5: Wearable Humanoid (since 2015)

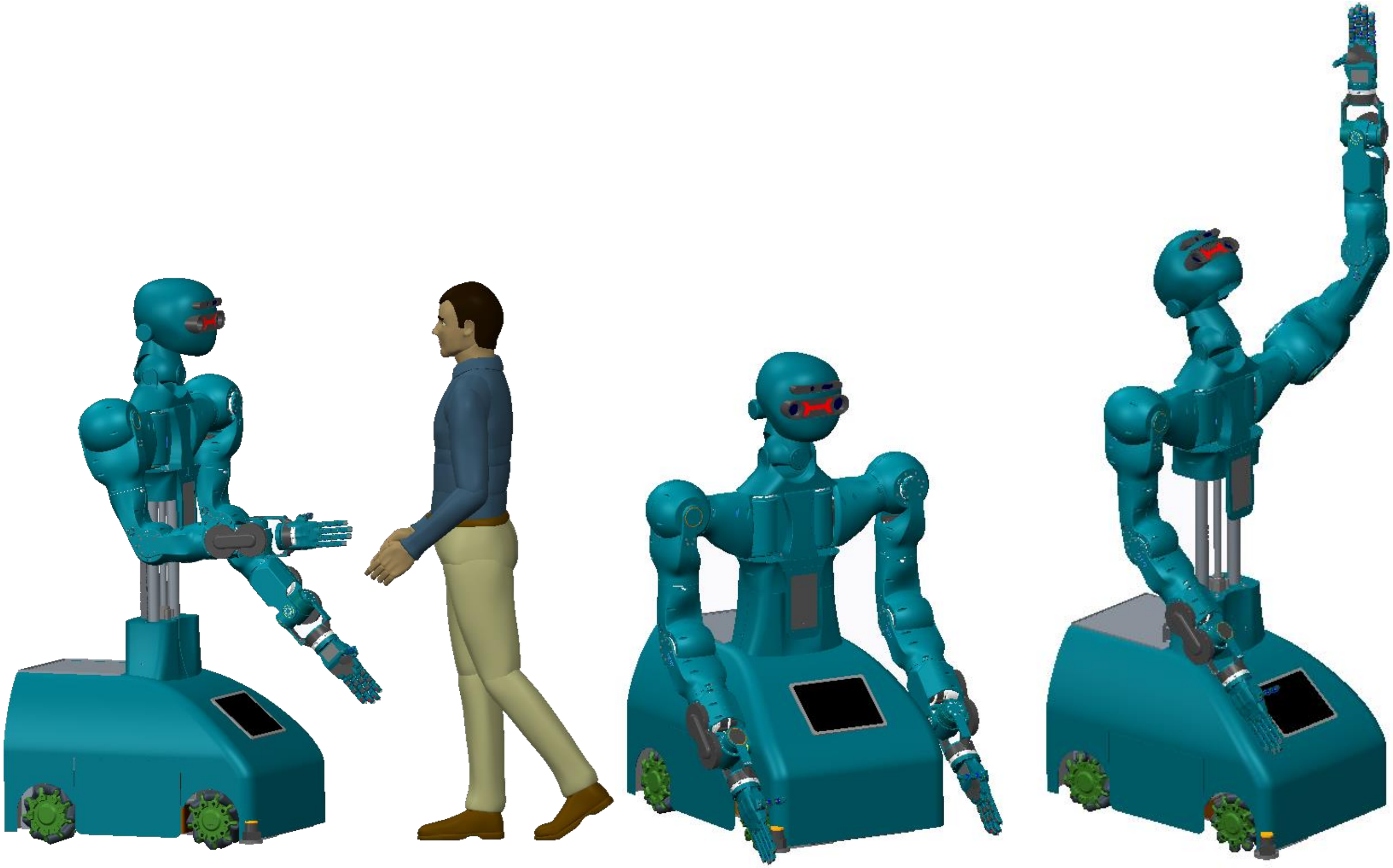


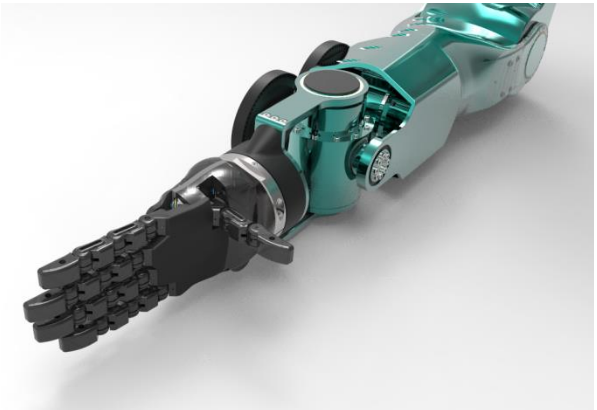
- Maximal „axial“ force 2900 N
- Force at nominal motor torque 930 N
- Speed 300 mm/sec

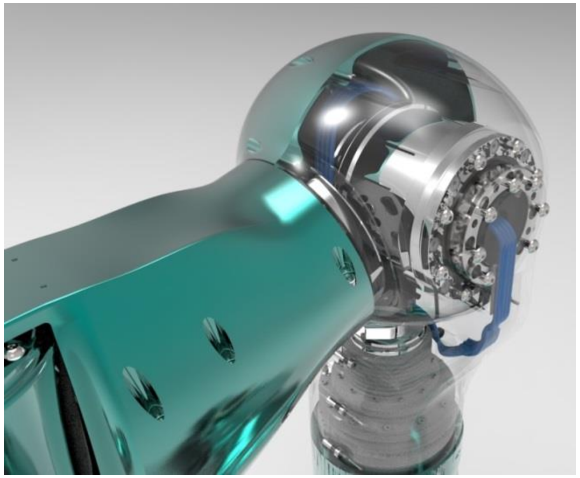




ARMAR-6-SH (2017)



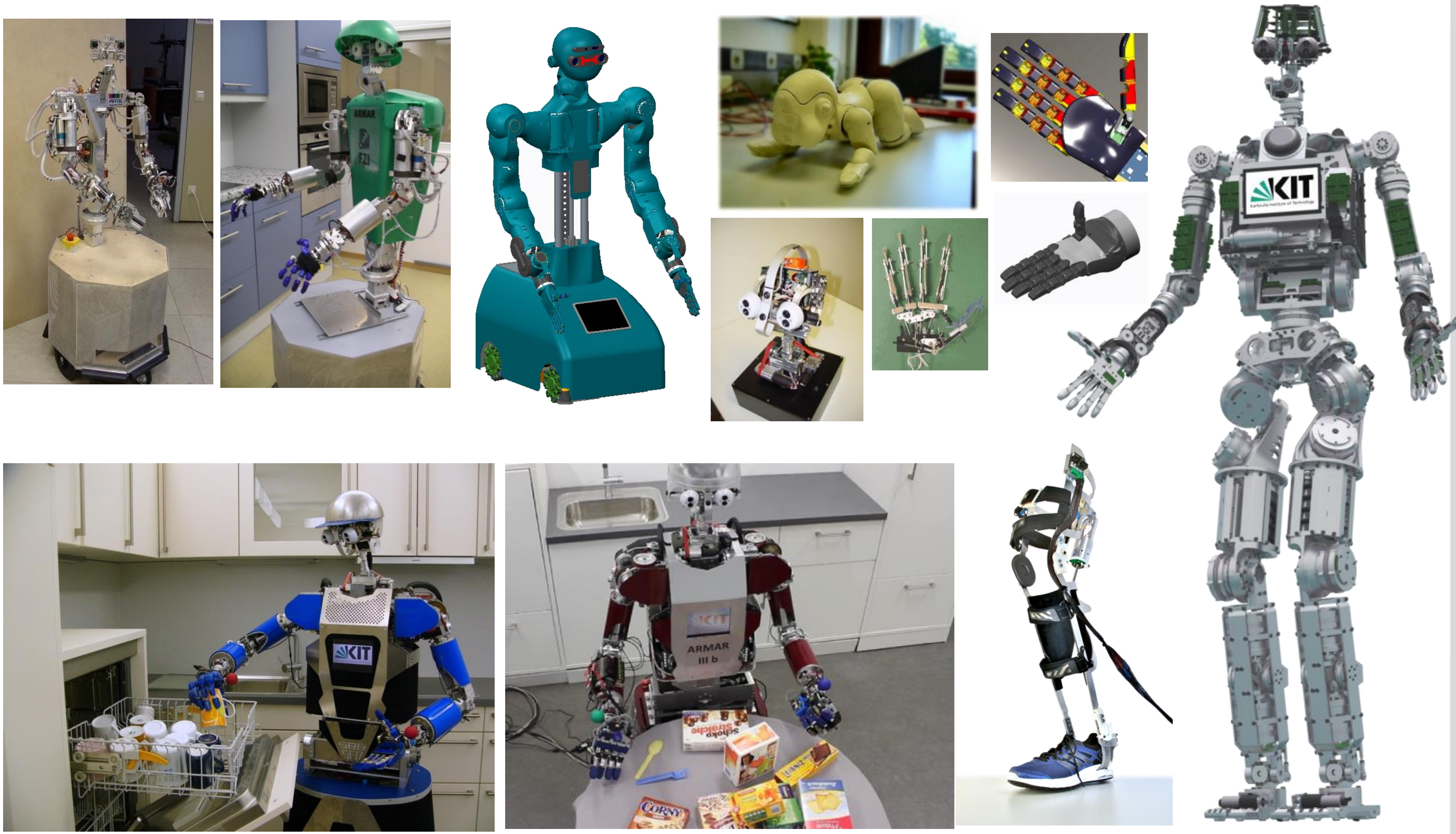
ARMAR-6-SH (2017)





The ARMAR robot family

Karlsruhe Institute of Technology



Humanoids in the real world

- Engineering Humanoids
- Grasping and manipulation
- Learning for human observation
- Natural Interaction and communication

© SFB 588

ARMAR-III in the RoboKITchen

45 minutes task, more than 2200 times since February 3, 2008

ARMAR-III in the RoboKITchen

Implemented robot skills

- Vision-based Object recognition and localization
- Vision-based grasping
- Vision-based self-localisation
- Grasp and motion planning
- Hybrid position/force control
- Combining force and vision for opening and closing door tasks
- Collision-free navigation
- Multimodal human-robot dialogs
- Continuous speech recognition
- Learning new objects, persons and words
- Audio-visual tracking and localization
- …

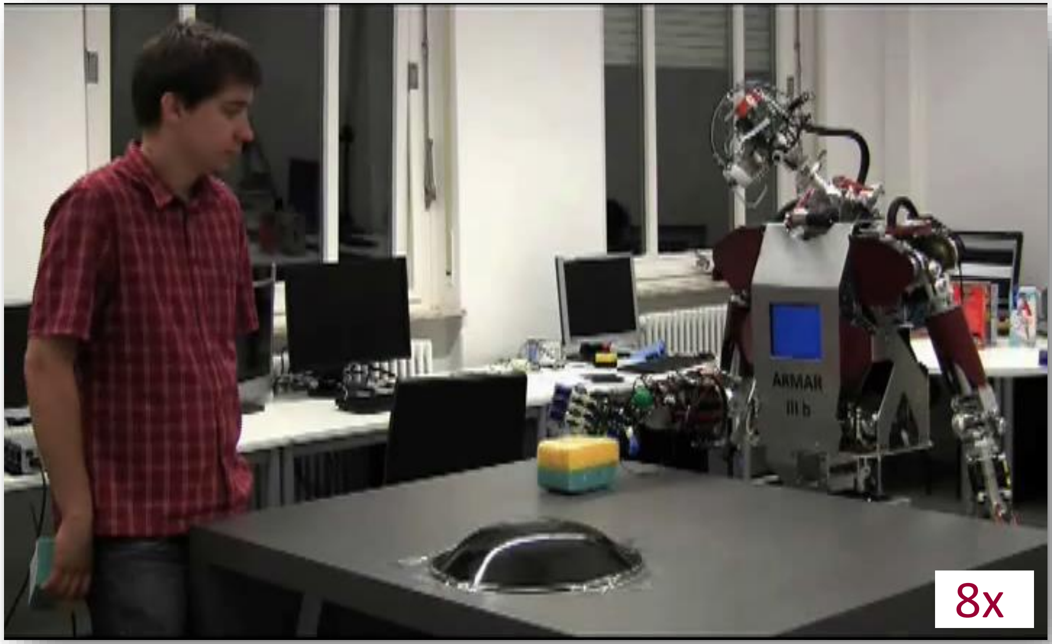
Humanoids in the real world

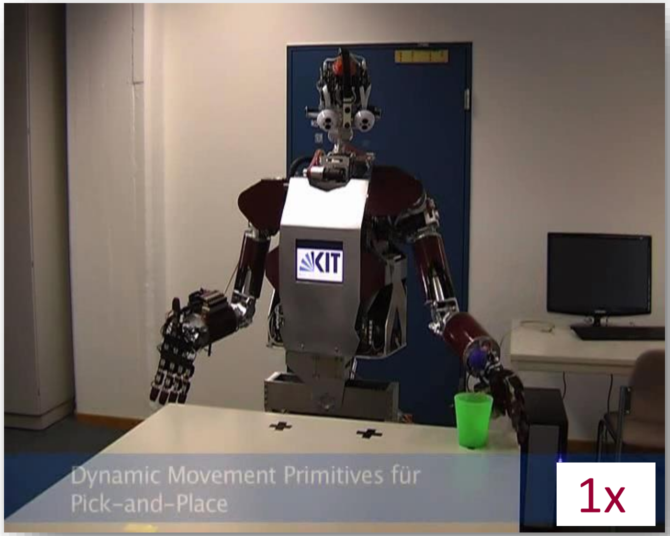
- Engineering Humanoids
- Grasping and manipulation
- Learning for human observation
- Natural Interaction and communication

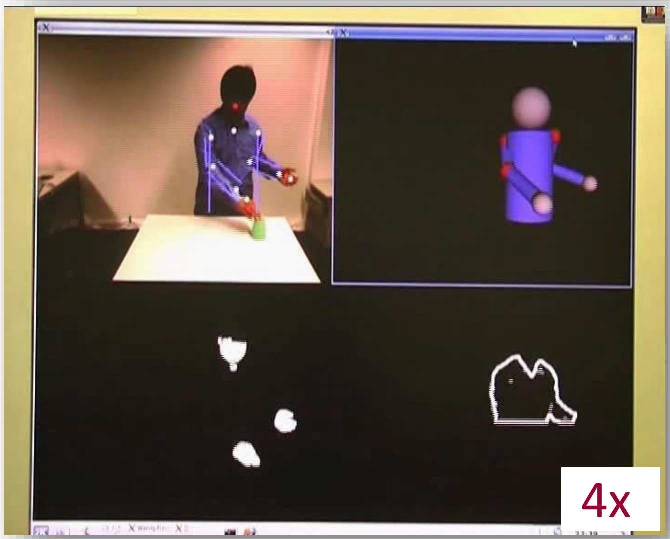
© SFB 588

Learning from observation

- Library of motion primitives (motion alphabet)
- Tasks as sequences of motion primitives

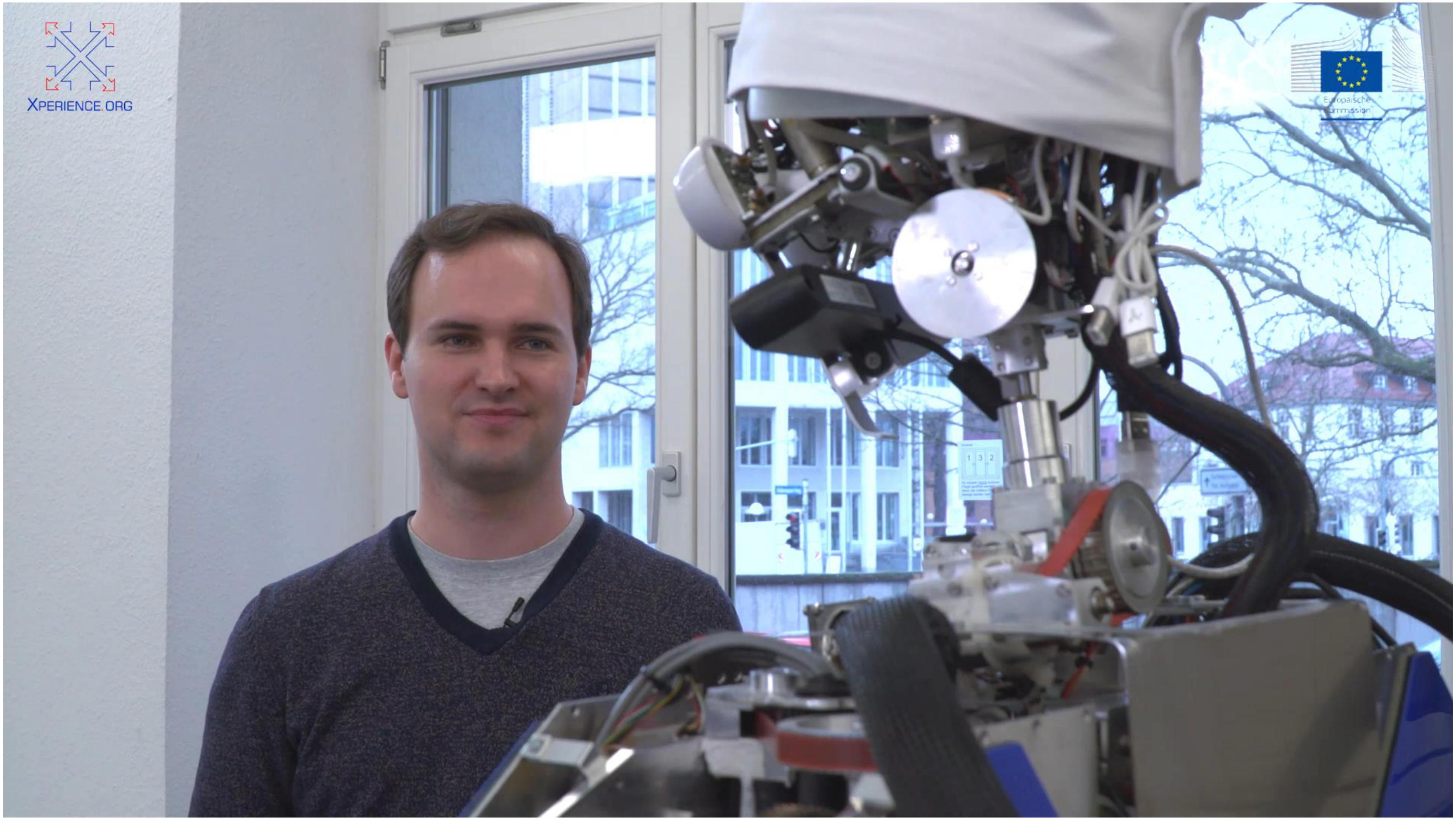






Integrating language, planning and execution with OACs

ARMAR, please help me to prepare dinner for two people

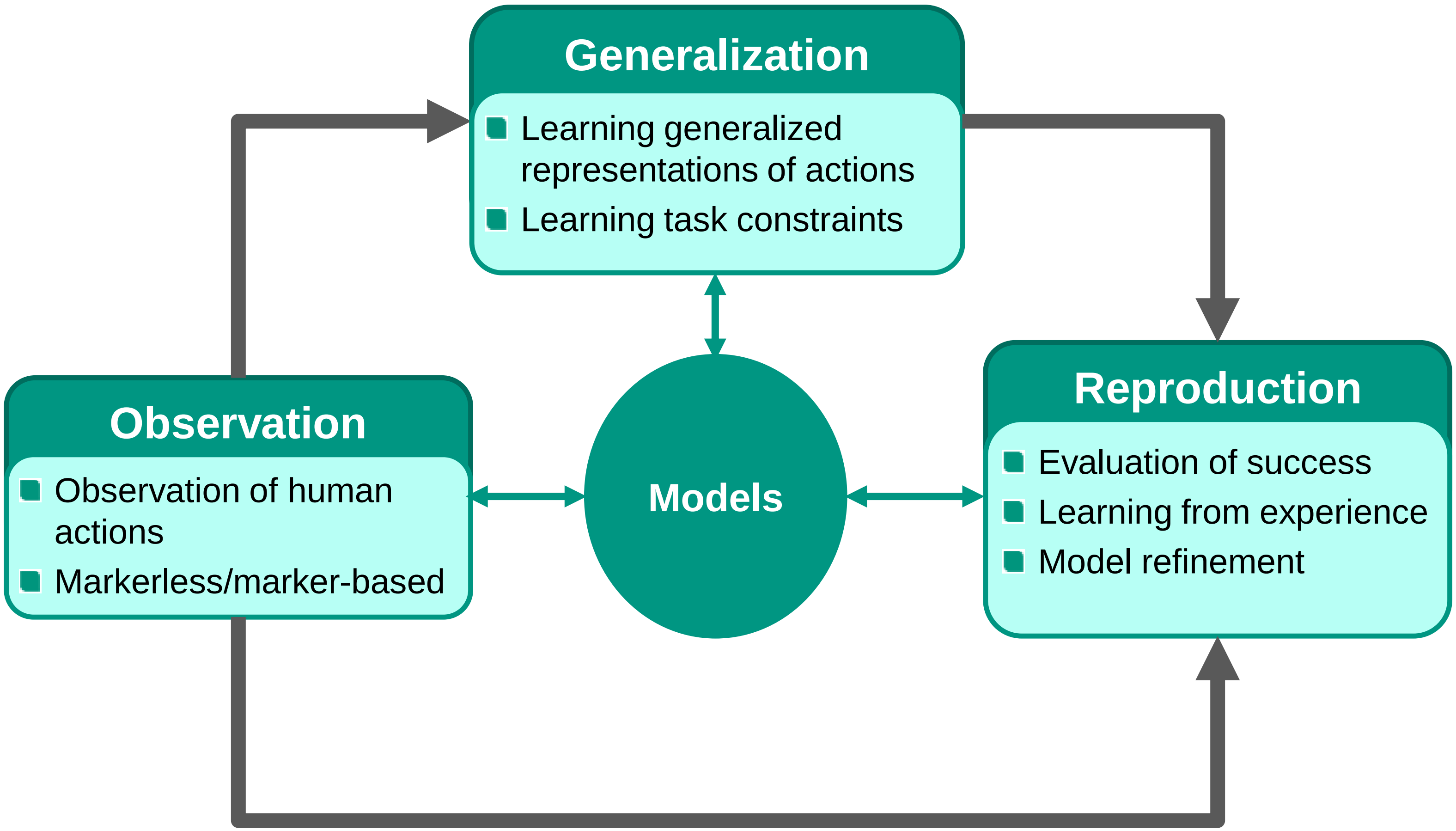


Integrating language, planning and execution with OACs

Implemented robot skills

- Complete robot architecture integrating low-level (control), mid-level (memory system) and high-level components (language, planning and reasoning)
- Learning from sensorimotor experience
- Learning skills from human observation and their adaptation to new situations
- Learning object affordances
- Resuable skills and sequences of skills implemented in hierarchical statecharts
- Automatic generation of domain descriptions for planning
- Reasoning about missing entities in plans and their replacement based on
  - Experience
  - Human feedback
  - Commonsense knowledge extracted from text corpora (text mining)
- Plan execution and monitoring based on sensory feedback
- Bimanual grasping and manipulation
- …

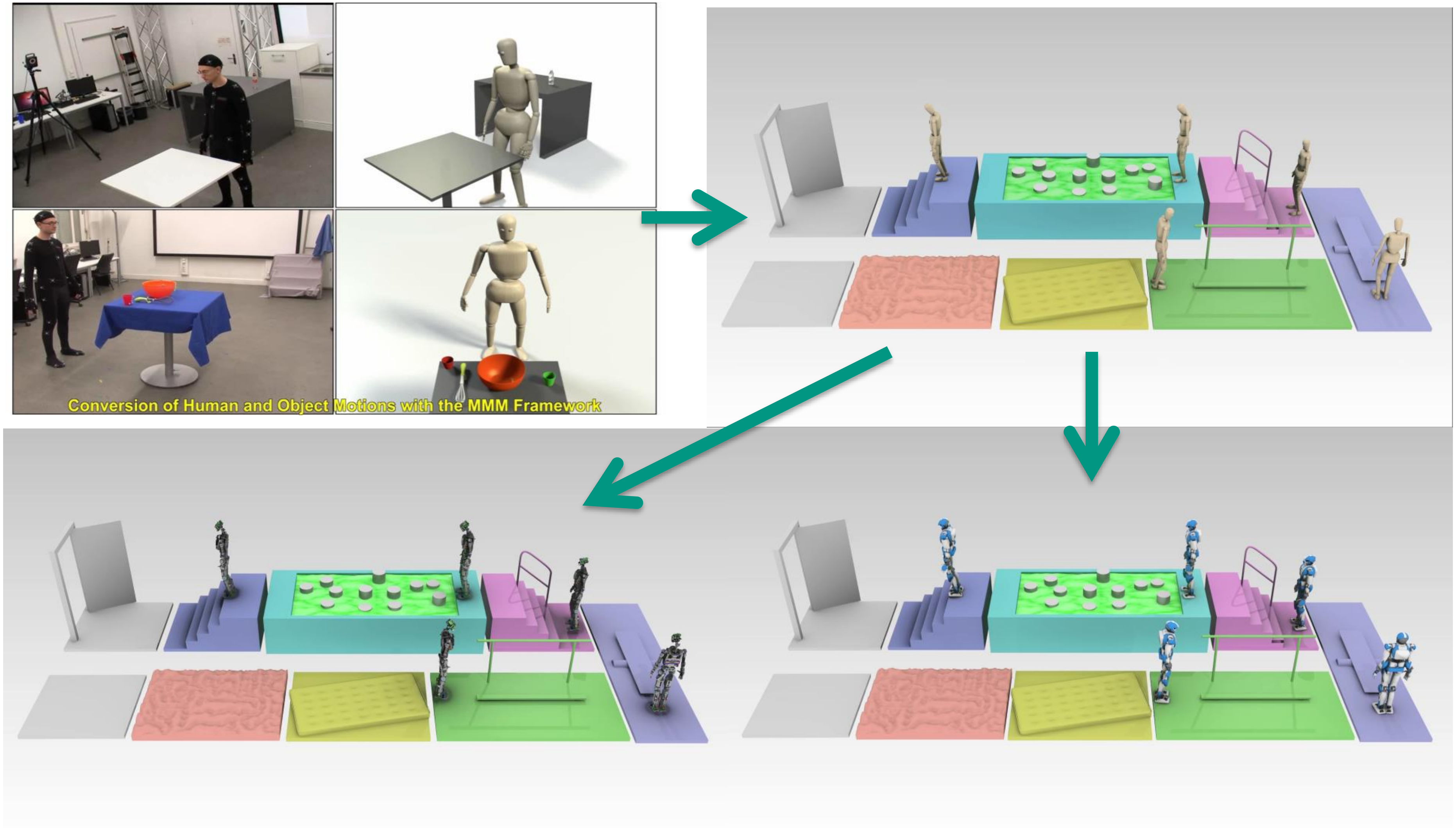
Learning from human observation



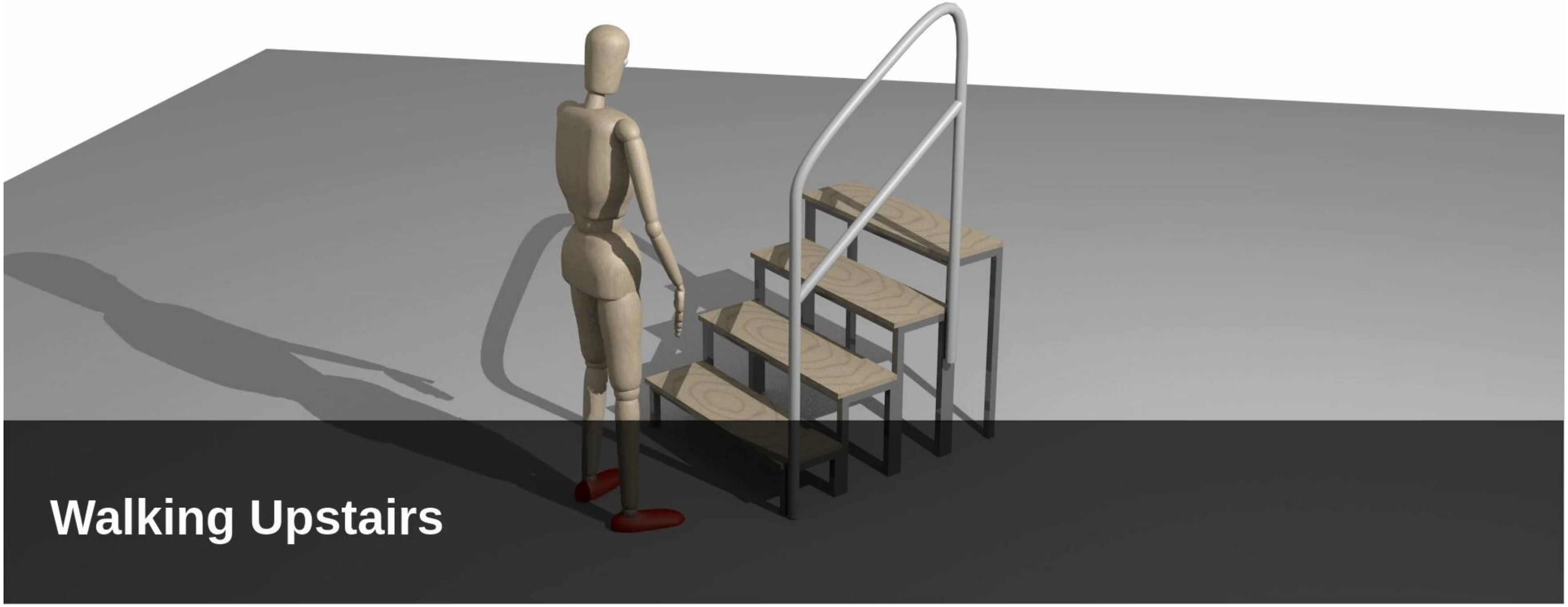
KIT whole-body human motion database

https://motion-database.humanoids.kit.edu/

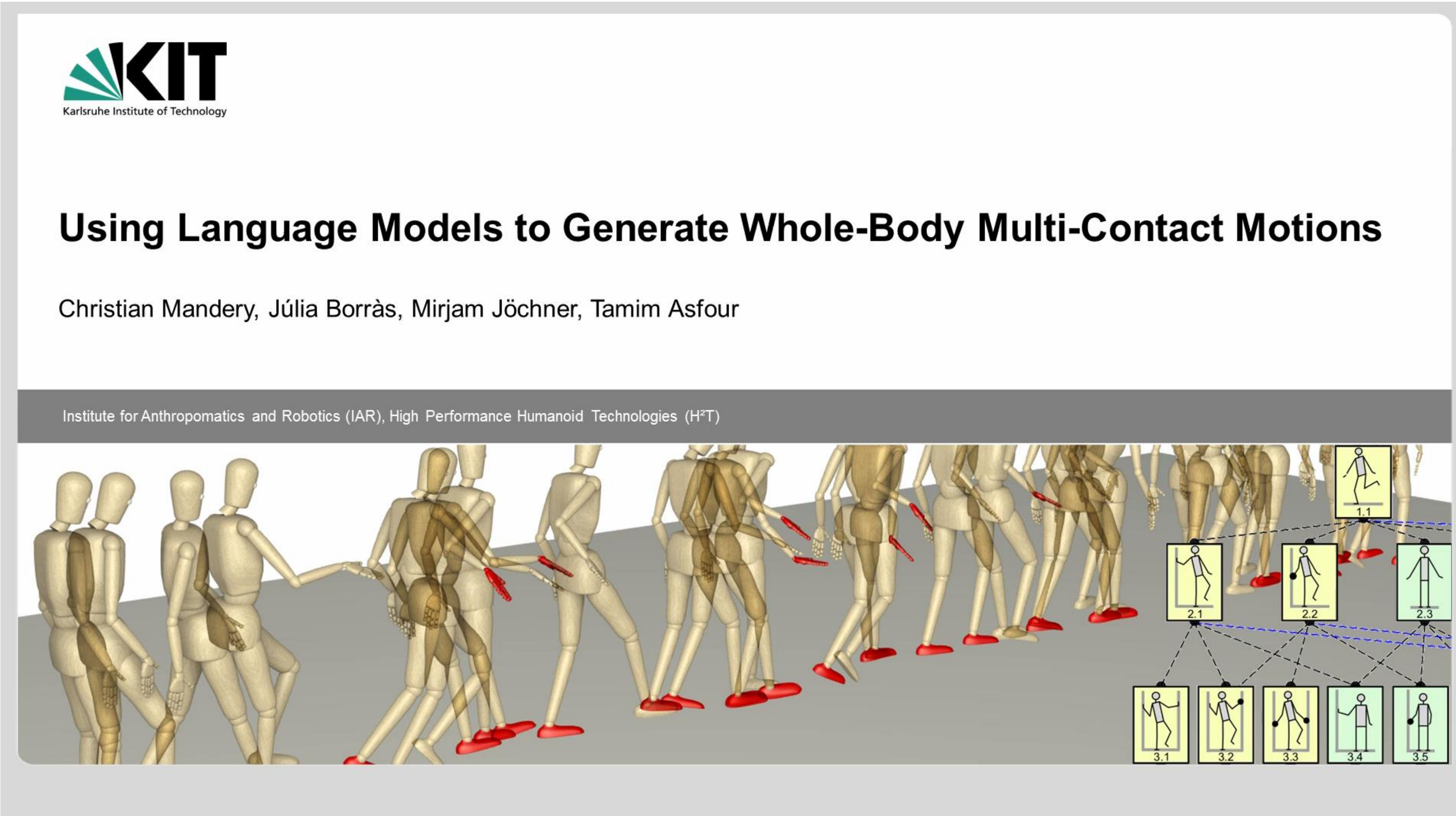
The KIT whole-body human motion database



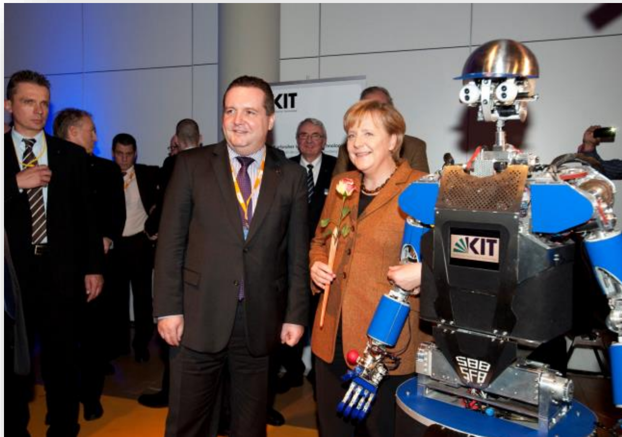
Semantic of human actions

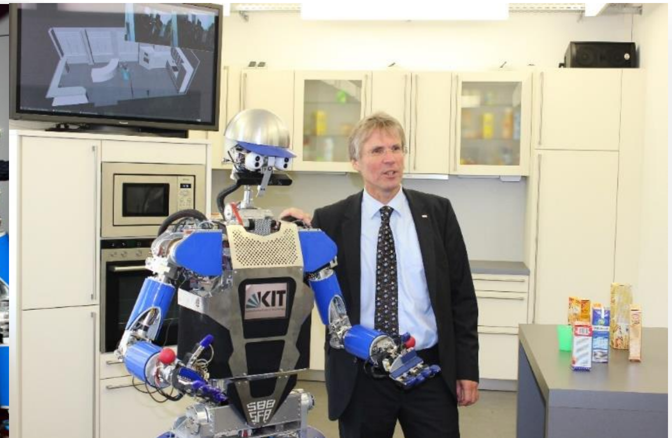


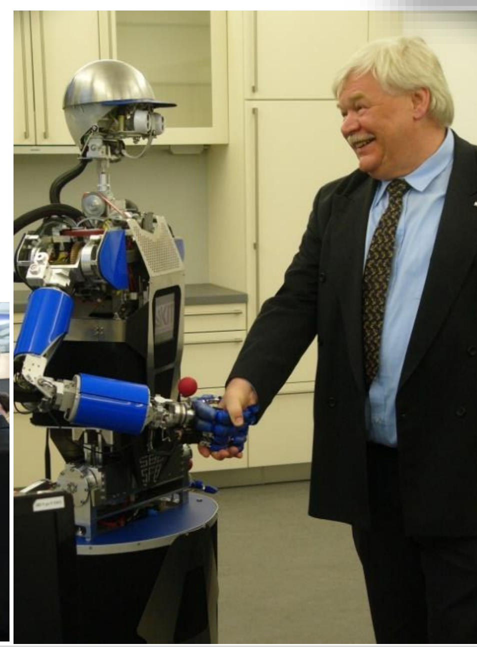
Machine learning for data-driven motion generation



ARMAR with Leaders







Outline of the lecture

- Introduction
  - Motivation
- Building humanoid robots
  - History of humanoid robotics
  - Biomechanical models of the human body
  - Mechatronics of humanoid robots
- Grasping
  - Grasping in humans
  - Grasping taxonomies
  - Grasp planning for single and dual-hand tasks
- Active Perception
  - Active vision and active touch
  - Visuo-haptic exploration
- Imitation-learning: Observation, representation and reproduction
  - Acquisition and analysis of human motion
  - Action representations: DMPs, HMMs, Splines
  - Mapping and motion reproduction
- From Signals to Symbols
  - From features to objects and from motions to actions
  - Object-Action Complexes: Semantic sensorimotor categories

Further information

- Humanoids@ KIT
  http://www.humanoids.kit.edu
- IEEE Robotics and Automation Society
  http://www.ieee-ras.org
- IEEE RAS Technical Committee on Humanoid Robotics
  http://www.humanoid-robotics.org/
- Deutsche Gesellschaft für Robotik (DGR)
  http://www.robotik-deutschland.de
- interACT
  http://www.informatik.kit.edu/interact.php

Nonlinear Model Predictive Control – Theory and Applications

Description

This elective Master course (4ECTS, 2+1 SWS) provides an **introduction to the theory and application of Nonlinear Model Predictive Control** (NMPC). It covers theoretical aspects as well as implementation-related topics. A **major focus** is put on **enabling students to implement efficient NMPC strategies using MATLAB**. The course welcomes students from Computer Science, Electrical Engineering and Mechanical Engineering.

Dates

The course is held on Mondays, starting April 24th, ending July 24th.

- Monday : 9:45- 11:15; G 50.34, R -107
- Monday : 11:30-13:00; G 50.34, R -107

Contact and Further Information

Dr.-Ing. Timm Faulwasser

Office: Institut für Angewandte Informatik, R 259, G 449, Campus Nord, KIT

E-Mail: timm.faulwasser@kit.edu

Phone: 0721 608 - 26 494

WWW: www.iai.kit.edu/control

Yet another course on control engineering?

Why Model Predictive Control?

Model Predictive Control (MPC) "[…] *is the only advanced control technique—that is, more ad-vanced than standard PID control—to have had a significant and widespread impact on industrial process control."*

J. Maciejowski (Univ. Cambrige, UK). *Predictive control: with constraints*. Pearson Ed. Limited, 2002

Industrial applications of MPC include