Karlsruher Institut für Technologie

Hochperformante Humanoide Technologien

Robotics II: Humanoid Robotics
Chapter 1 – Introduction

Tamim Asfour

http://www.humanoids.kit.edu





Organization

Lecture Team

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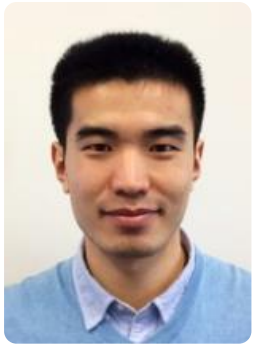

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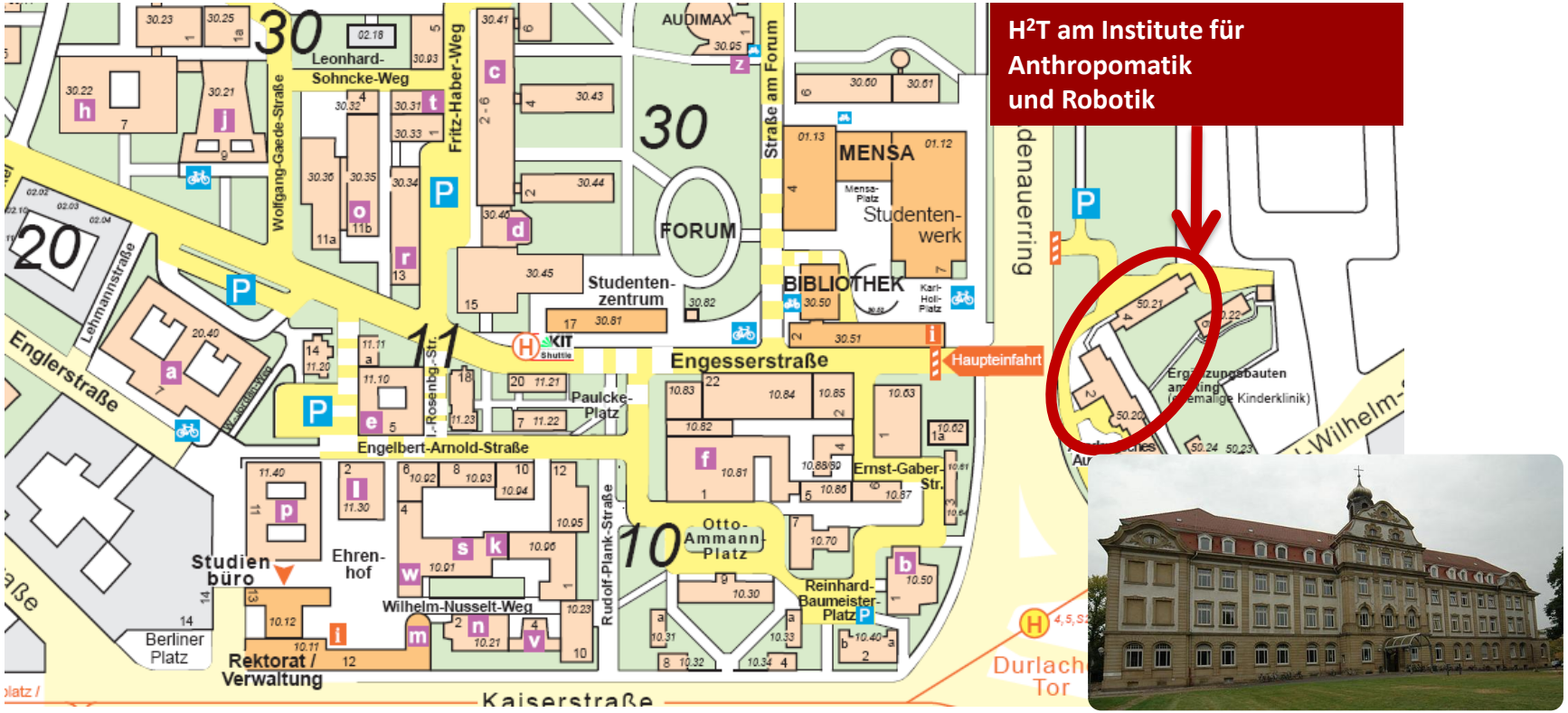
H²T: Geb. 50.20


H²T am Institute für Anthropomatik und Robotik
Haupteinfahrt
Engesserstraße
Engelbert-Arnold-Straße
Englerstraße
Lehmannstraße
Wolfgang-Gaede-Straße
Leonhard-Sohncke-Weg
Fritz-Haber-Weg
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Studien büro
Ehren-hof
Rektorat / Verwaltung
Berliner Platz
Durlach Tor
Kaiserstraße
Adenauerring
KIT Shuttle

Office hours

- Tamim Asfour
  - Wednesday 14:00 – 16:00
    appointment via email asfour@kit.edu

- Other office hours: See H²T Website
  - www.humanoids.kit.edu
  - www.humanoids.de

Lecture-related information (I)

- KIT **ILIAS-Portal:** https://ilias.studium.kit.edu
  - Password for ILIAS: **armar@kit**
  - Lecture slides will be available after each lecture
  - Announcements will be sent via email to participants of this course

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

Lecture-Related Information – Previous Recordings

- Previous recordings of the lecture are available:
  - SS 2020
    - YouTube: https://www.youtube.com/playlist?list=PLLfZgQJNfLgMGD09nVKRjyHnZKp4N5aSq
  - SS 2019
    - YouTube: https://www.youtube.com/playlist?list=PLfk0Dfh13pBNEbbUlMRPe2aVFUm6WBp9B
    - iTunes: https://podcasts.apple.com/de/podcast/robotik-2-humanoide-robotik-ss19/id1462755128
    - DIVA: https://mediaservice.bibliothek.kit.edu/#/details/DIVA-2019-C24/1
- Check the following link for a complete list of all KIT public lectures http://www.zml.kit.edu/veroeffentlichte_vorlesungen.php

Dates of the Exams at H²T – SS 2023

Exam	Date	Time	Deadline for registration
Robotics I: Introduction to Robotics	**July 12, 2023**	17:30 – 18:30	July 5, 2023
Mechano-Informatics and Robotics	**July 19, 2023**	17:30 – 18:30	July 12, 2023
Human Brain and Central Nervous System	**August 9, 2023**	13:00 – 14:00	August 2, 2023
Robotics II: Humanoid Robotics	**September 1, 2023**	15:00 – 16:00	August 25, 2023
Wearable Robotic Technologies	**September 7, 2023**	15:00 – 16:00	August 31, 2023
Robotics III: Sensors and Perception in Robotics	**September 19, 2023**	14:30 – 15:30	September 12, 2023

Lecture-related information and exam

- Credit points: 3 ECTS

- Exam in SS 2023
  - **Written exam in English (schriftlich)**
  - Date: **September 1, 2023; 15:00 – 16:00**
  - Registration: **Campus-System,** https://campus.studium.kit.edu
  - Last registration date: **August 25, 2023**

- Exam in WS 23/24 (Date will be announced later)

- All information regarding lectures and exams will also be published on our homepage: http://humanoids.kit.edu/

Teaching @ H2T

Karlsruher Institut für Technologie

WS
SS
WS & SS

Robotics I – Introduction to Robotics
Stammmodul (6 ECTS)

Lectures

- Mechano-Informatics and Robotics (4 ECTS)
- **Robotics II: Humanoid Robotics (3 ECTS)**
- Wearable Robotic Technologies (4 ECTS)
- Robotics III – Sensors and Perception in Robotics (3 ECTS)
- Advanced Artificial Intelligence (6 ECTS)

Practical Courses

- Lego Mindstorms (3 ECTS)
- Humanoid Robots (3 ECTS)
- Robotics (6 ECTS)
- Mobile Robots (4 ECTS)

Seminars

- Humanoid Robots (3 ECTS)
- Neural Networks (3 ECTS)
- Motion in Human and Machine (3 ECTS)

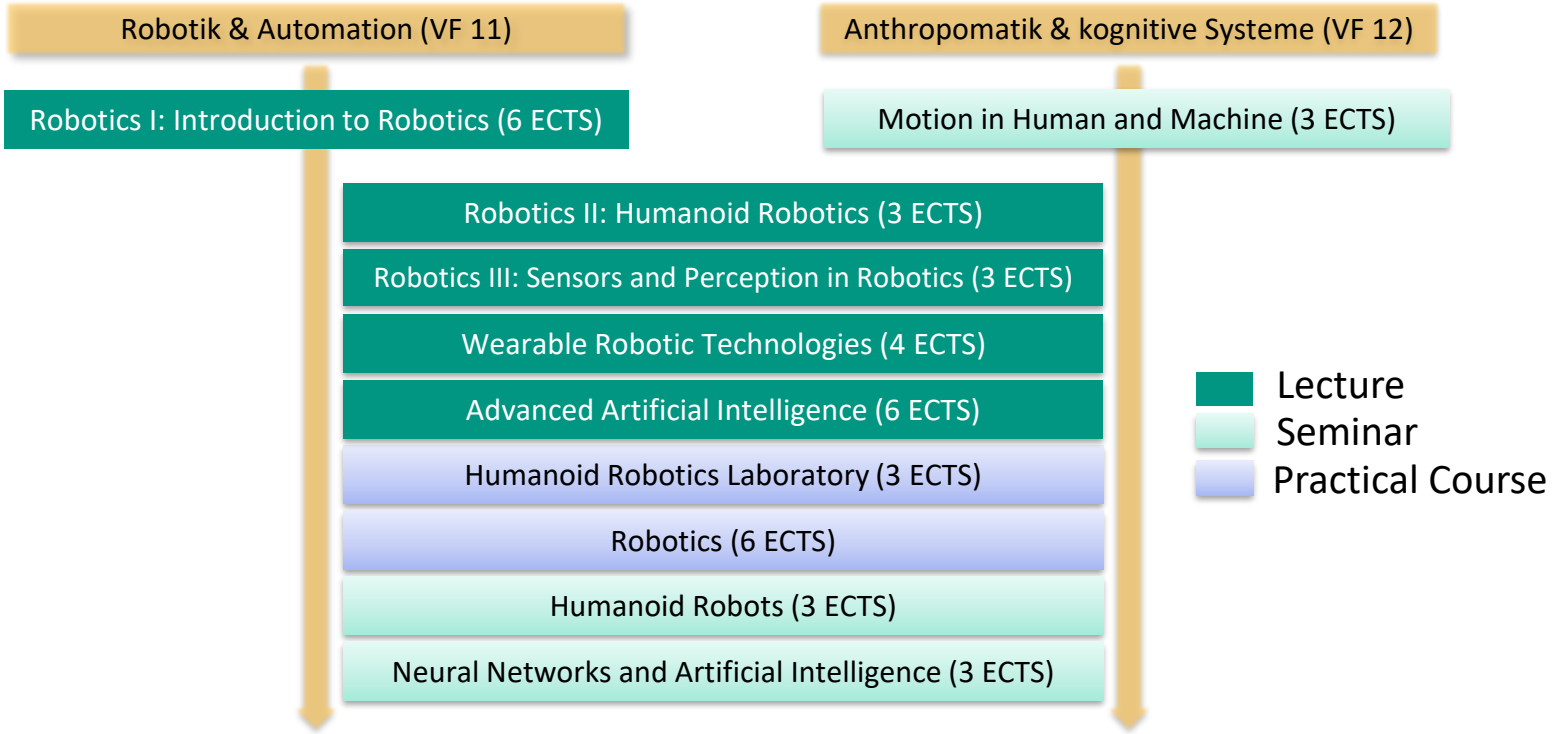
Praxis der Softwareentwicklung (6+2 ECTS)

Praxis der Forschung (24 ECTS)

Pupil (Robotik AG, BOGY, Hector Seminar)

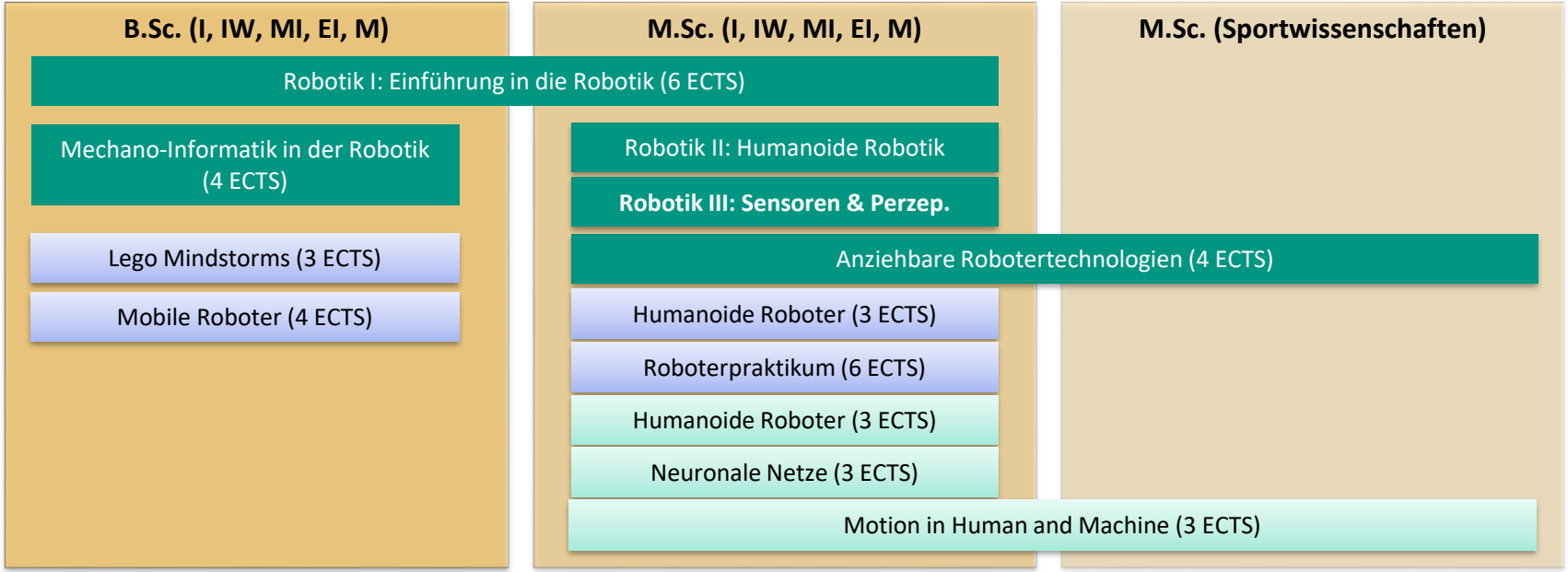
H2T

Teaching @ H2T – Specialization Subjects (Informatics)



Teaching @ H2T

Vorlesung
Seminar
Praktikum



I = Informatik (* = gilt **nur** für Informatik)
IW = Informationswirtschaft
MI = Mechatronik & Informationstechnik
EI = Elektrotechnik & Informationstechnik
M = Maschinenbau

This lecture: Robotics II – Humanoid Robotics

- The lecture focuses on humanoid robots as embodied AI and cognitive systems, not on the mechatronics of humanoids
- 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**

Outline of Table of Content

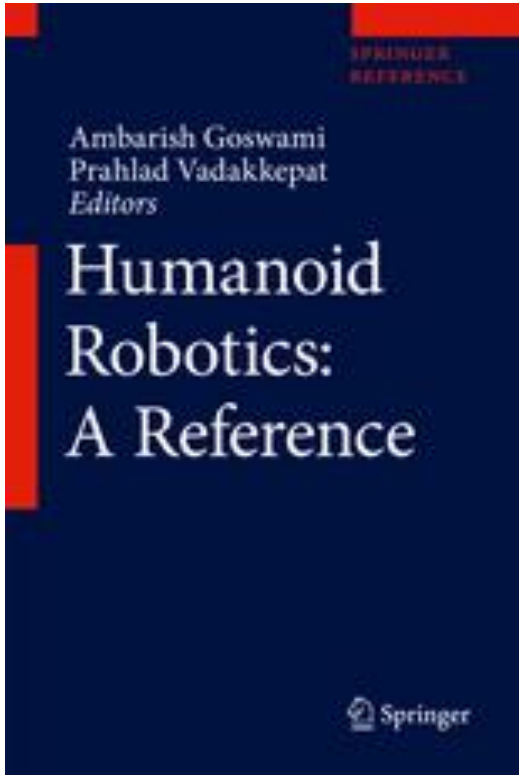
- **Introduction**
  - Why humanoids?
- **Building humanoid robots**
  - History of humanoid robotics
  - State of the art
  - Biomechanical models of the human body
  - Mechatronics of humanoid robots
- **Grasping**
  - Grasping in humans
  - Grasping taxonomies
  - Grasping familiar objects
  - Grasping unknown objects
- **Imitation learning**
  - Observation of human actions and demonstrations
  - Action representation (movement primitives)
  - Learning task models
  - Reproduction and execution
- **From Signals to Symbols**
  - From features to objects and from motions to actions
  - Object-Action Complexes: Semantic sensorimotor categories

Literature

- **Humanoid Robotics: A Reference**
  Editors: **Goswami**, Ambarish, **Vadakkepat**, Prahlad (Eds.)

- First comprehensive reference on Humanoid Robotics

- Springer Link
  https://link.springer.com/referencework/10.1007%2F978-94-007-6046-2



Outline

- Humanoids@KIT
- What is Anthropomatics?
- Why Humanoids?

Humanoids at KIT – Introduction to H^{2}T

Our Goal: Humanoids in the Real World

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

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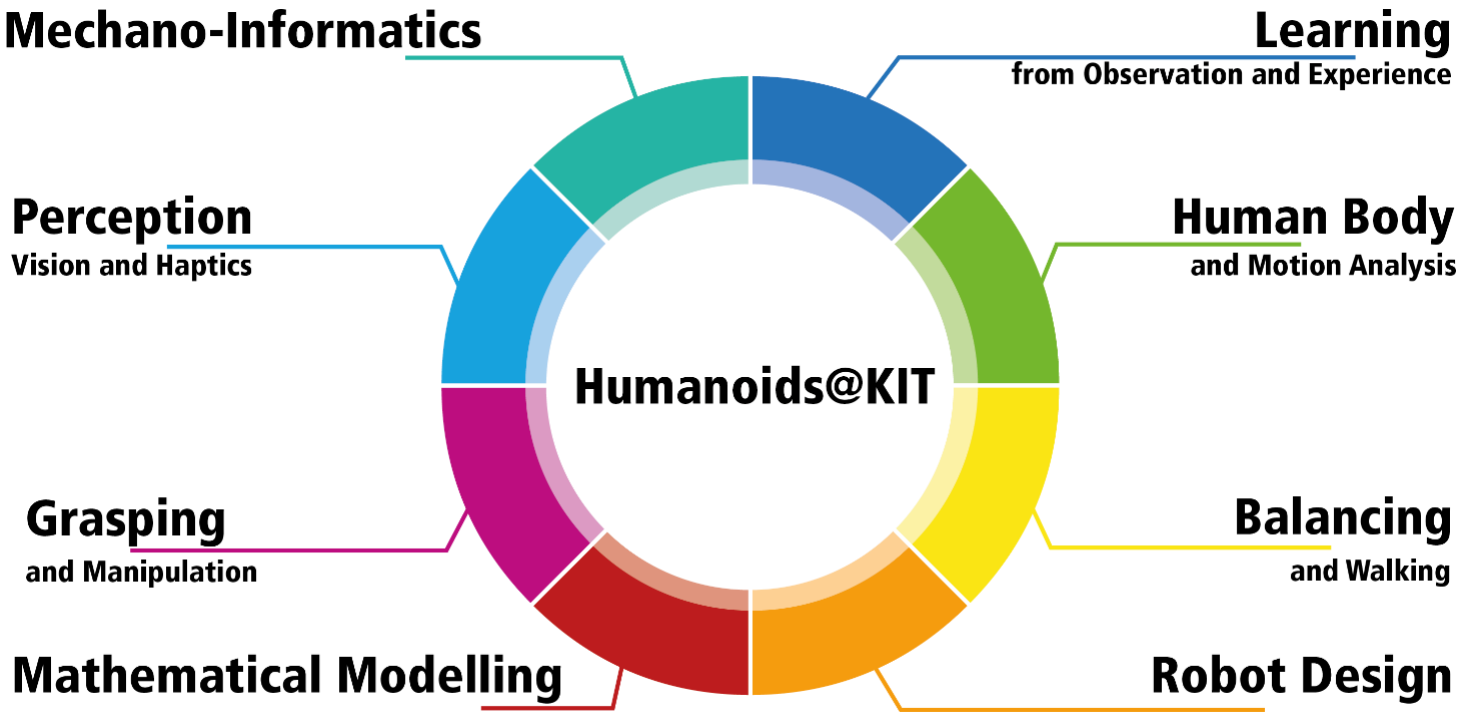
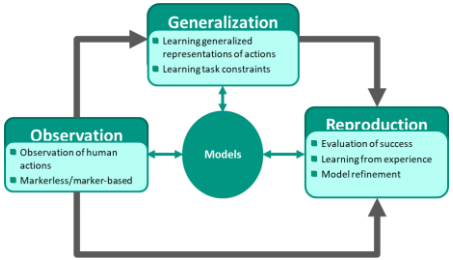
Research Topics at H²T

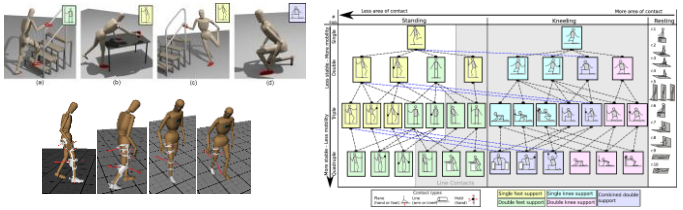


Humanoid Robotics @ KIT

Humanoid Assistance Robotics

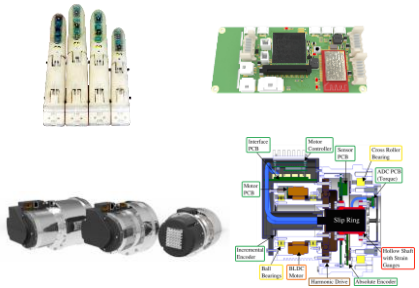


Learning from Human



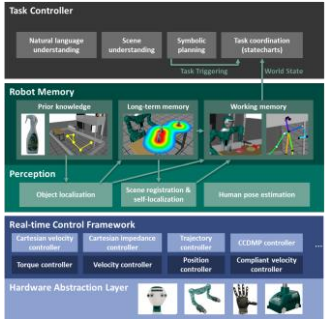
Human Motion Intelligence

Collaborative Robotics



Robotronics

Wearable Robotics



Mechano-Informatics

Our Goal: Humanoids in the Real World

- **Engineering** Humanoids
- **Grasping and manipulation**
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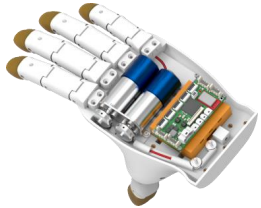
The ARMAR robot family





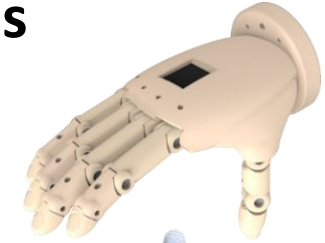




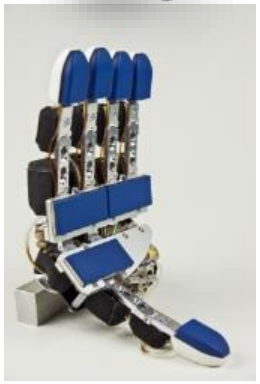



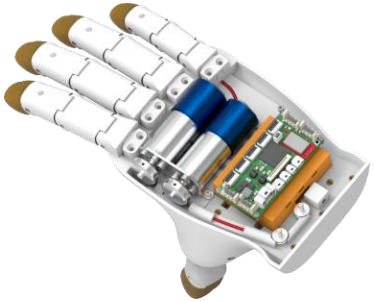
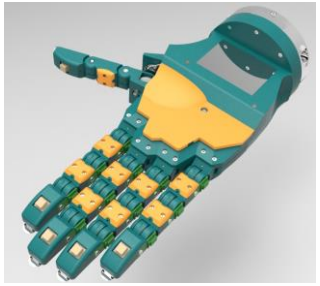

The ARMAR Family: Hands



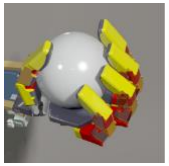
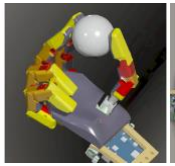
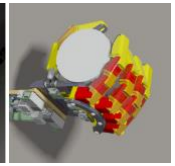




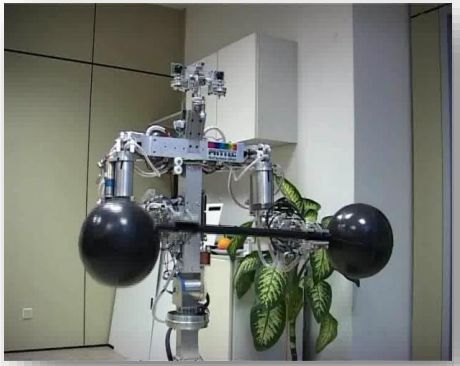




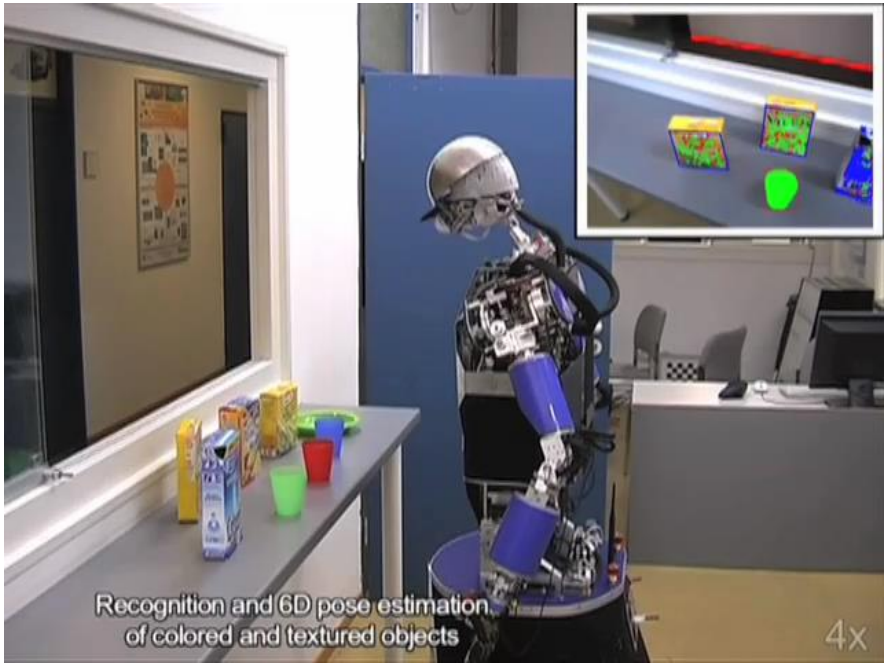

ARMAR-I (1999) and ARMAR-II (2003)



First demonstrator of the SFB 588

Demo at CEBIT 2006

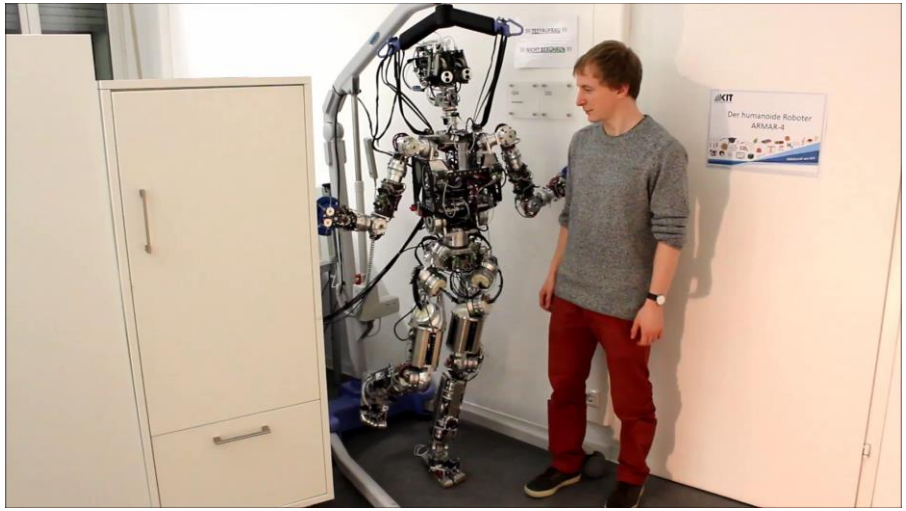
ARMAR-III (2008)



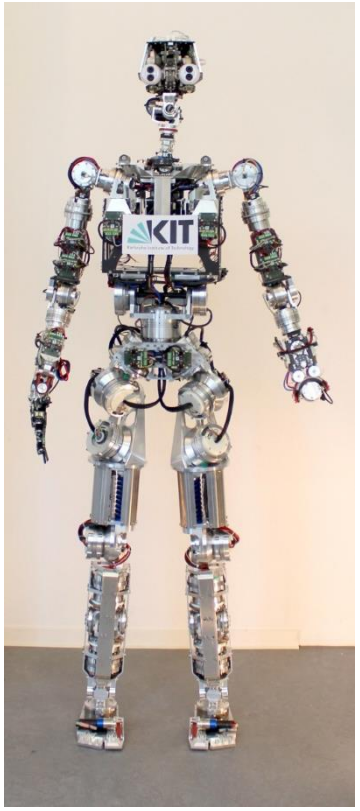
45 minutes household task, performed more than 4000 times since February 3, 2008

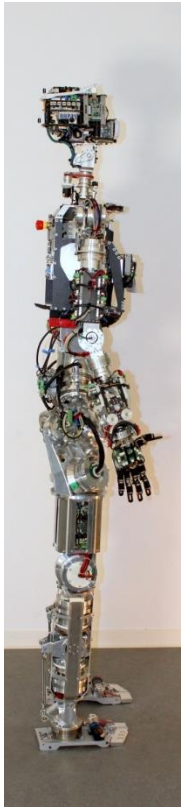
ARMAR-4 (2014)

- 63 DOF
- Torque-controlled!

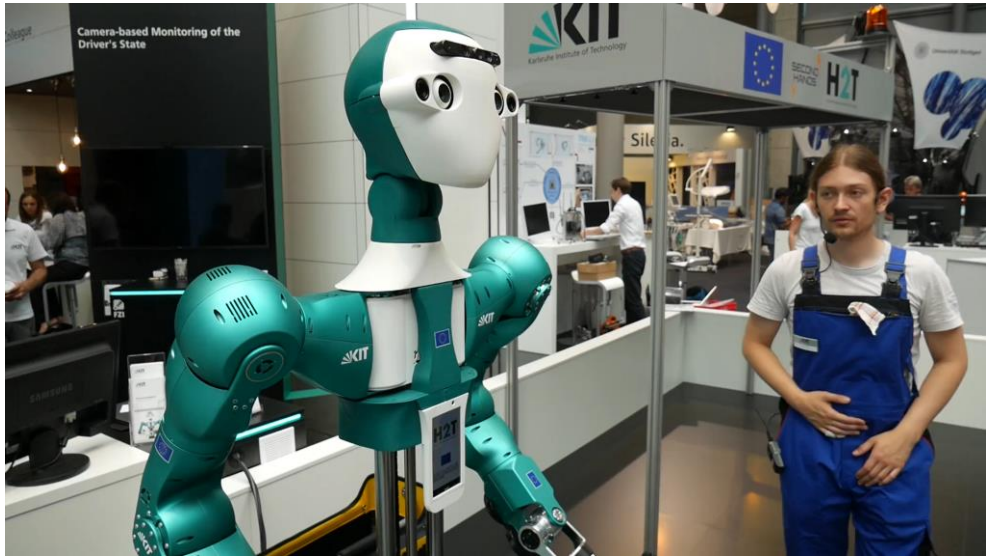


Multi-contact active compliance balancing controller





ARMAR-6 (2017)



Assistant of a human technician in maintenance and repair tasks in industrial environments

ARMAR-5: Humanoids for Human Augmentation

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

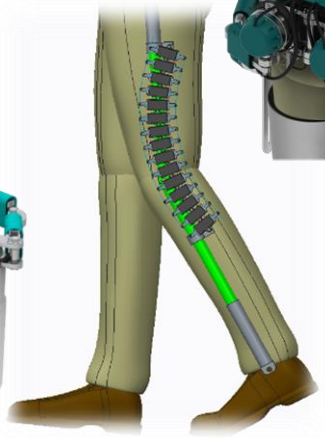
Helper, Assistant and Companion

Wearable Humanoid „Body Suit“

ARMAR-5: Wearable Humanoid (since 2015)









Humanoids in the Real World

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

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Grasping and manipulation

- **Known objects**
- Vision-based Object detection and pose estimation
- Vision-based grasping
- Vision-based self-localisation
- Grasp and motion planning
- Hybrid position/force control
- Collision-free navigation
- …

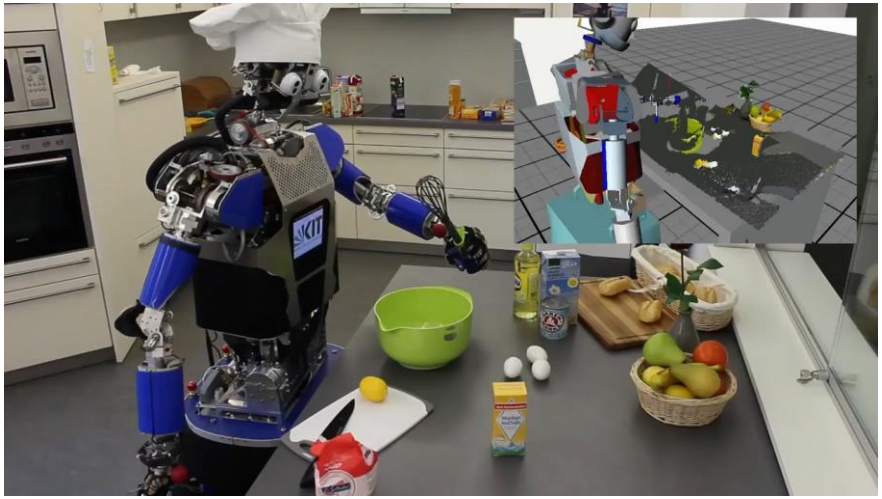
Grasping and manipulation with ARMAR-6



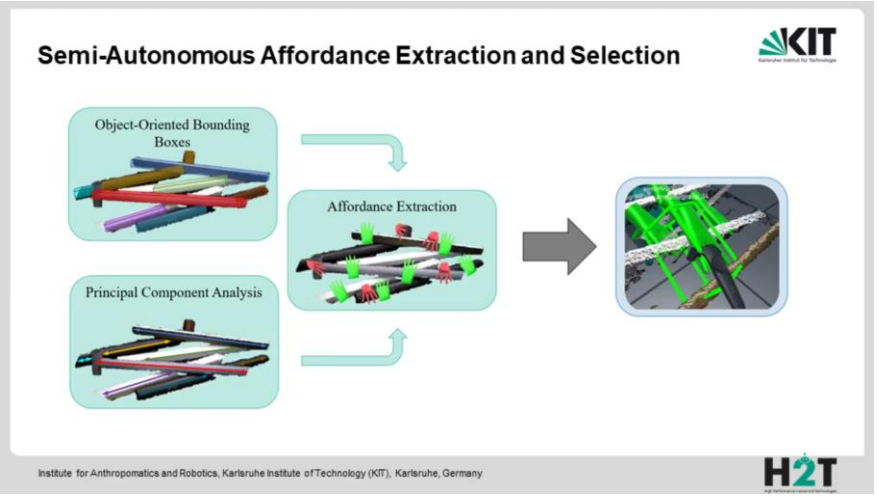
4x

- **Known and unknown objects**
- Vision-based Object detection and pose estimation
- Vision-based grasping
- Grasp and motion planning
- Self-collision avoidance
- Collision-free navigation
- …

Grasping unknown objects



Deep CNN based grasping



Affordance-based grasping

Humanoids in the Real World

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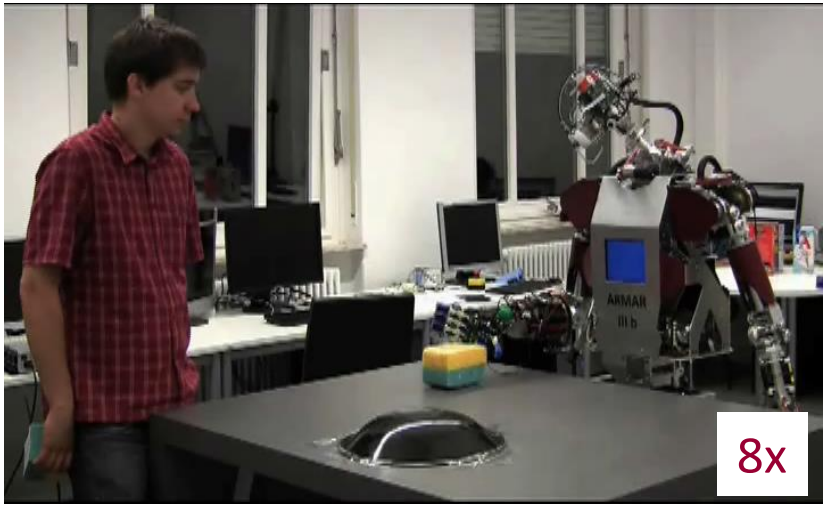
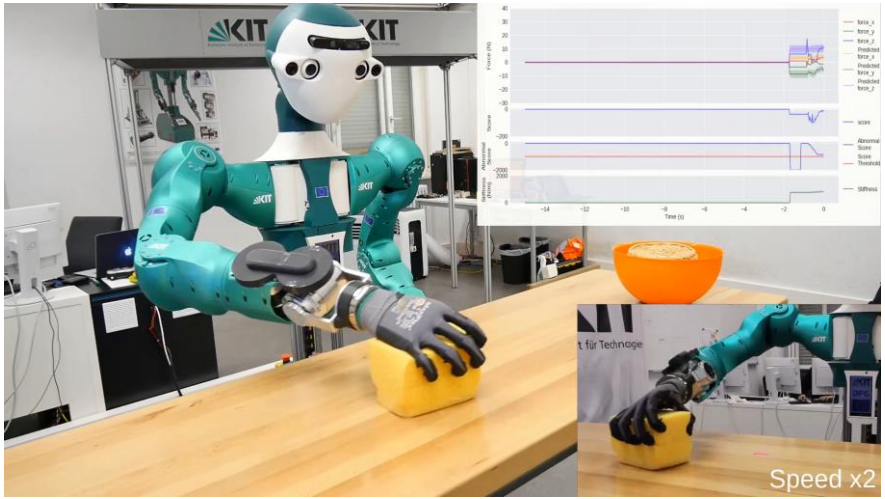
Imitation Learning

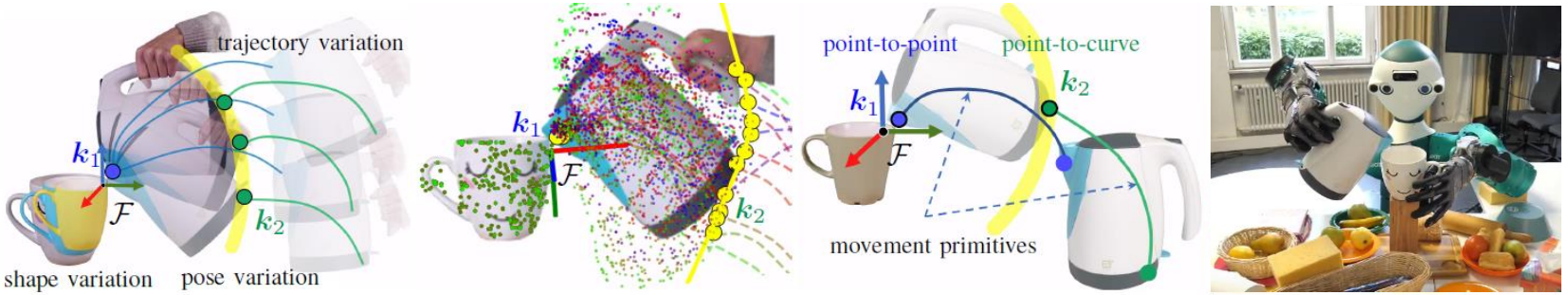
- Learning from Human Demonstration
- Library of motion primitives (motion alphabet)
- Tasks as sequences of motion primitives





Imitation Learning

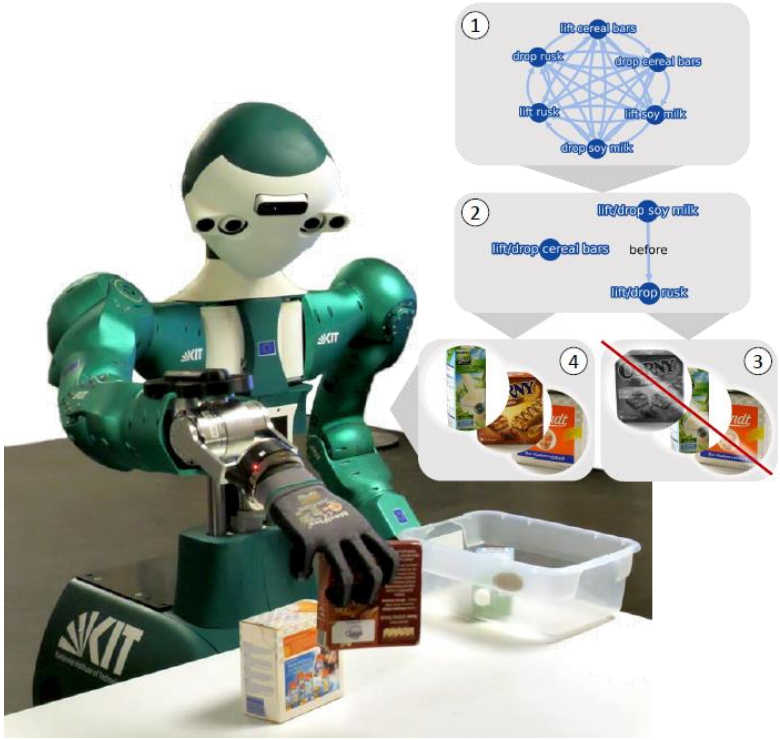
- Learning key-point based task models from human demonstration videos
- Generalization to novel scenes/objects
- Robot vision, machine learning and control



(a) Human demonstrations (b) Extraction of keypoints (c) Geometric task representation (d) Reproduction

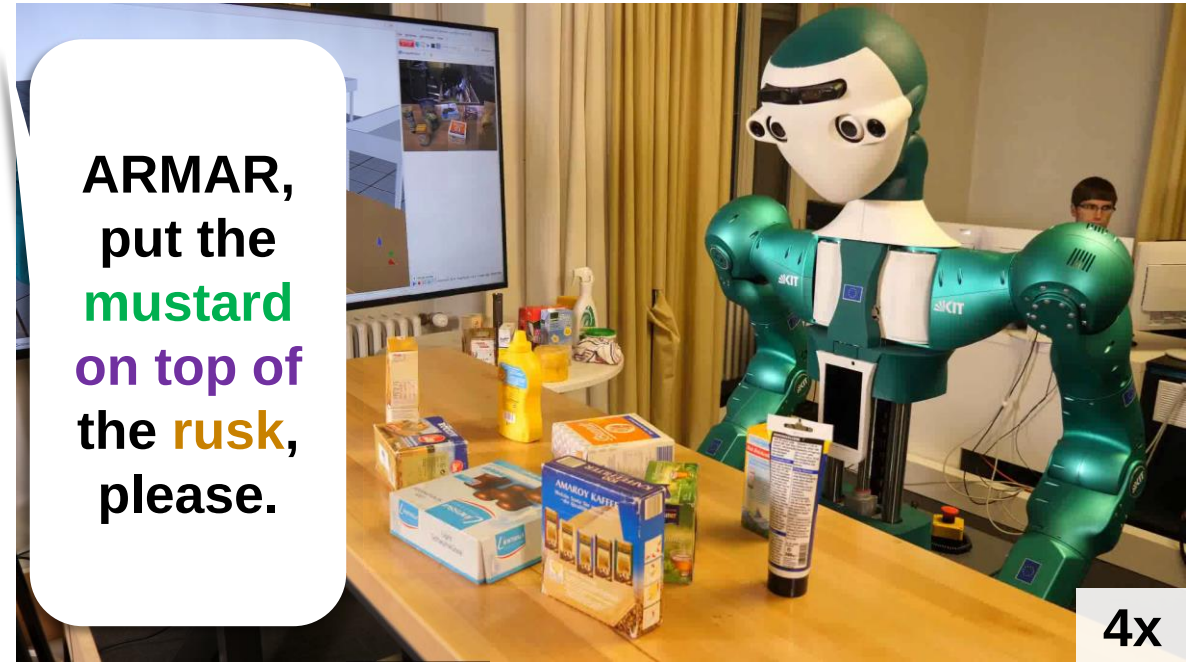
Imitation Learning

- Learning Temporal Task Models
  - Learning temporal relations between actions of a bimanual manipulation task, e.g., cutting the banana before pouring it into a bowl
  - Temporal task constraints are inferred from the temporal task models using graph-theoretical operations in a version-space-inspired approach



Interactive learning for scene manipulation

- Manipulating the scene based on verbal instructions and spatial relations
- Generative models of spatial relations are learned incrementally and interactively from human demonstrations



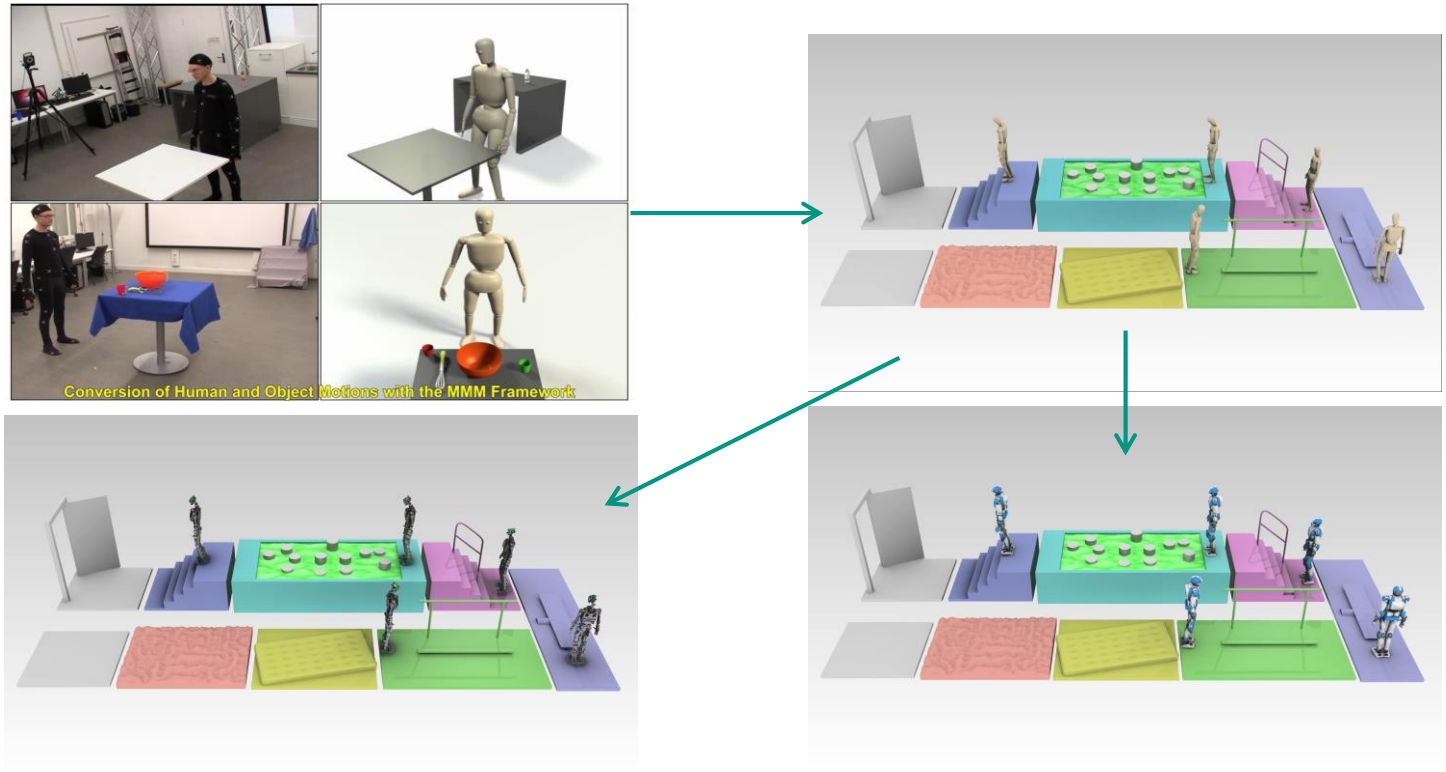
Robot Internet of Skills

- KIT whole-body human motion database: **A Robot Motion Alphabet**

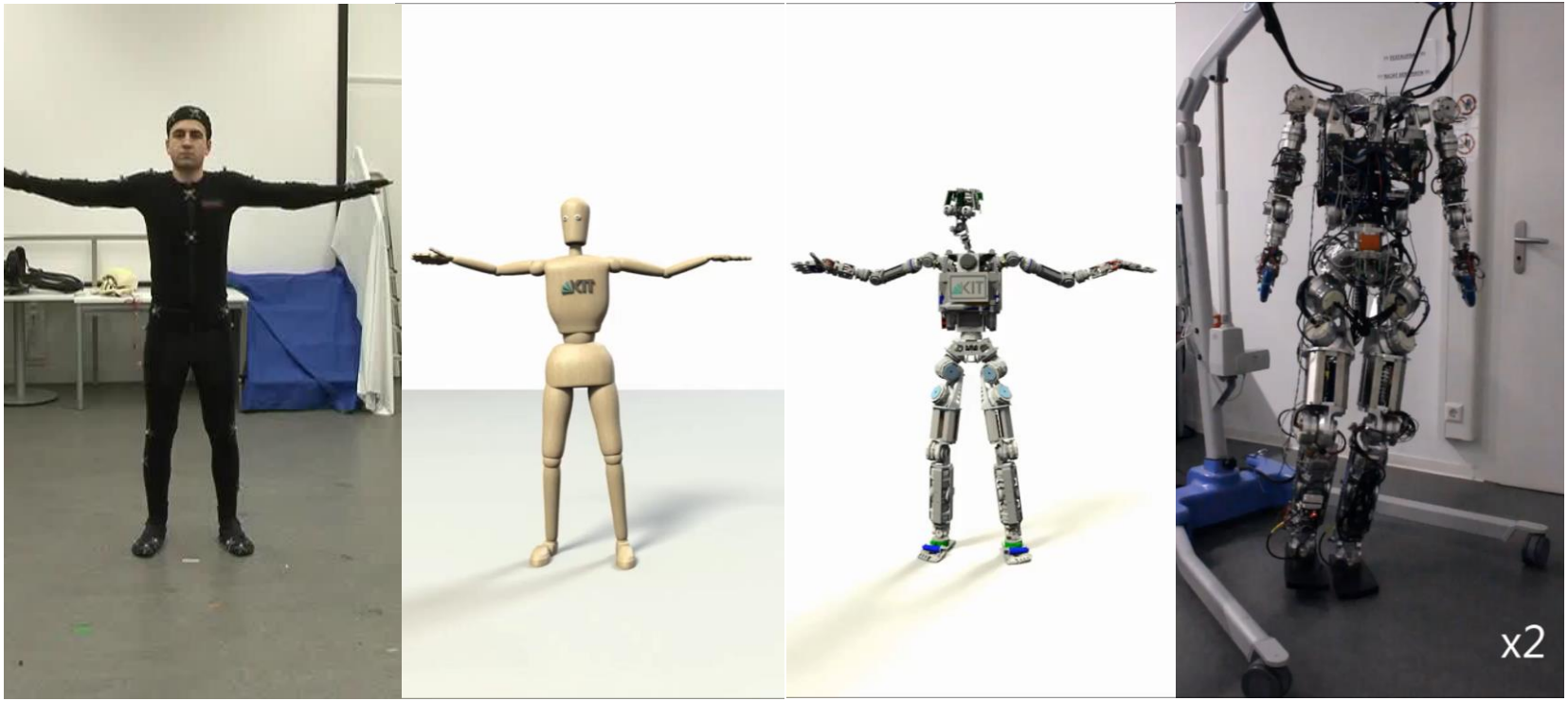
42 hours of manually labeled human motion data (including object information); 9375 motions; 229 (108/40) subjects and 158 objects.

motion-database.humanoids.kit.edu
https://gitlab.com/mastermotormp

The KIT whole-body human motion database

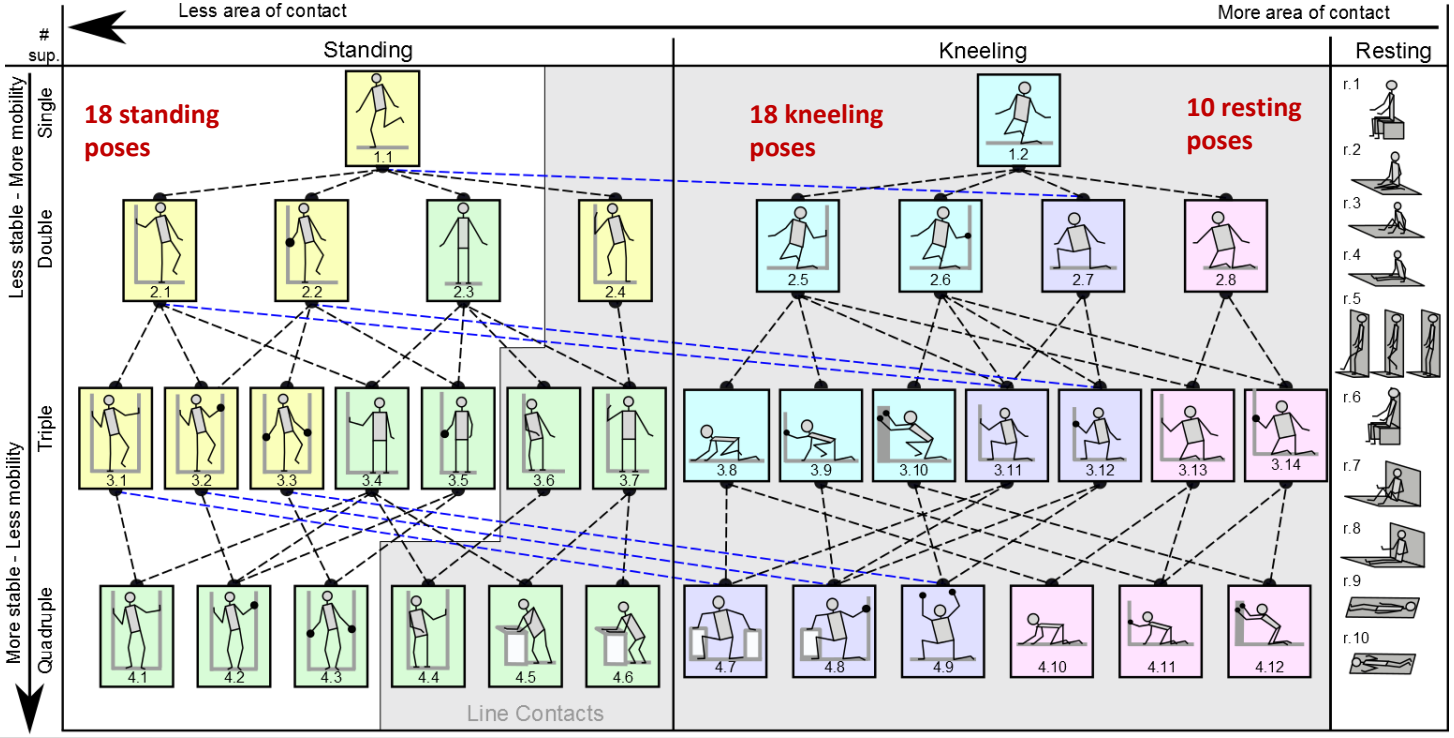


Learning to balance from human observation

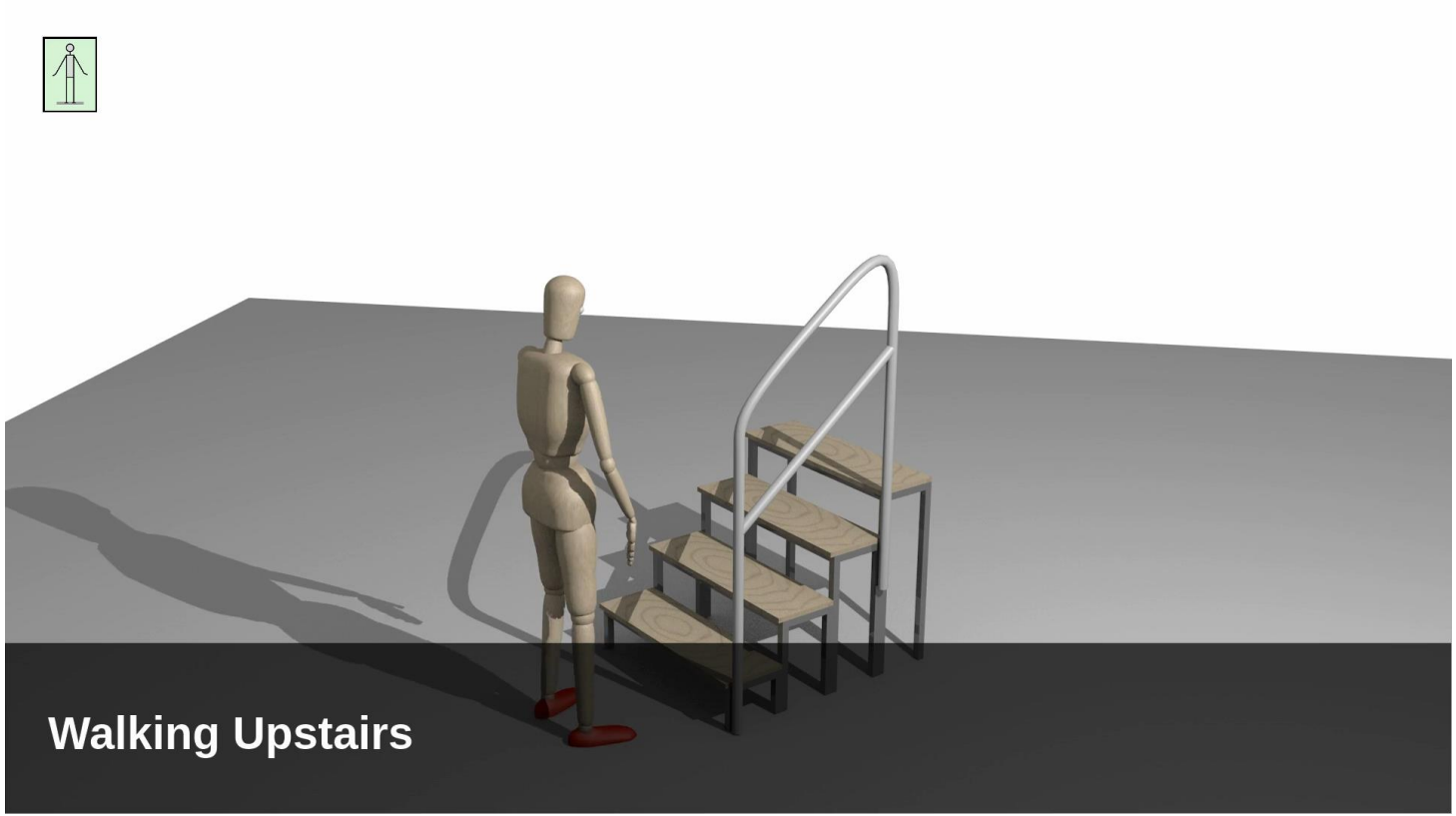


Understanding human motion intelligence

Taxonomy of whole-body poses with 46 classes



Semantic of human actions



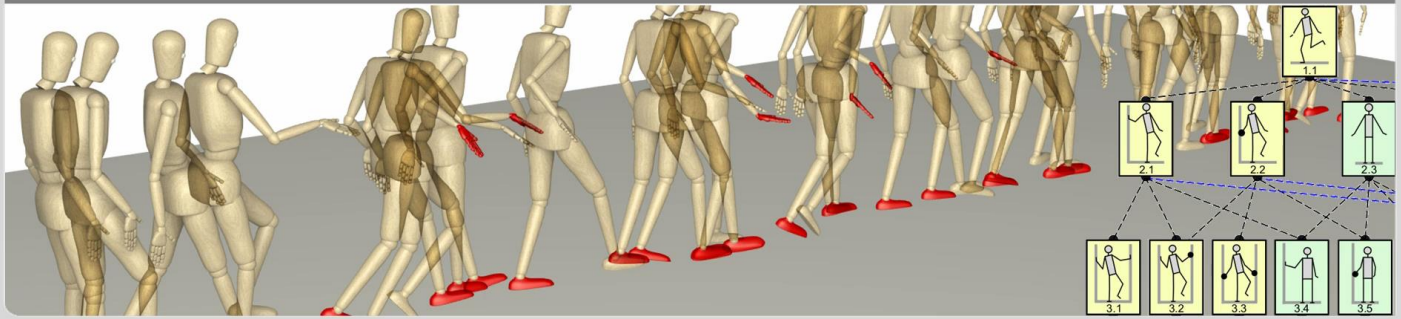
Machine learning for data-driven motion generation

Karlsruhe Institute of Technology

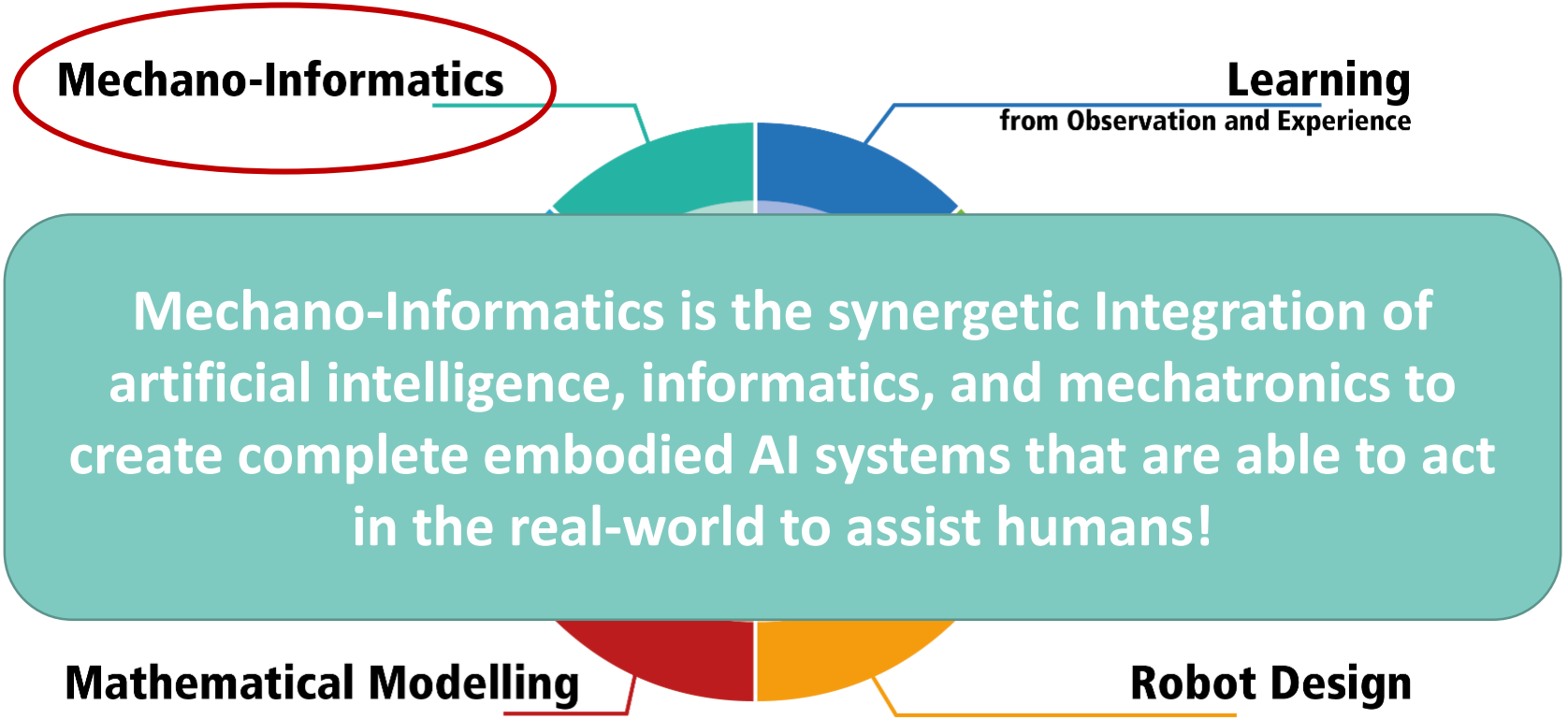
Using Language Models to Generate Whole-Body Multi-Contact Motions

Christian Mandery, Júlia Borràs, Mirjam Jöchner, Tamim Asfour

Institute for Anthropomatics and Robotics (IAR), High Performance Humanoid Technologies (H²T)

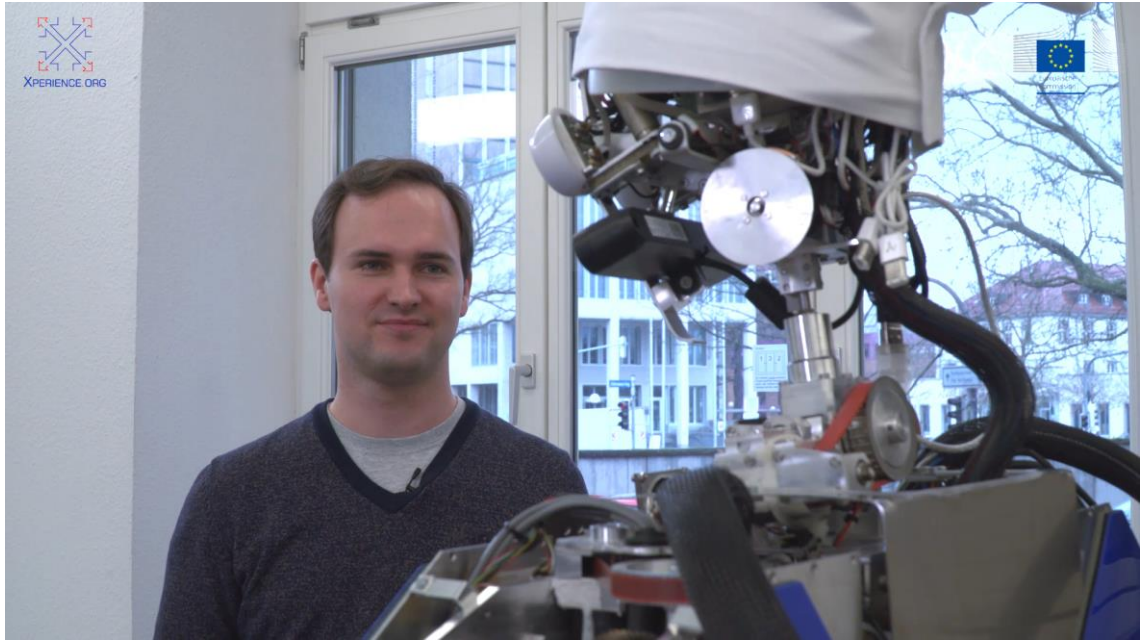


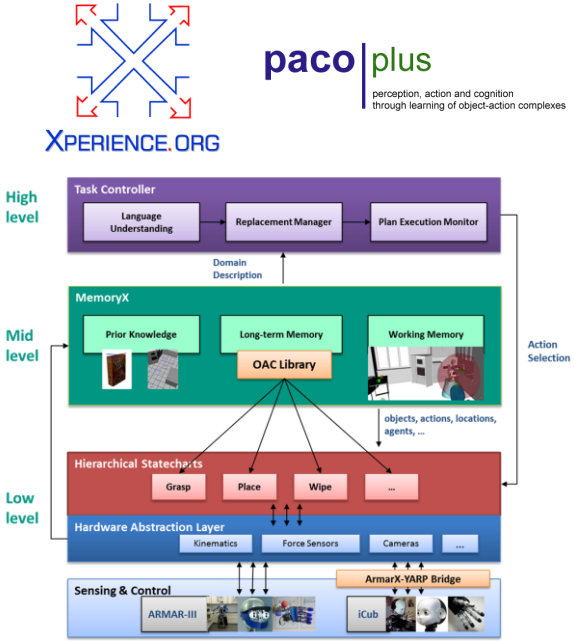
Mechano-Informatics



Integration of AI, machine learning, vision and control

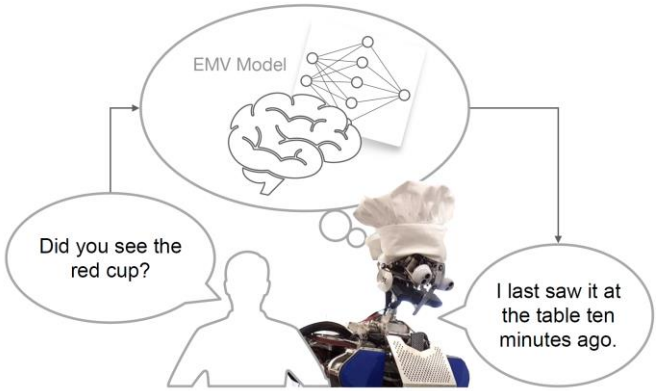
- „ARMAR, please help me to prepare dinner for two people!“





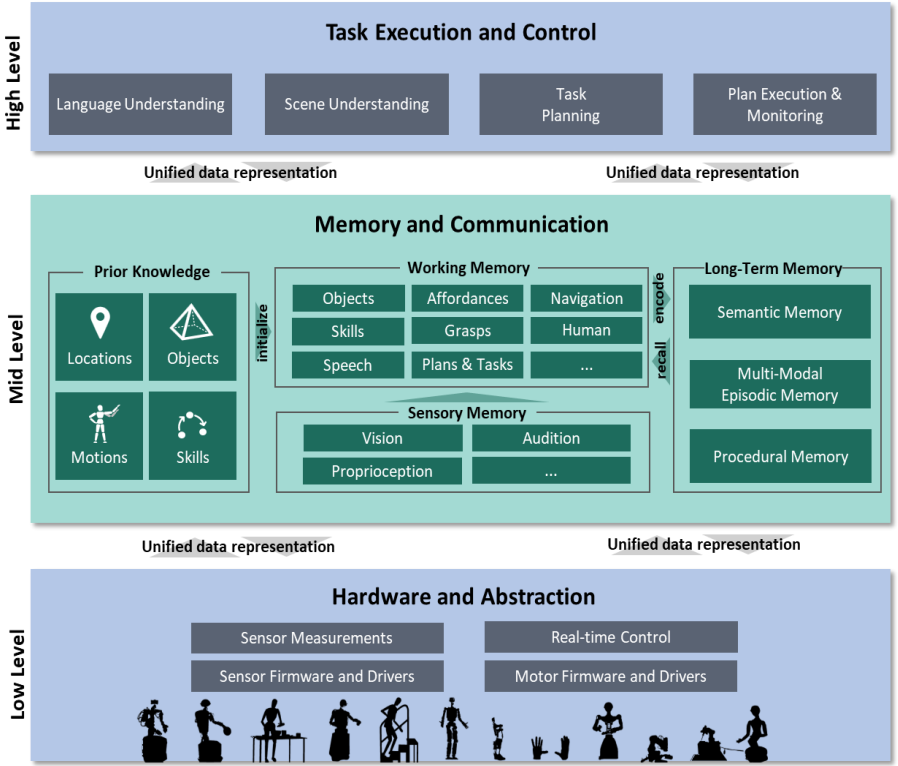
Verbalization of Robot Experience

- Deep Learning based Episodic Memory



Memory-Centric Robot Cognitive Architecture

Memory-centered, hybrid architecture
that supports semantic and sensorimotor representations



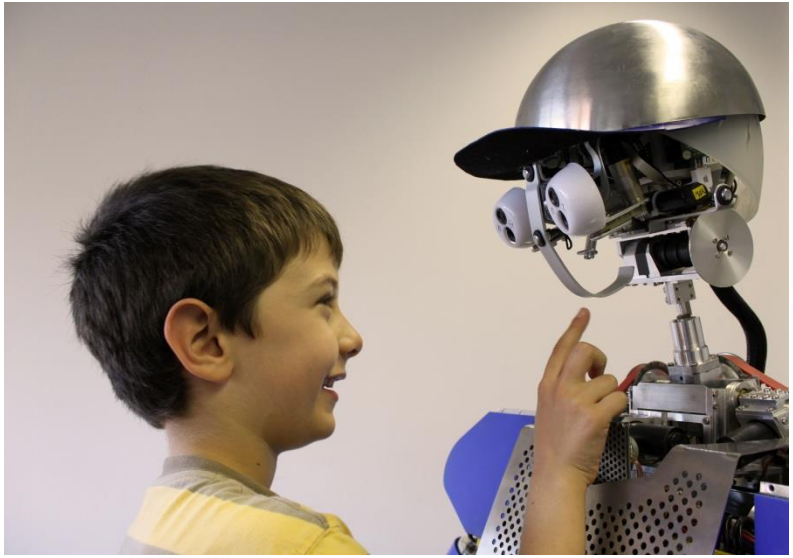
Cognitive architecture implemented in ArmarX

Outline

- Humanoids@KIT
- **What is Anthropomatics?**
- Why Humanoids?

Anthropomatics is …

… the science of the symbioses between human and machine



Outline

- Humanoids@KIT
- What is Anthropomatics?
- **Why Humanoids?**

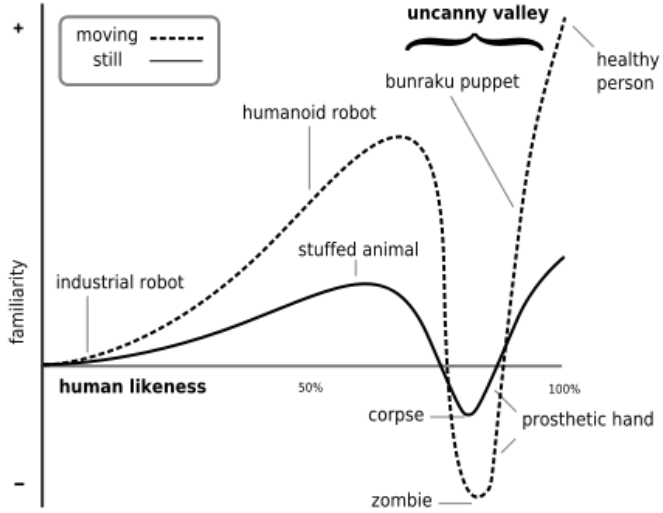
Why humanoids?

- **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. This 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



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

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

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

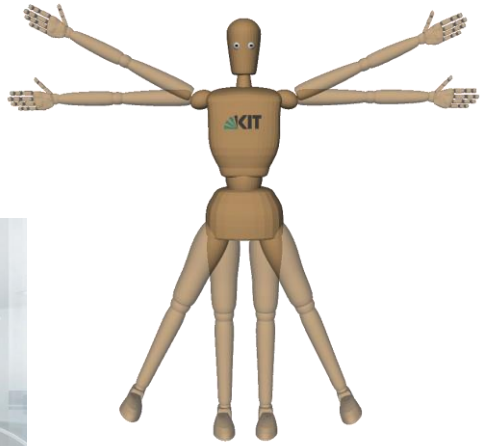
Major goals in humanoid research

- Advanced human-like mechatronics systems

- Tools to study humans

My Motivation

- Understanding human motion intelligence
- Creating embodiments for intelligence
- Engineering human-centered versatile robot technologies



My inspiration

- Biology

- Science Fiction

Understanding human performance

Roger Federer

https://www.youtube.com/watch?v=SoGz8H9xRjM

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

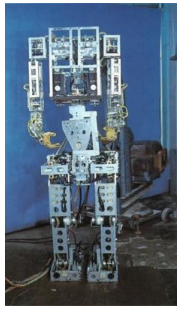
https://www.youtube.com/watch?v=ou5rtTyuW1c

Understanding human performance

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

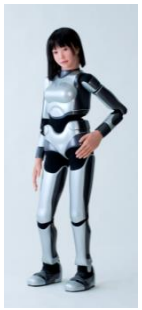
WorldCup 2010 Final
https://www.youtube.com/watch?v=v9rShM1Y2Rw

Humanoid Robotics (1970 – 2023)

















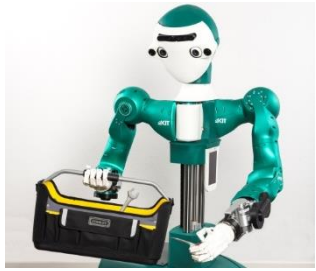
Huge Potential

Underwater Diving
Ocean One, Stanford

Space Exploration
Valkyrie, NASA

Manufacturing
Nextage, Kawada Industries

Rescue
Momaro, Uni Bonn



Maintenance
ARMAR-6, KIT

Household
ARMAR-III, KIT

Social Interaction
Pepper, Softbank

...

Humanoid assistive robotics: market is expected to grow from $1.5 billion in 2022 to $17.3 billion by 2027

AI robotics market is expected to grow from $6.1 billion in 2020 to $37.9 billion by 2027

MARKETSANDMARKETS

Ambitious goals have been set for humanoid robotics

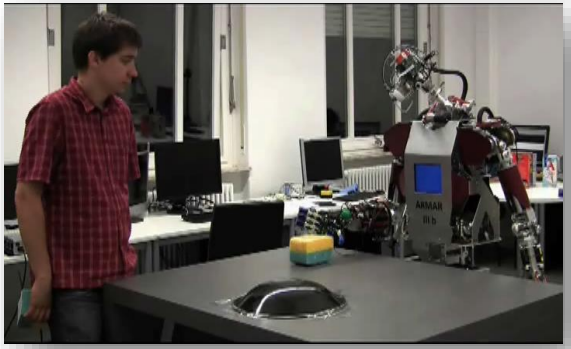
- Companions and assistants for humans in daily life
- Helpers in man-made and natural disasters
- Winners against the winner of the most recent World Cup in 2050
- DARPA Robotics Challenge

Some examples

ASIMO, Honda, Japan
https://www.youtube.com/watch?v=UKRfkP15tzE

HRP-4C, AIST, Tsukuba, Japan
https://www.youtube.com/watch?v=xcZJqiUrbnI

Atlas, Boston Dynamics, USA
https://www.youtube.com/watch?v=rVIhMGQgDkY



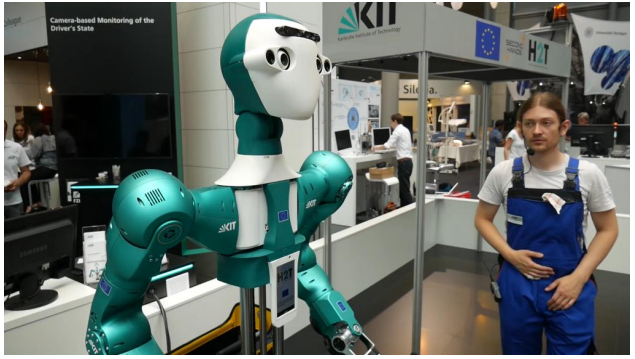
ARMAR-IIIb, KIT, Germany

Some examples

T-HR3, Toyota, Japan
https://www.youtube.com/watch?v=jJYsOsoBIZU

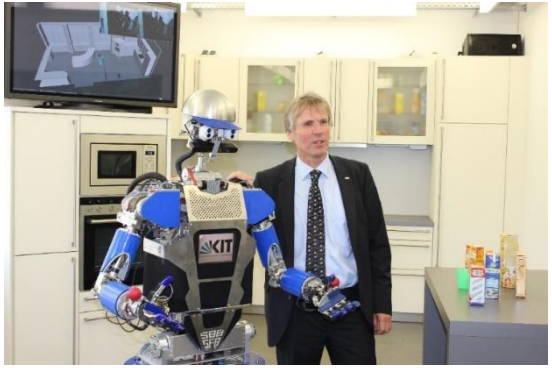
HRP-5P, AIST, Tsukuba, Japan
https://www.youtube.com/watch?v=fMwiZXxo9Qg

iCub, IIT, Italy
https://www.youtube.com/watch?v=ErgfgF0uwUo

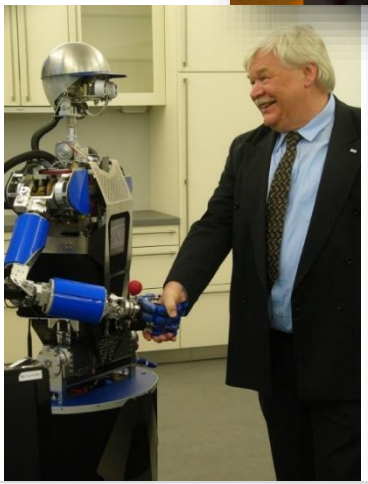


ARMAR-6, KIT, Germany

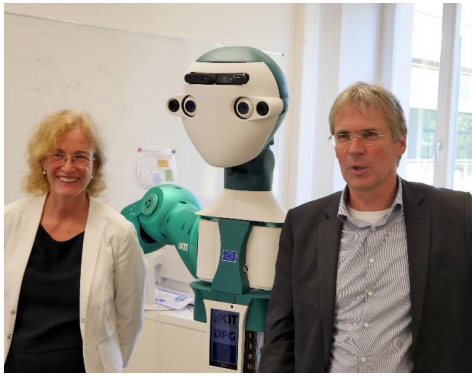
ARMAR-III with Leaders




ARMAR-6 with Leaders



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
  https://www.ieee-ras.org/humanoid-robotics

- interACT
  http://www.informatik.kit.edu/interact.php