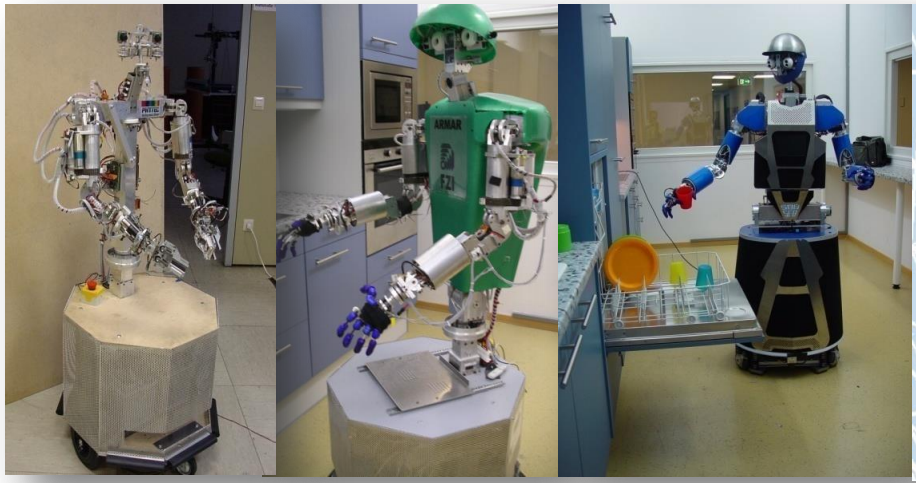
Karlsruhe Institute of Technology

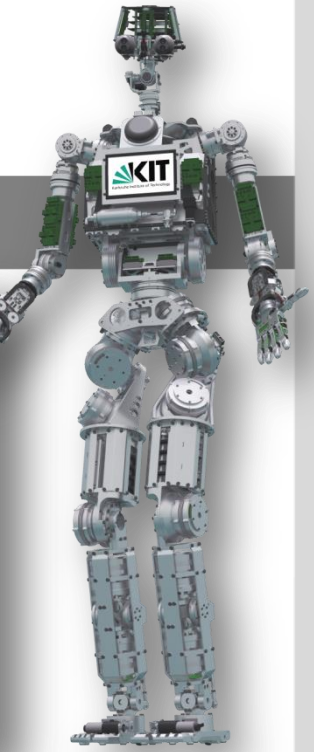
23. May 2014

Humanoid Robotics Research @ KIT

Tamim Asfour

Institute for Anthropomatics and Robotics, Humanoid Robotic Systems



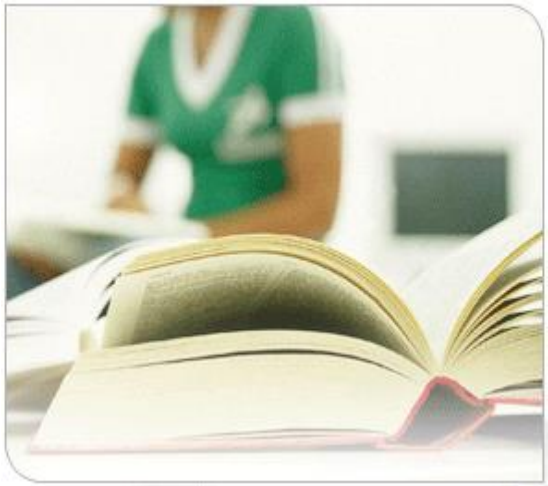


http://www.humanoid.kit.edu

http://h2t.anthropomatik.kit.edu

KIT – Our Mission

Research & Development



Higher Education

Innovation

„… to form a novel Quality of Cooperation, and to overcome the Separation between Federal Research Facilities and State Universities …“

KIT in Figures

Employees

9.261

Students

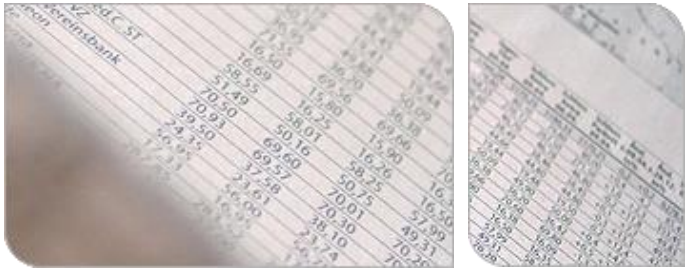
23.836

364

Professors

789

Annual Budget in Million Euros



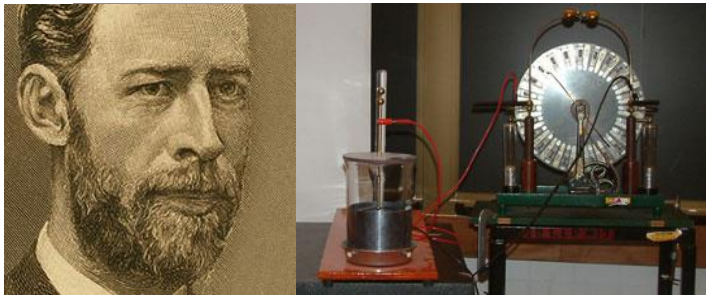
figures in 03/2013

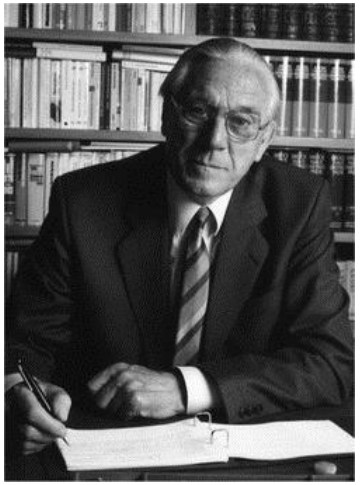
Engineering Tradition

Karl Benz: inventor of the modern automobile

Ferdinand Braun: inventor of cathode ray tube → television

Heinrich Hertz: confirmation of electromagnetic waves

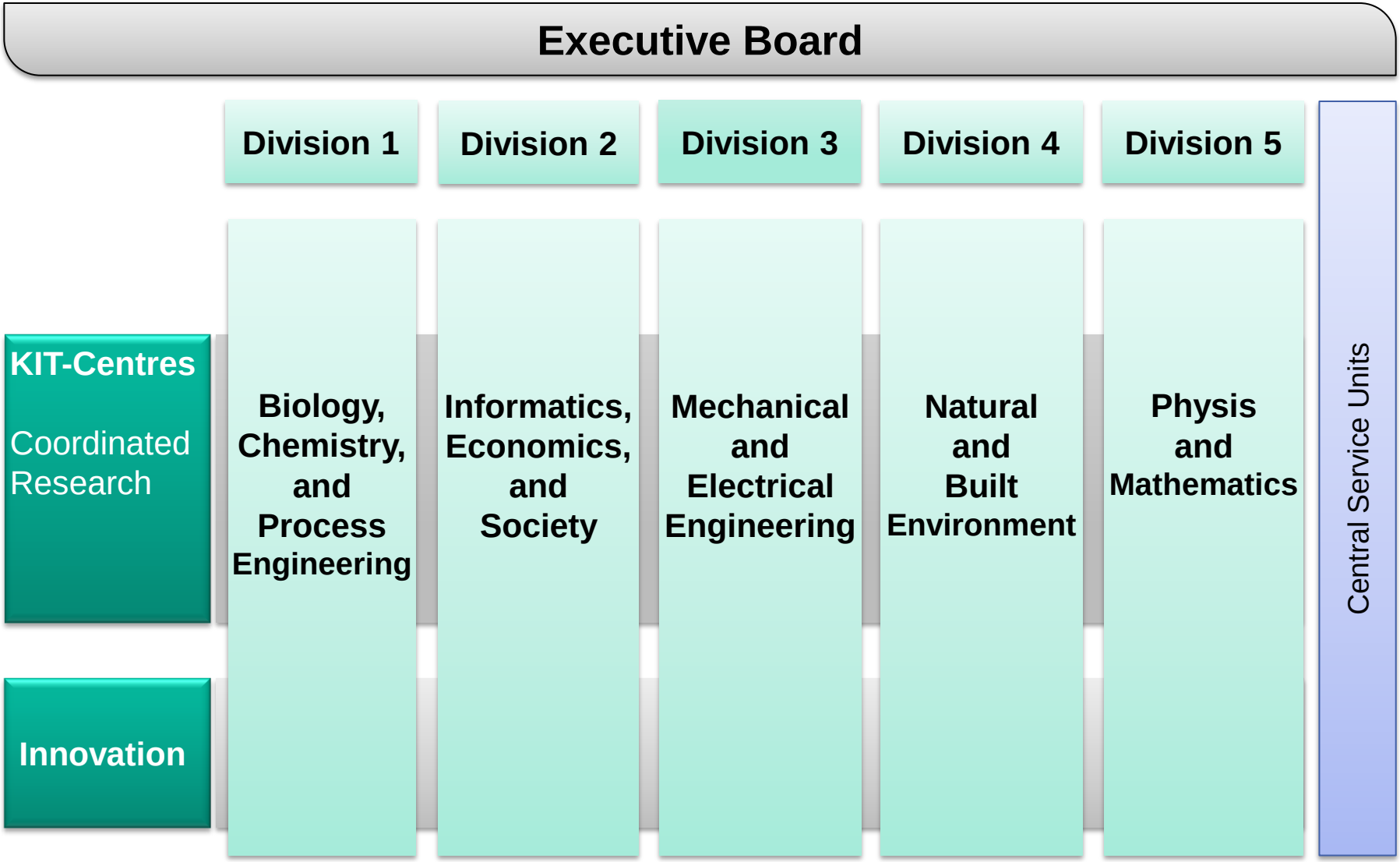




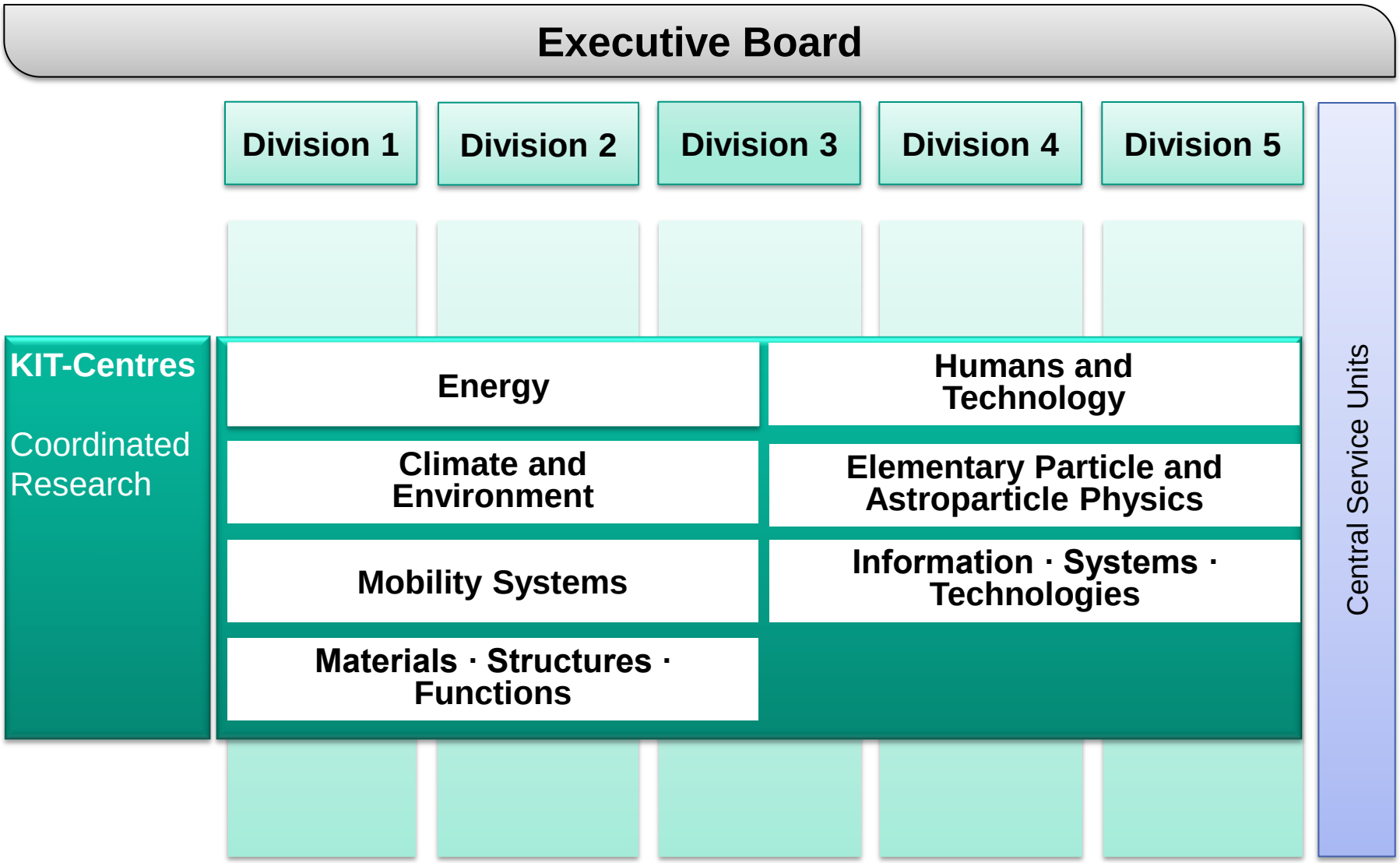
Karl Steinbuch: coined the term *Informatics* in 1957

Fritz Haber: fixation of atmospheric N_2 → synthetic ammonia

Disciplines organized in Divisions



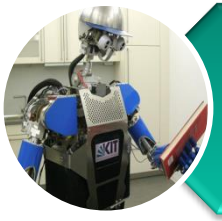
Coordinated Research in KIT-Centres



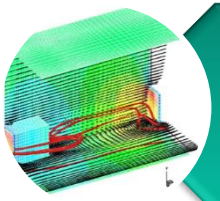
Energy	7 Topics 1250 Empl.
Climate and Environment	7 Topics 500 Empl.
Mobility Systems	7 Topics 900 Empl.
Materials · Structures · Functions	14 Topics 1100 Empl.
Humans and Technology	6 Topics 400 Empl.
Elementary Particle and Astroparticle Physics	9 Topics 400 Empl.
Information · Systems · Technologies	10 Topics 450 Empl.

KIT Center - Information · Systems · Technologies

Networked complex adaptive Systems (COMMputation)



Robotics, Anthropomatics, Mechano-Informatics

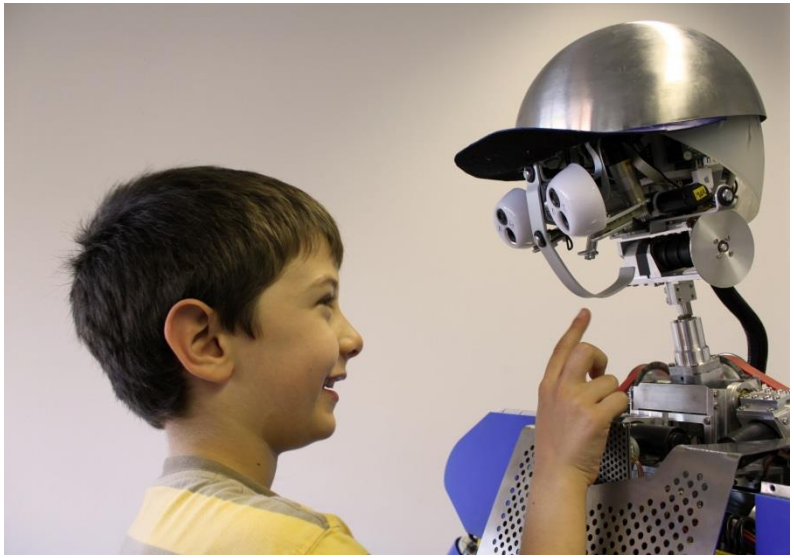


Scientific Computing and Data-intensive Research

Dependable and Trusted Information and Communication

Anthropomatics is …

… the science of the symbioses between human and machine



Institute for Anthropomatics and Robotics (IAR)

10 chairs, ca. 150 researchers

- **High Performance Humanoid Technologies** — Asfour 
- **Vision and Fusion** — Beyerer 
- **Humanoids and Intelligence Systems** — Dillmann 
- **Intelligent-Sensor-Actuator System** — Hanebeck 
- **Intelligent Industrial Robotics** — Hein 
- **Cognitive Systems** — Schultz 
- **Computer Vision for Human Computer Interaction** — Stiefelhagen 
- **Interactive Systems** — Waibel 
- **Process Control, Automation and Robotics** — Wörn 
- **Applied Technical Cognitive Systems** — Zöllner 

My team

Karlsruhe Institute of Technology

Humanoids@KIT

My motivation

Building Humanoids = Building Human-Centered Technologies



- Assistants and companions for people in different ages, situations, and environments to improve the quality of life
- Key technologies for future robotic systems
- Experimental platforms to study theories about humans from other disciplines

My inspiration

- Biology

- Science Fiction

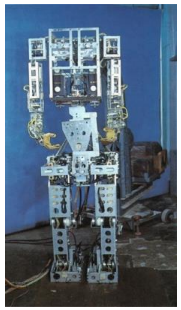
Human performance

Roger Federer

Human performance

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

Humanoid robotics has made progress !


WABOT-1


P2

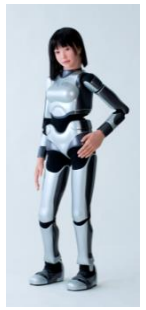

ASIMO


DB

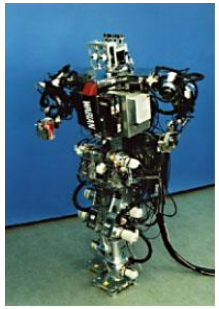

CB

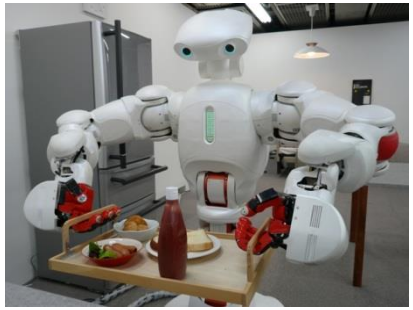

HRP-2


HRP-4


HRP-4C


ARMAR-IV


WABIAN


Twendy-one


ARMAR-III


iCub


kojiro


Partner Robot


HUBO


KOBIAN


Petman


Robonaut


Justin


NAO


DARwIN-OP

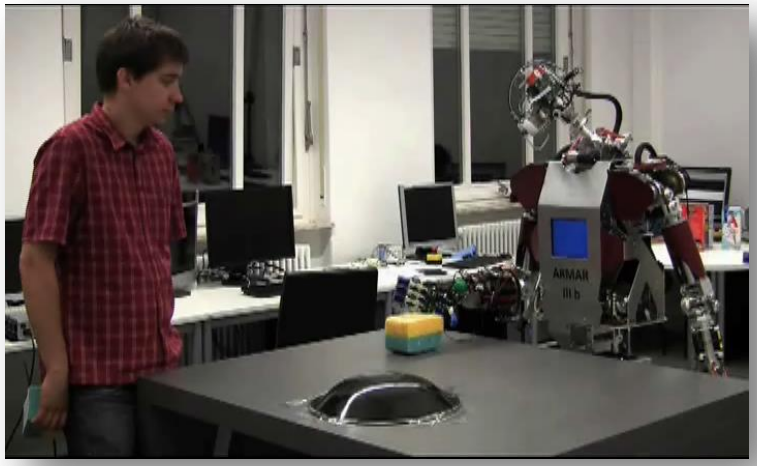

Lola

Some examples

ASIMO, Honda, Japan

HRP-4C, AIST, Tsukuba, Japan

Atlas, Boston Dynamics, USA



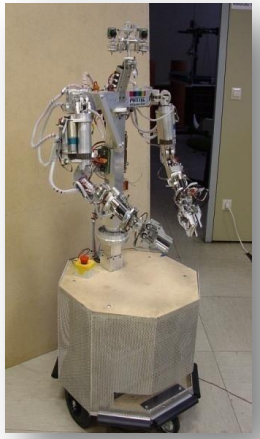
ARMAR, KIT, Germany

Ambitious goals have been set for humanoid robotics

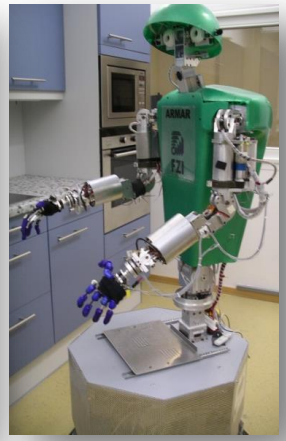
- Companions and assistants for humans in daily life
- Helpers in man-made and natural disasters
- Winners against the winner of most recent World Cup in 2050
- DARPA Robotics Challenge

Humanoid Robots @ KIT

Deutsche Forschungsgemeinschaft

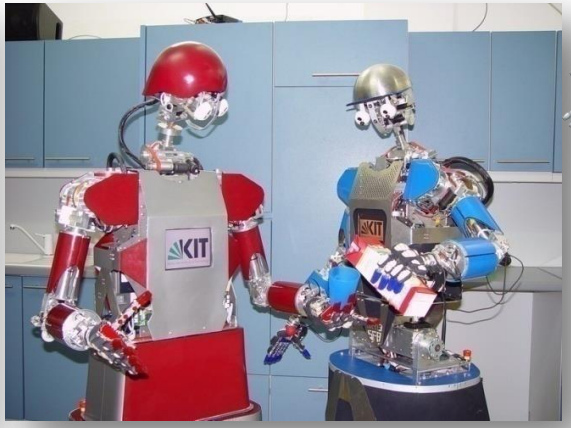


ARMAR, 2000



ARMAR-II, 2002

ARMAR-IIIa, 2006

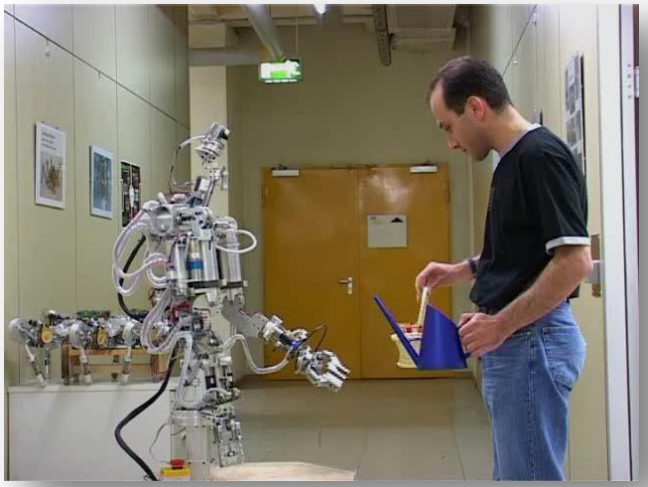


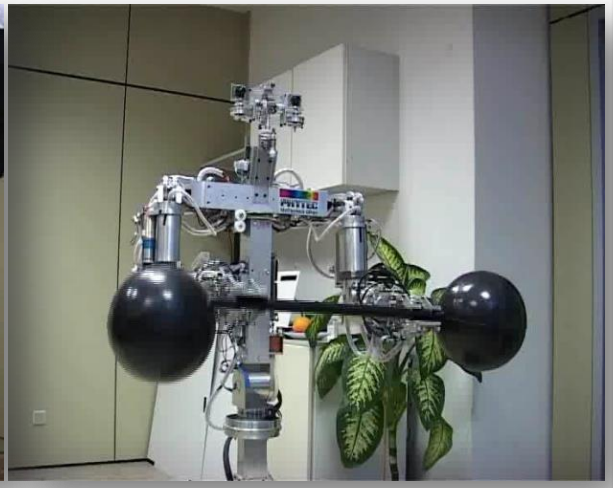
ARMAR-IIIb, 2008

ARMAR-IV, 2011

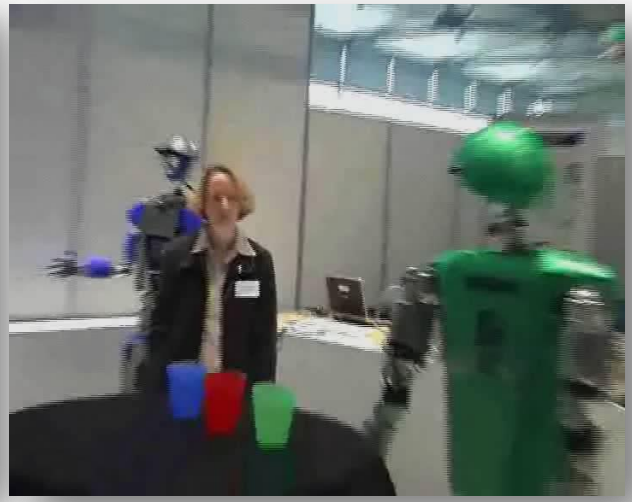
- Collaborative Research Center 588: Humanoid Robots - Learning and Cooperating Multimodal Robots (SFB 588)
  - Funded by the German Research Foundation (DFG: Deutsche Forschungsgemeinschaft)
  - 2001 – 2012
  - http://www.sfb588.uni-karlsruhe.de/

ARMAR-I and ARMAR-II





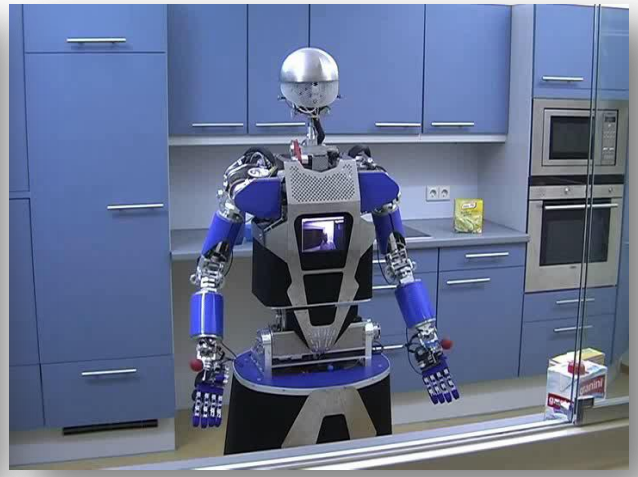
First demonstrator of the SFB 588

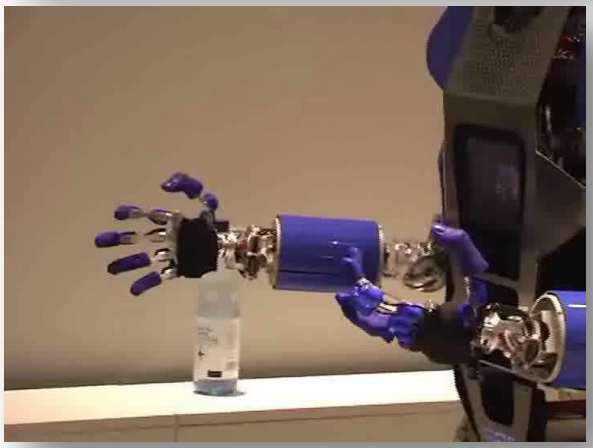


Demo at CEBIT 2006

ARMAR-IIIa and ARMAR-IIIb

- 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

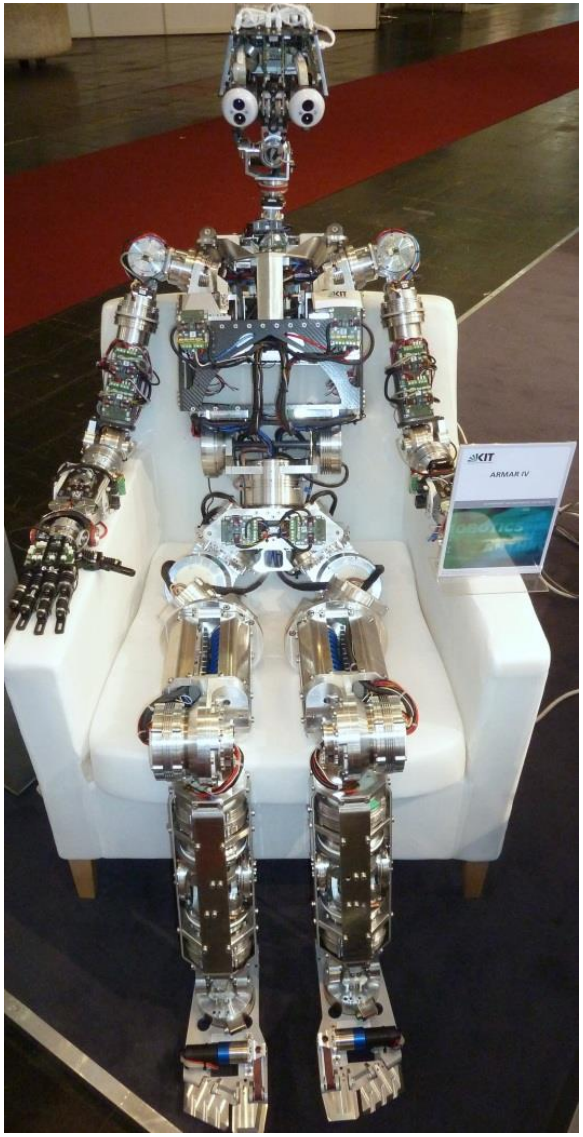


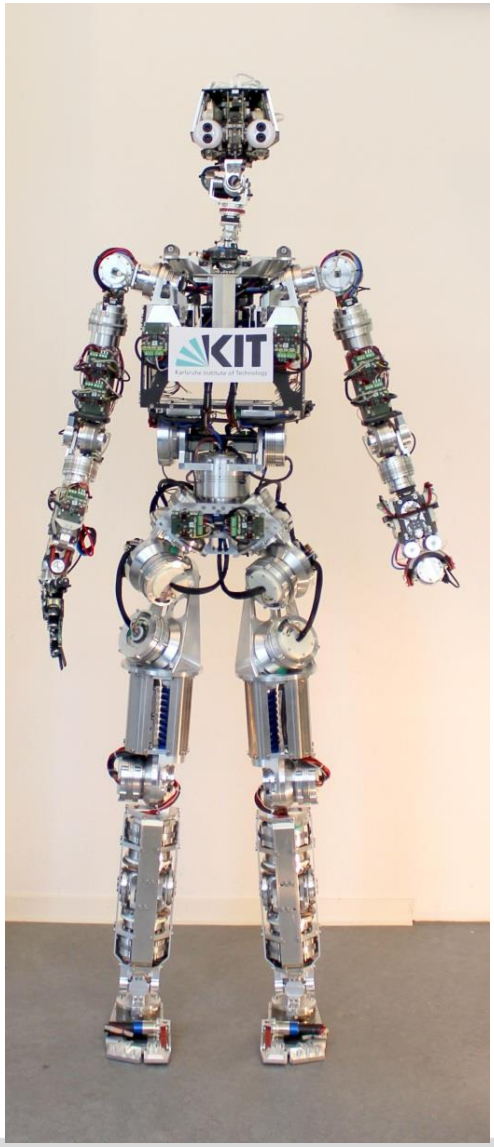


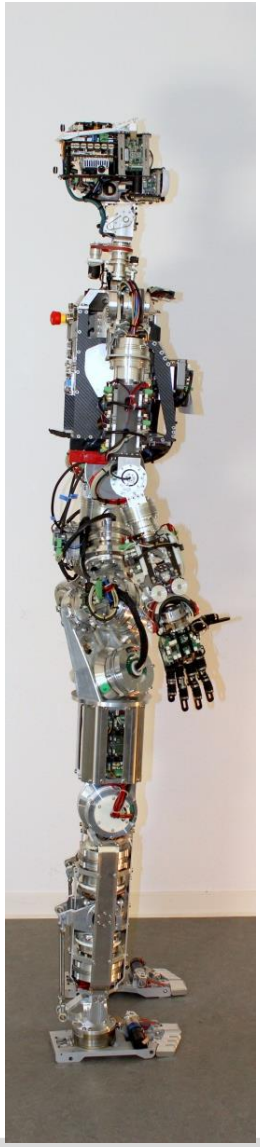
Fully integrated humanoid system

ARMAR-IV

- 63 DOF
- 170 cm
- 70 kg
- Torque-controlled!







ARMAR-IV: Mechano-Informatics

- 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

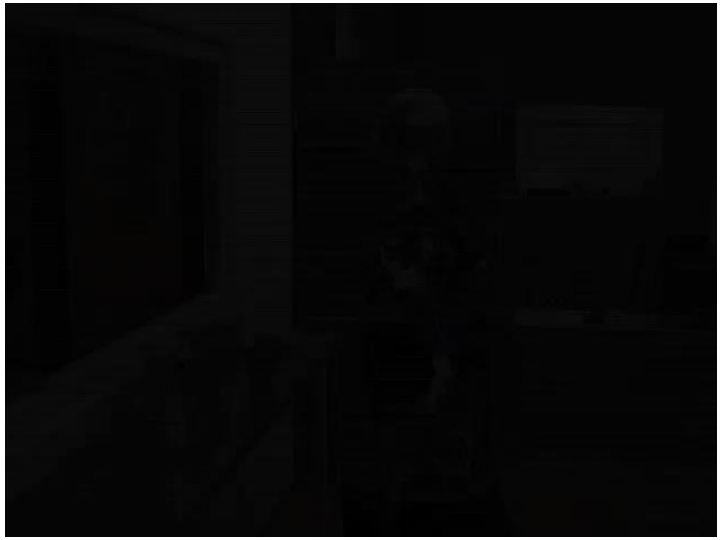
made@KIT

70 kg

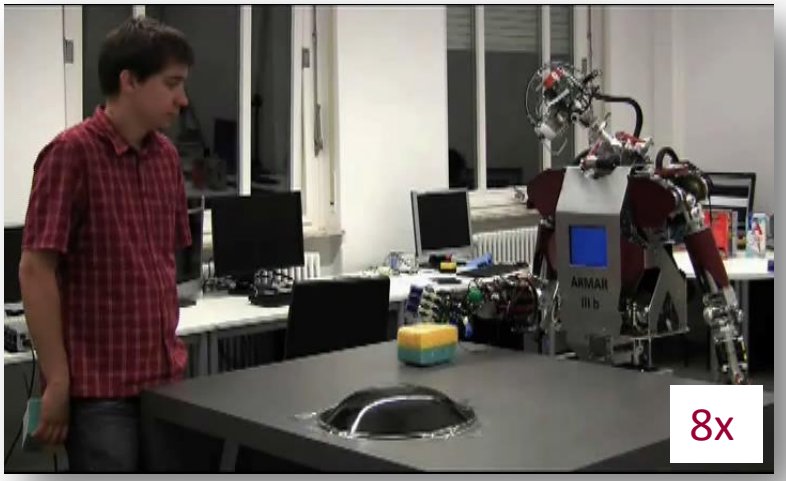
170 cm

Humanoids in the real world

- Grasping and manipulation



- Learning for human observation



ARMAR-III in the RoboKITchen

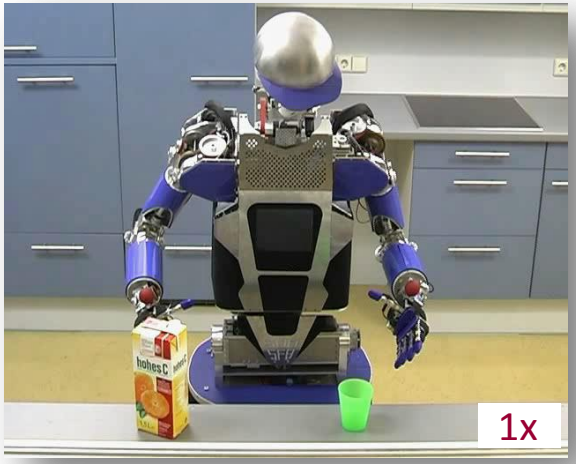
- Object recognition and localization
- Vision-based grasping
- Hybrid position/force control
- Combining force and vision for opening and closing door tasks
- Collision-free navigation
- Vision-based self-localisation
- Multimodal human-robot dialogs
- Continuous speech recognition
- Learning new objects,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

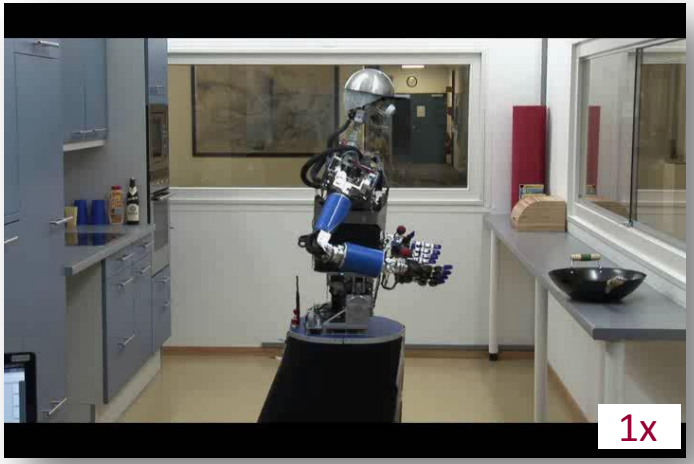
ARMAR-III in the RoboKITchen

- First step towards 24/7
  - 45 minutes demonstration
  - Shown more than 950 times, since 03. February 2008, to experts and public
    - 75 times in 5 days for approx. 5000 visitors at CeBIT 2012
    - 30 times during the EFFEKTE weekend, 2013 in Karlsruhe

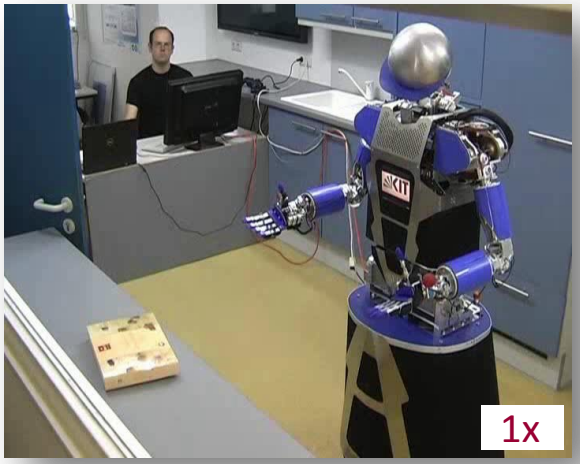
Advanced grasping capabilities

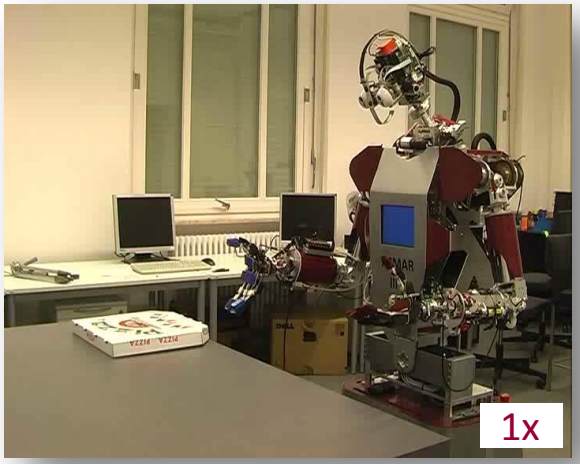
- Bimanual grasping and manipulation





- Pre-grasp manipulation

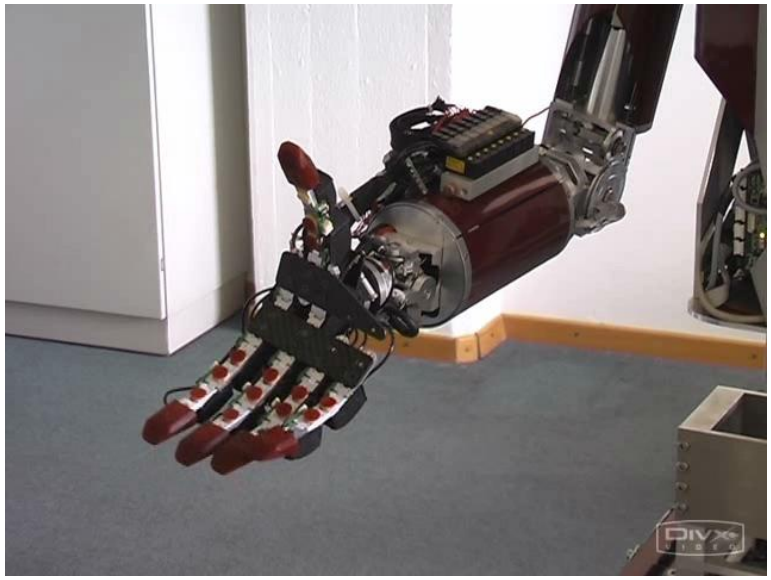


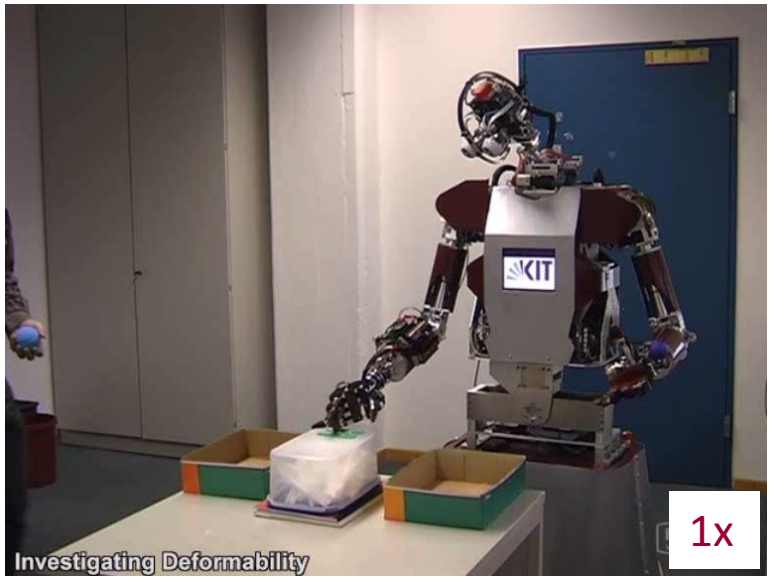


Humanoids 2009
Humanoids 2010
IROS 2011
RAS 2012
RAS 2008

Haptic exploration of unknown objects

- Multisensory (contact, pressure, force, proprioception) approach for
  - Detection of contact and “objectness”
  - Assessment of object deformability
  - …

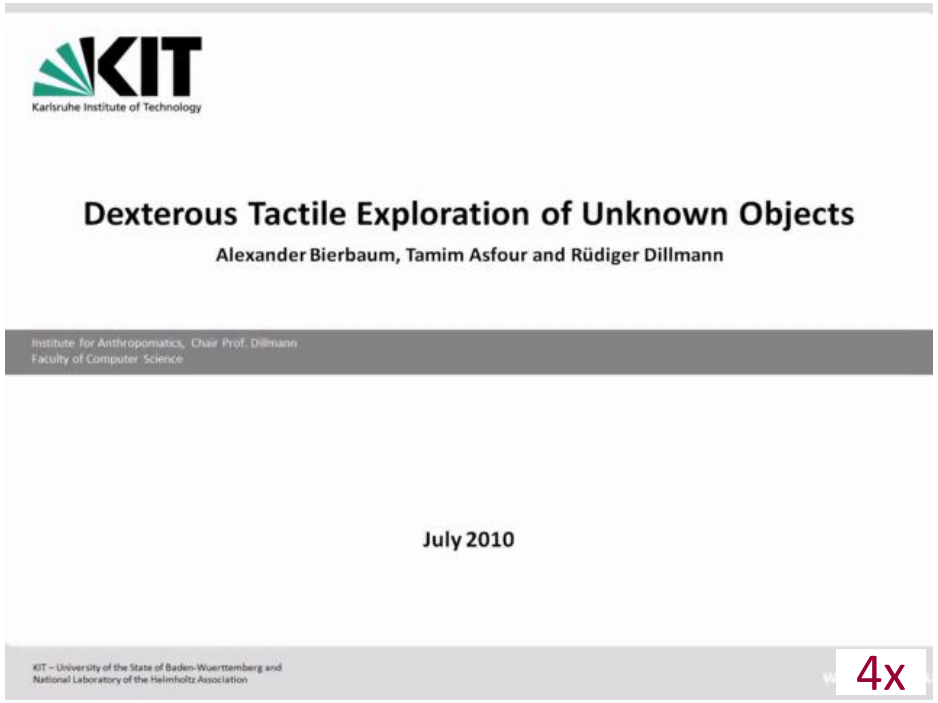




Humanoids 2008, 2009
BioRob 2012

Haptic object exploration

- Potential field guides the robot hand along the object surface
- Oriented 3D point cloud from contact data
- Compute face pairings from 3D point
- Calculate grasping hypotheses using a geometric feature filter pipeline

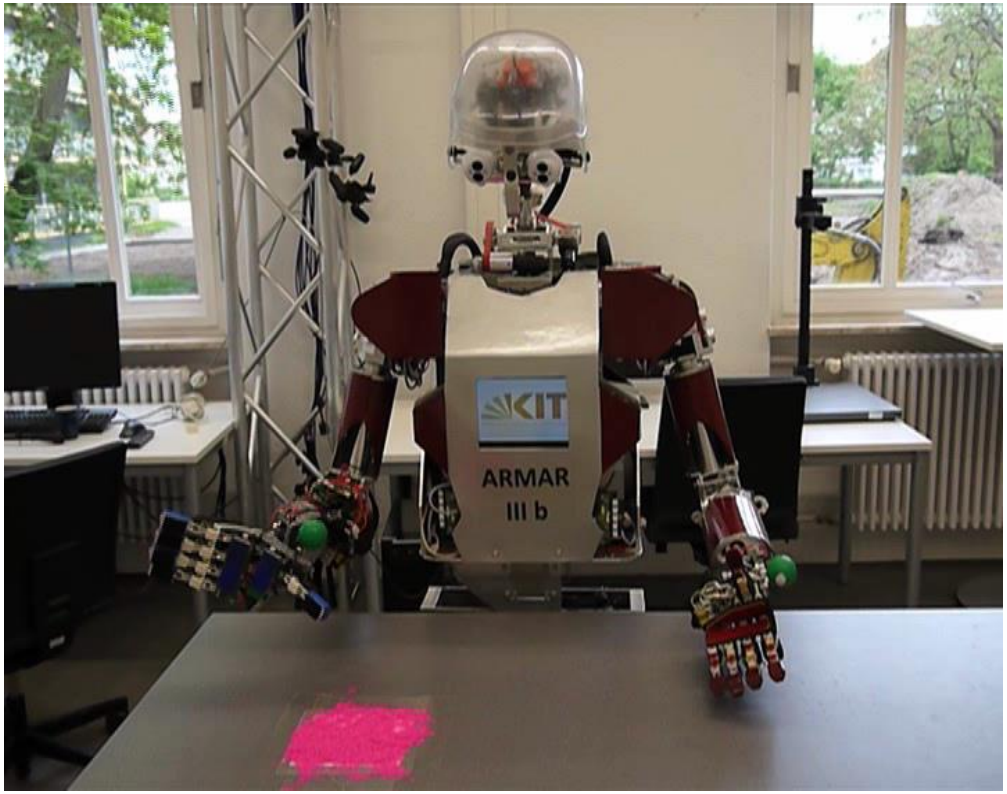


Humanoids 2008, 2009, BioRob 2012

Association between "objects" and grasping actions → "grasp affordances"

Learning object-action-effect correlations

- Objects and Actions are inseparably intertwined
  → Object-Action Complexes (OACs)

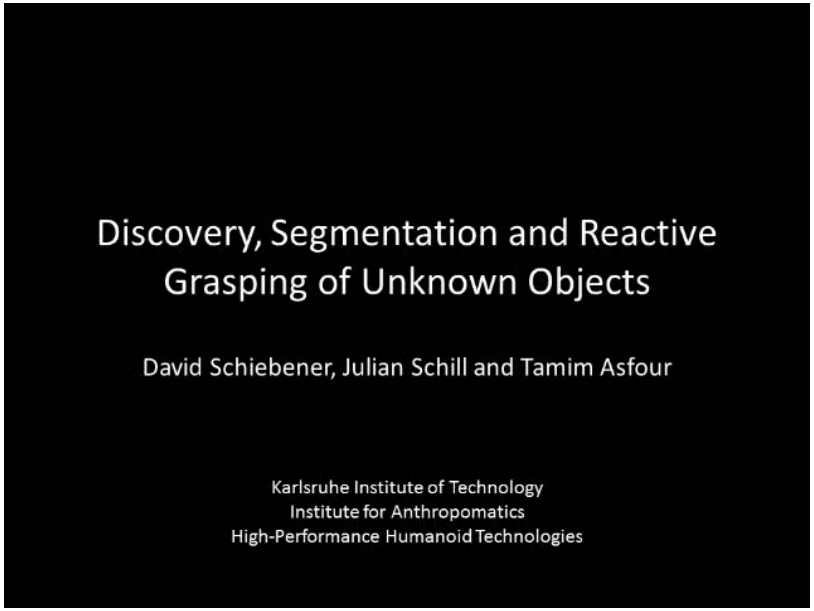


Discover, segment and grasp unknown Objects

- Physical interaction (pushing) to separate unknown object from unknown background

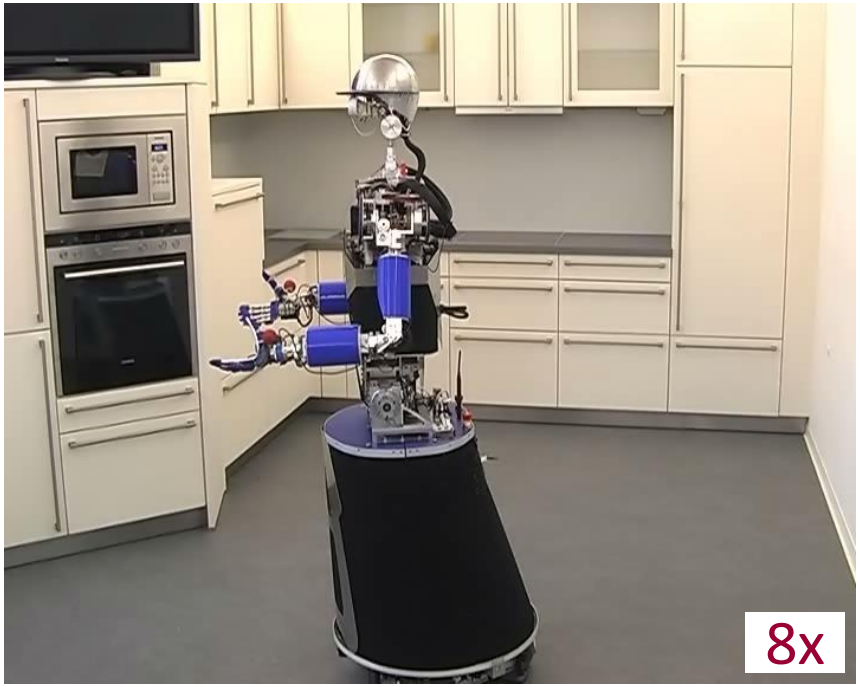
→ Reliable, correct and complete object segmentation

- Reactive grasping based on haptic feedback:
  - No object model needed
  - No grasping planning



ICRA 2012, Humanoids 2011, 2012
Adaptive Behavior 2013

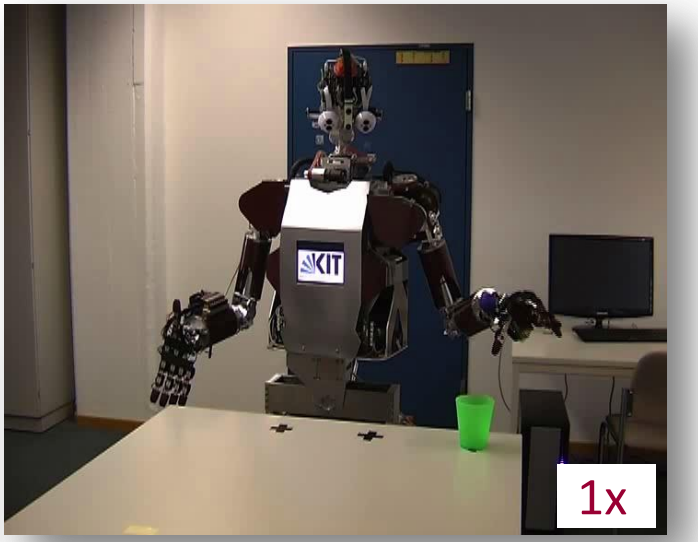
Physical human-robot interaction

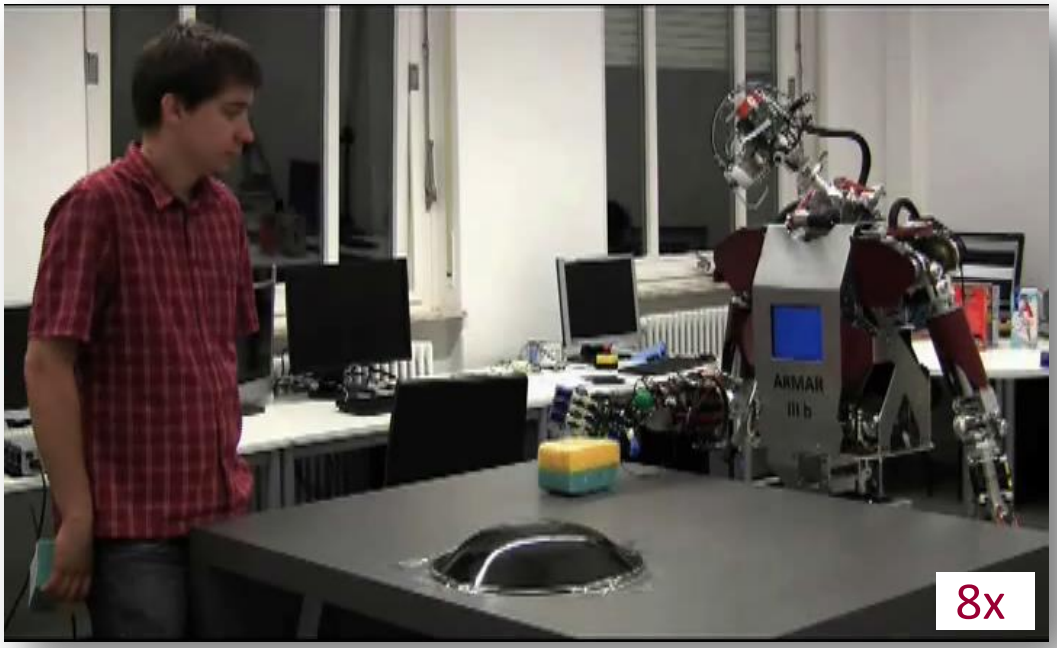


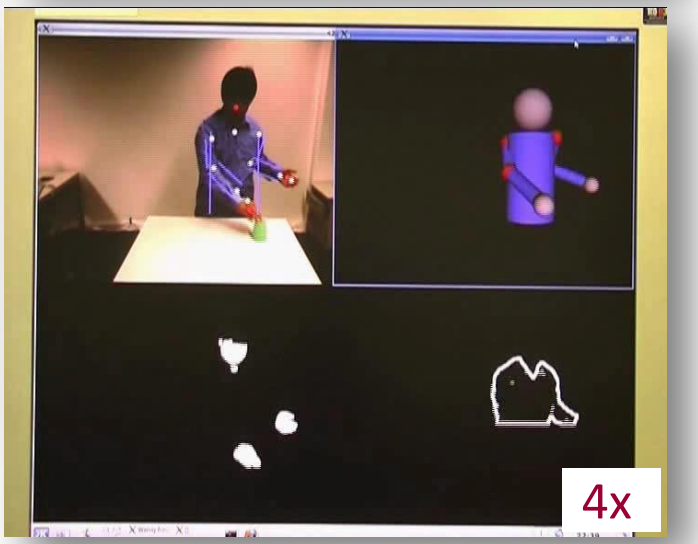
Predicting human motion “intention” based on force feedback

Learning from Observation

- Building a library of motion primitives
- Dynamic movement primitives for discrete and periodic movements







Humanoids 2006, IJHR 2008, Humanoids 2007, ICRA 2009, Humanoids 2009, TRO 2010, Humanoids 2012

On discrete and periodic motion primitives

- Observation: **periodic motions start with a discrete part**
  - Stirring – first move the hand to the vessel containing the liquid.
  - Wiping – first move the hand to the surface to be wiped.
  - Peeling – first bring the peeler to the potato.
  - Cutting – first move the hand to the object.
  - Walking – first step vs. all other steps.
  - Juggling – bringing the balls into the air vs. juggling itself.

  We call this non-periodic part the transient.

- Encode the periodic movement and all corresponding transients into a single dynamical system (DMP)

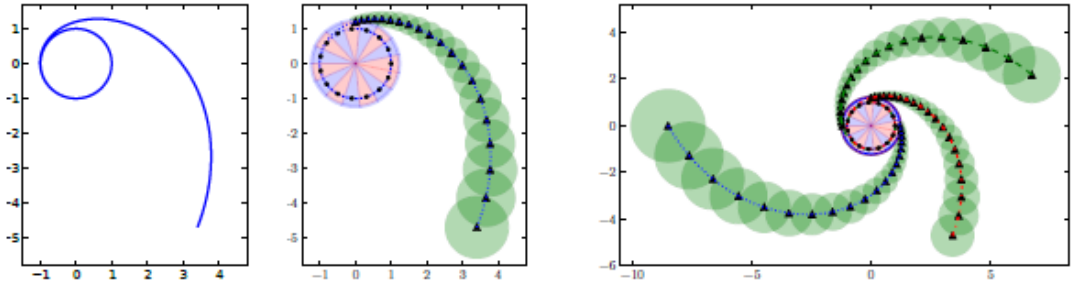
Humanoids 2012

Two dimensional canonical system

- $s(t) := (\varphi(t), r(t))$ in $\boldsymbol{R} \times (0,\infty)$ for φ, r solution of

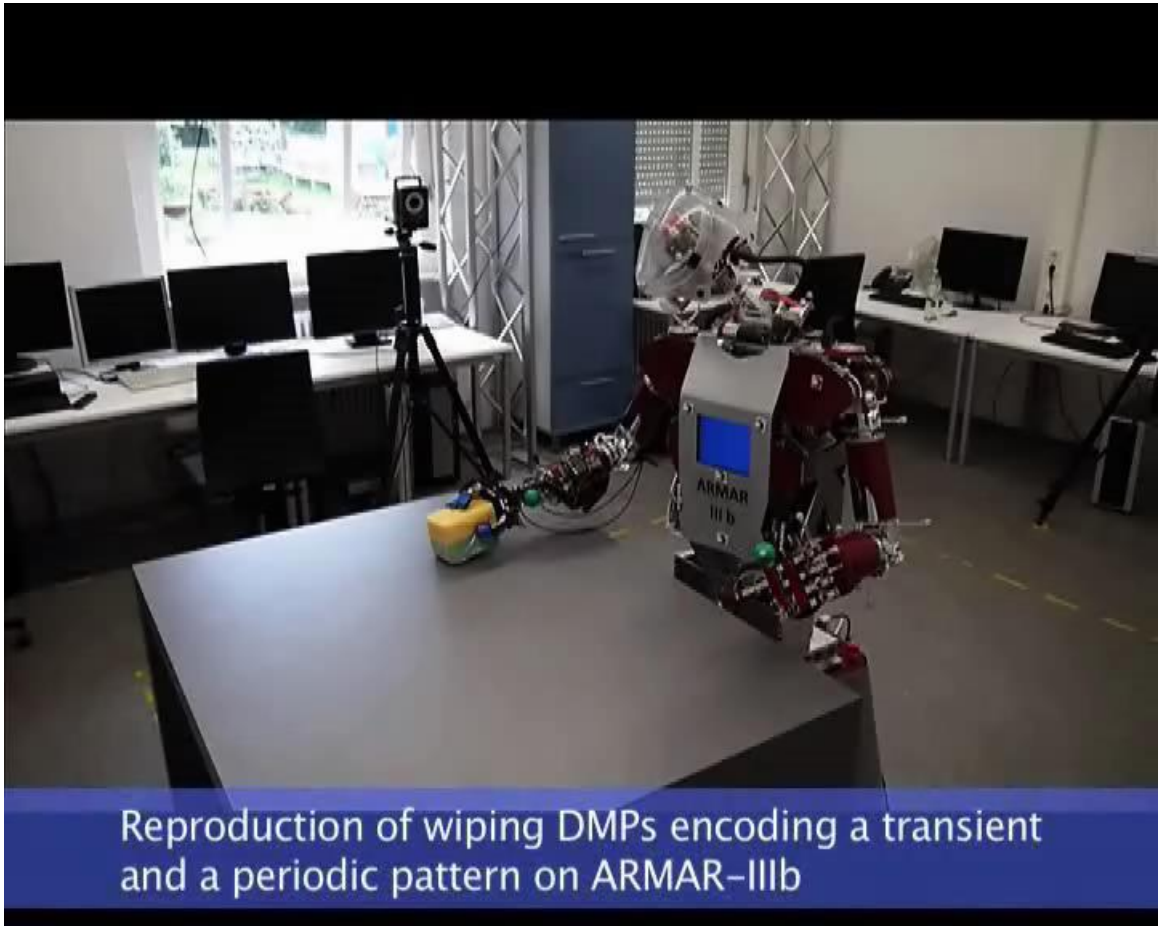
$$\begin{cases} \dot{\phi} = \Omega, \\ \dot{r} = \eta(\mu^{\alpha} - r^{\alpha}) r^{\beta}, \\ \phi(0) = \phi_0, \; r(0) = r_0 \end{cases}$$

- ψ_j "living" outside the limit cycle (transient).
- φ_i "living" on the limit circle (periodic pattern).



- Each transient has its separate set of basis functions ψ_j.

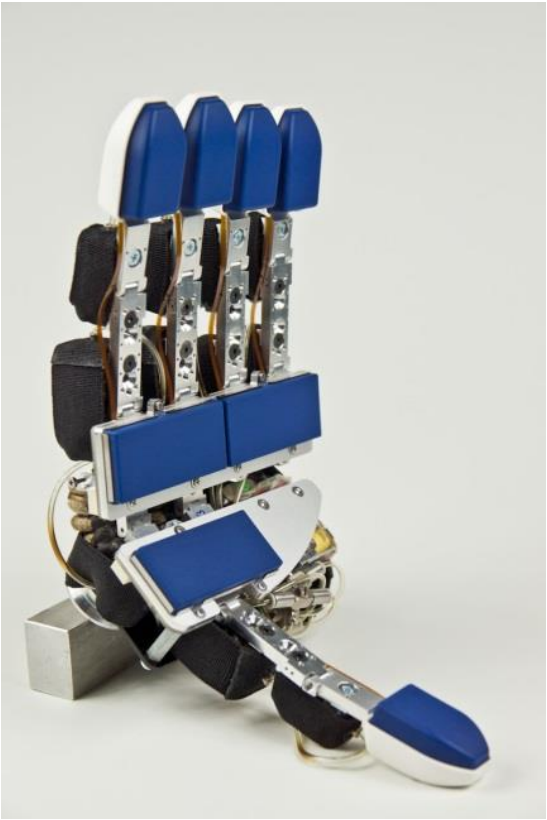
Periodic and transient motions



Humanoids 2012

Learn to wipe

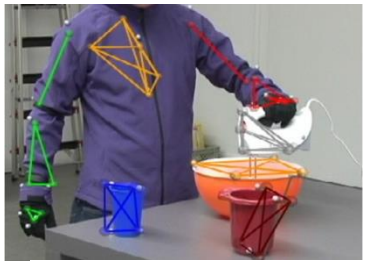
- Learning associations between object properties and action parameter



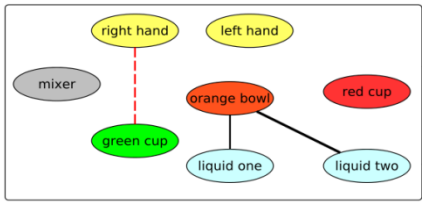
Learning from Human Observation

Action Sequence Reproduction

Observation of **complex task** by human demonstration

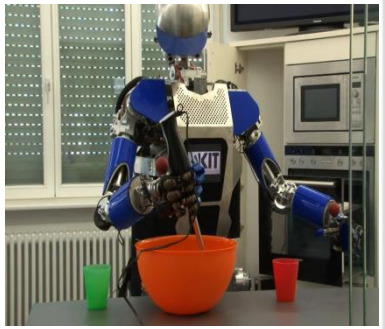


Automatic segmentation of the action sequence by detection of **object relation changes**



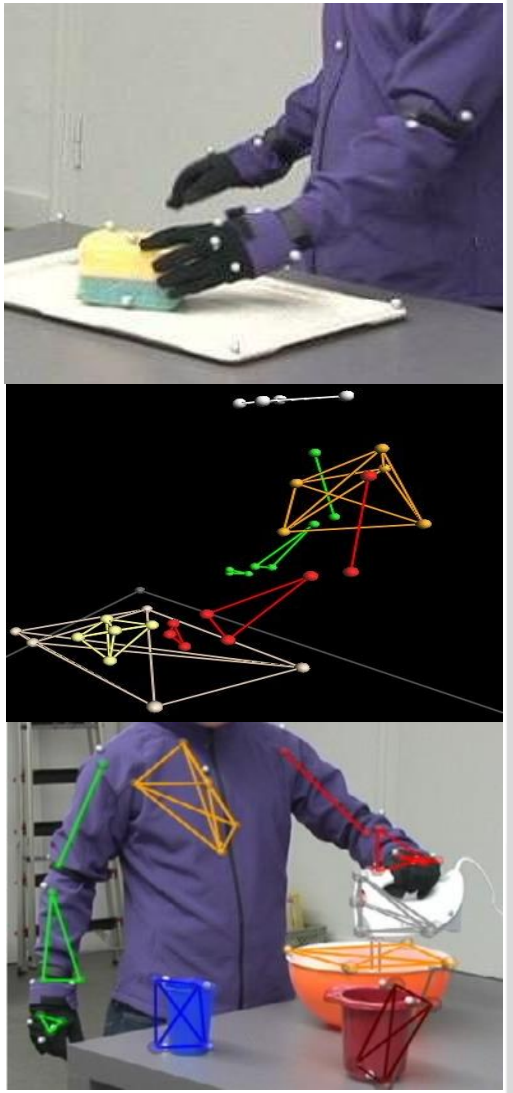
Association of action segments with known Object-Action Complexes (OACs)

Reproduction of task with **sequence** of OACs



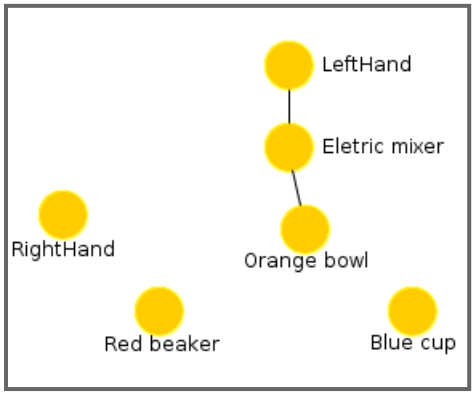
Observation of task demonstration

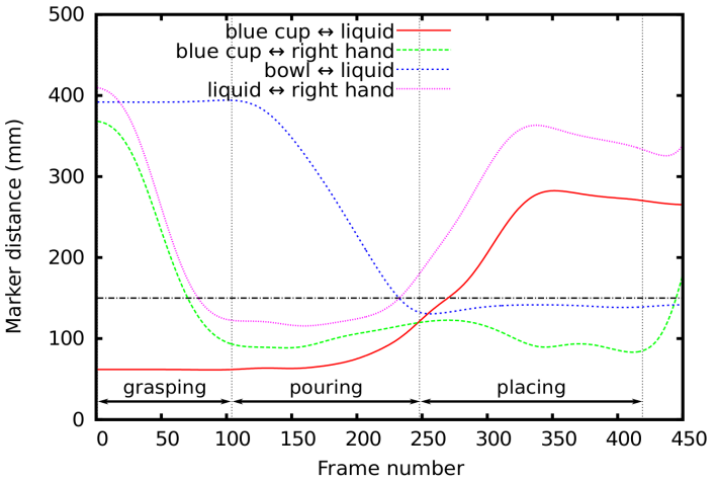
- **Vicon with 10 cameras**
  - Precision (~1mm)
  - Frame rate (200Hz)
- **Markers** attached to human body and all objects
- Markers **grouped by** human body and all objects
  - **Relative position** to other markers of a group trained and used for marker identification
- Extraction of **3D trajectories** of all markers



Automatic Action Segmentation

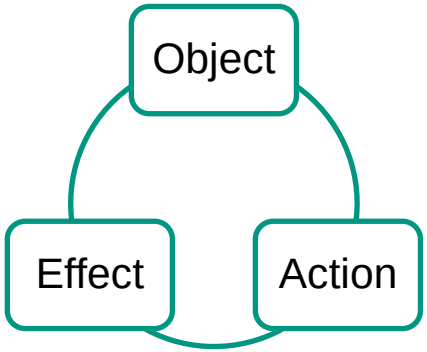
- Segmentation based on detection of **key frames**
- **Based on the Semantic Event Chains concept (Wörgötter et al.)**
- Detection of **key frames** based on **change** of **marker distance**
- Key frames are determined by **object relation changes**
  - Touching/Non-Touching relations between objects
- **World states** stored for every key frame
  - World state is represented as **object relations**



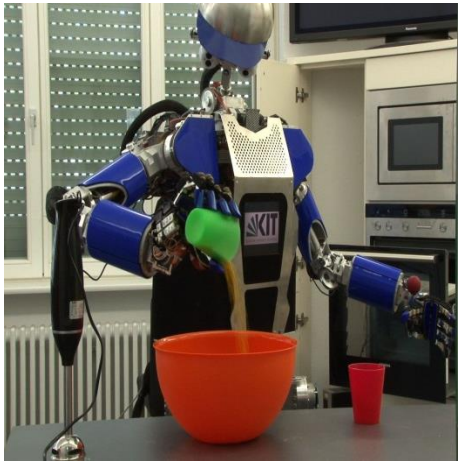


Object-Action Complex library

- Object-Action Complex (simplified)
  - **Motor actions** with object/agent information
    - Object pos.
    - Force/torque information
    - …
  - Stored with **preconditions** and **effect** on the world



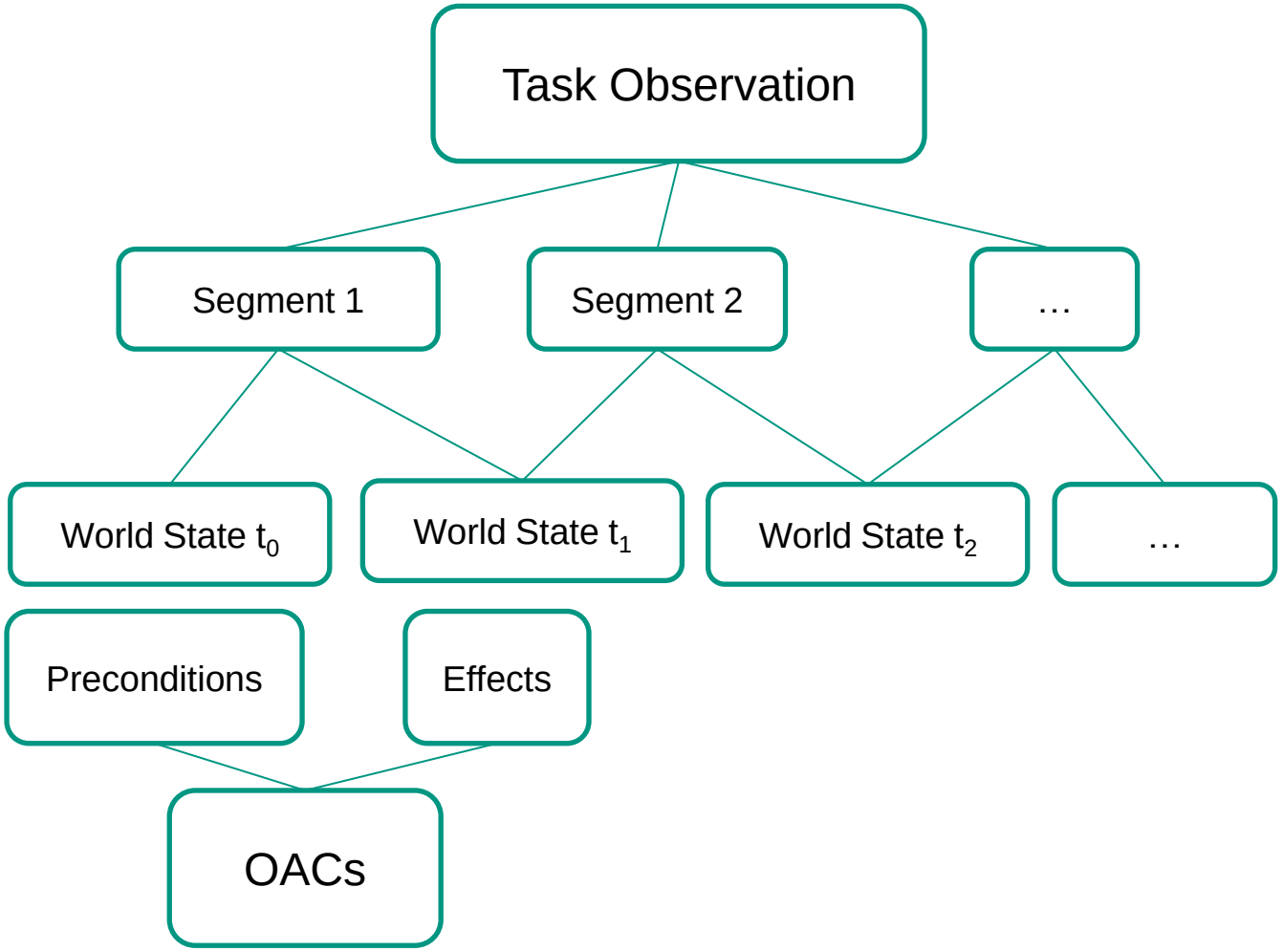
- Basic skills predefined in library:
  - grasping
  - placing
  - pouring
  - …



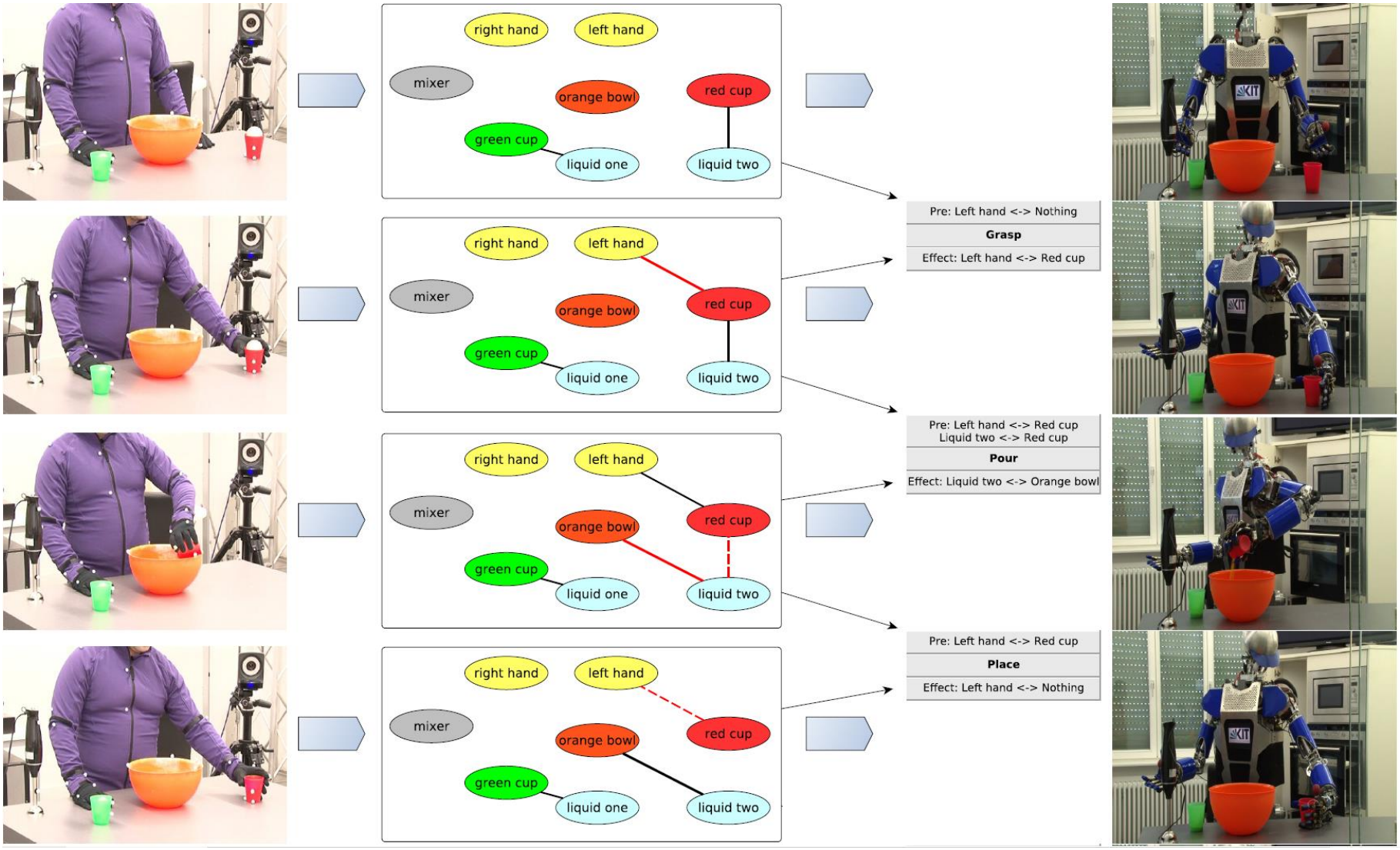
Associating OACs with observed action segments

- OACs have **preconditions** and **effects**
- **Observed segments** are between 2 key frames
  - **Key frames** have the current **world state** attached
- Preconditions and effects of OACs are **subsets** of a world state
- **Matching** preconditions and effects of OACs with observed world states
  - Find an OAC for all observed segments

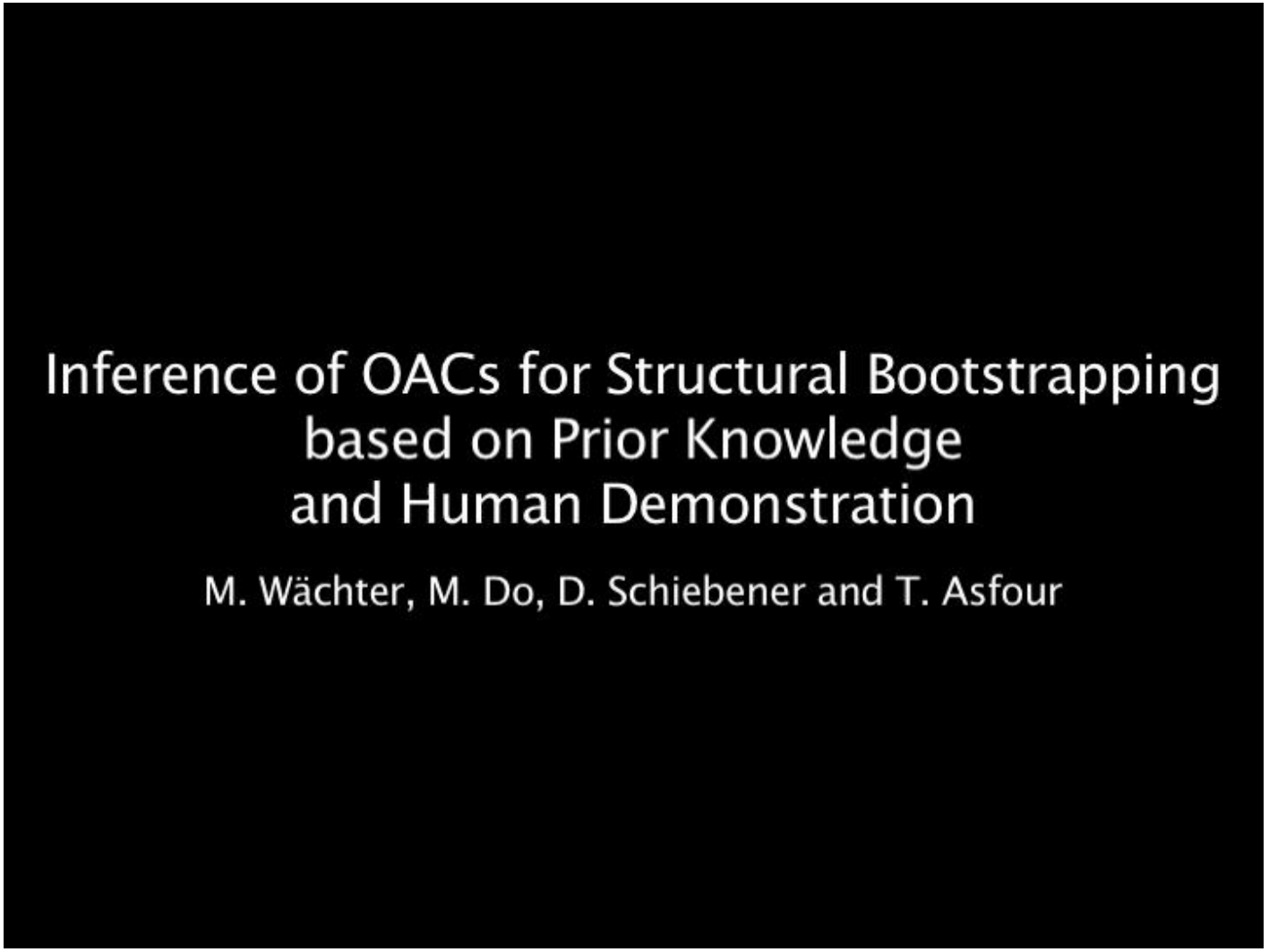
Associating OACs with observed action segments



Example sequence of actions



Learning from observation: OAC replacement



Master Motor Map (MMM)

Master Motor Map (MMM) – Motivation

- Design of humanoid robots

  → models of body parts are needed

- Various human motion capture systems action recognition systems, imitation systems, visualization modules, and robot systems for reproduction

  → Unified representation is needed!

Master Motor Map (MMM)

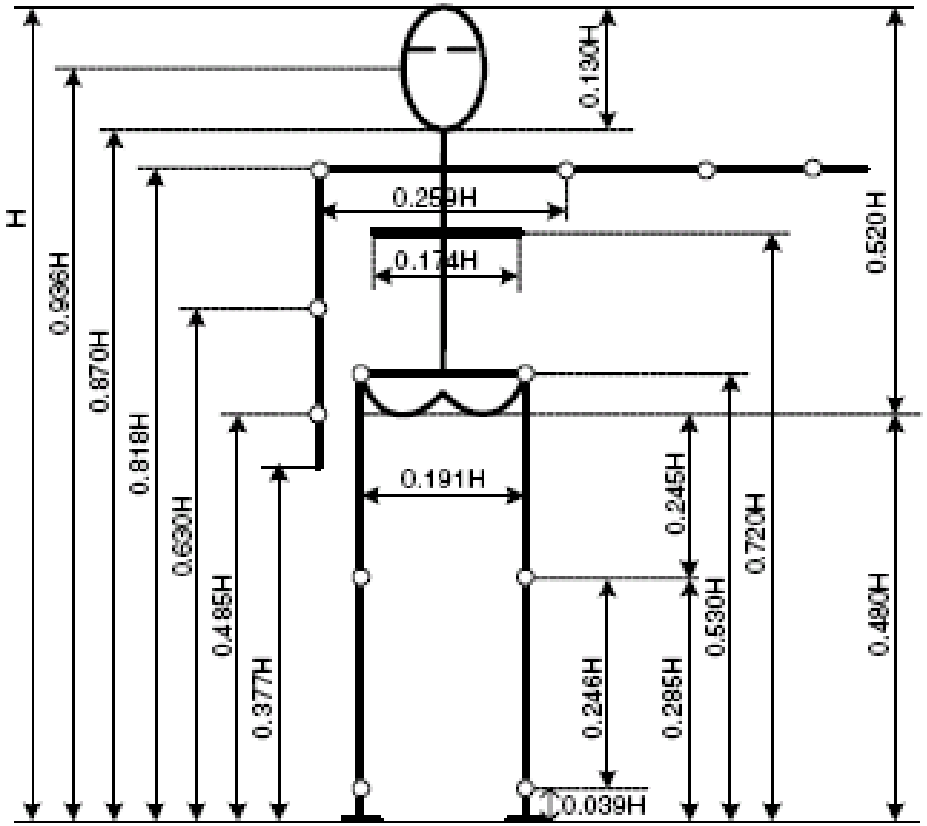
- Reference model of the human body
  - For humanoid robot design
  - Imitation of human actions
  - Action recognition
  - Visualisation of human movements

- Interfaces and data structures for the transfer of motor knowledge between different embodiments

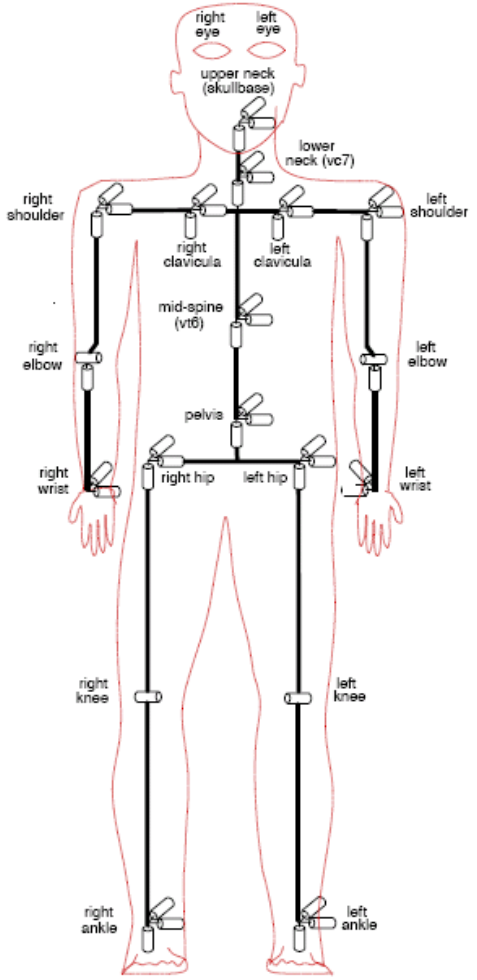
Pedram Azad, Tamim Asfour and Ruediger Dillmann. ***Toward an Unified Representation for Imitation of Human Motion on Humanoids****. IEEE International Conference on Robotics and Automation, 2007*

S. Gärtner, M. Do, C. Simonidis, T. Asfour, W. Seemann and R. Dillmann, ***Generation of Human-like Motion for Humanoid Robots Based on Marker-based Motion Capture Data****, 41th International Symposium on Robotics (ISR), pp. 1 - 8, 2010*

Human body model



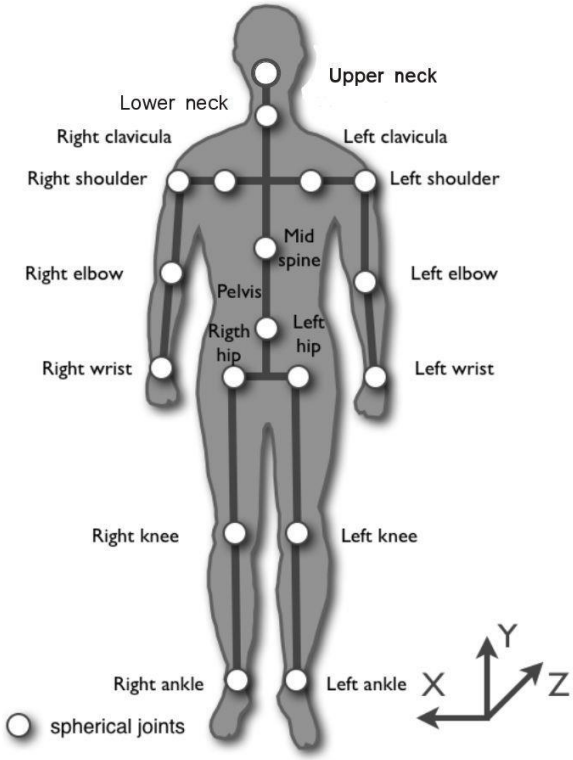
D.A. Winter, Biomechanics and Motor Control of Human Movement, John Wiley & Sons Inc. 1990



P. Azad, T. Asfour, and R. Dillmann, "Toward an Unified Representation for Imitation of Human Motion on Humanoids," in IEEE International Conference on Robotics and Automation, Rome, Italy, April 2007.

Master Motor Map (MMM)

- Reference model of the human body
  - Kinematic model: joints and segment lengths
  - Dynamic model: segment mass, center of mass and moments of inertia
  - Statistic/anthropomorphic model: Segment properties (e.g. length, mass etc) defined as a function (regression) of global parameters (e.g. body height, weight)
  - 96 DoFs (44 for the hands)



(ICRA 2007, ISR 2010, Humanoids 2012)

MMM Specification

- Types of Model:
  - Kinematic Model
    - Arrangement of segments and joints
  - Statistic/ Anthropomorphic Model
    - Body Segment Properties (Winter 2005)
  - Dynamic Model
    - Kinematic model enriched with pre-defined segment properties e.g. mass, length etc.
- Each MMM model is defined as XML Schema
- MMM Software https://i61mmm.ira.uka.de/

Statistic/ Anthropomorphic Model

- Body segment properties (e.g. length, mass etc) are defined as a function (regression) of certain global parameters (e.g. body height, weight etc.)

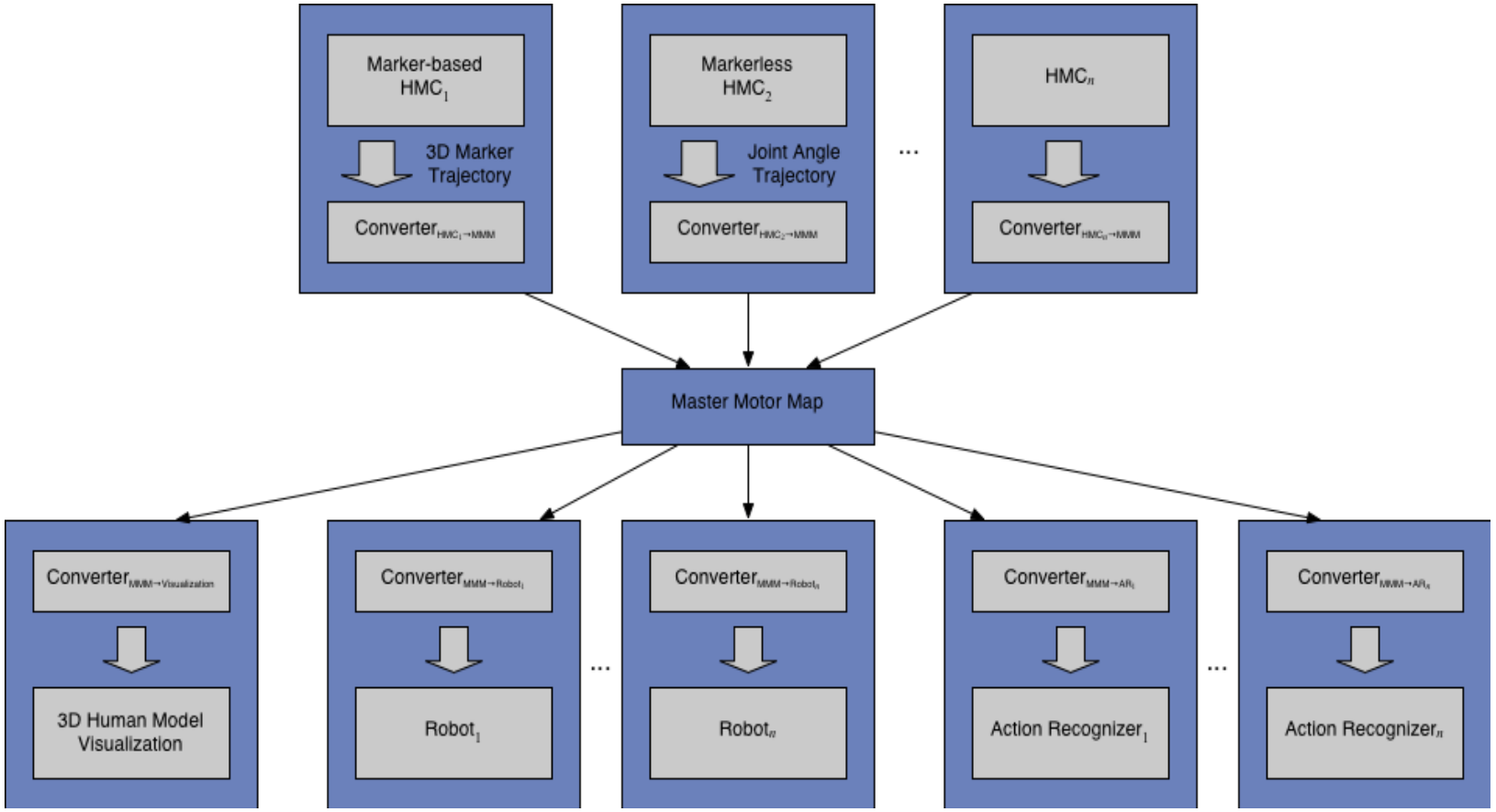
- Models have been discovered and verified by various researchers (see for example de Leva 1996, Winter 2005, Pronost et al., 2006)

D.A. Winter, Biomechanics and Motor Control of Human Movement, John Wiley & Sons Inc. 1990

P. de Leva, "Adjustments to zatsiorsky-seluyanov's segment inertia parameters," J. of Biomechanics, vol. 29, no. 9, pp. 1223 – 1230,1996.

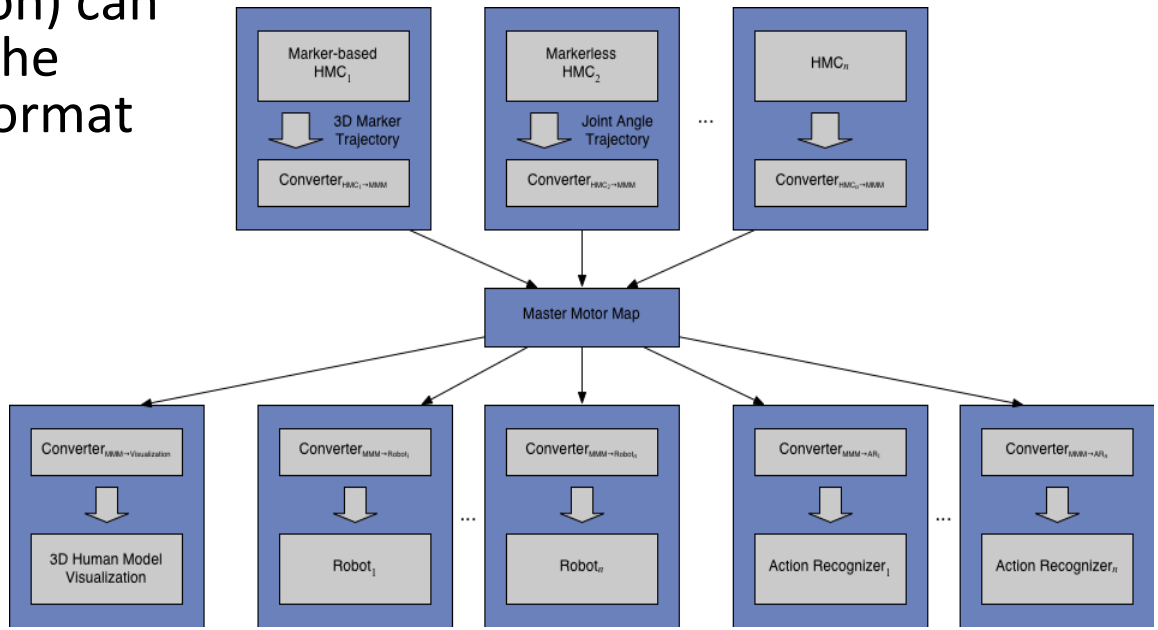
Master Motor Map (MMM)

- Interfaces and data structures for the transfer of motor knowledge between different embodiments



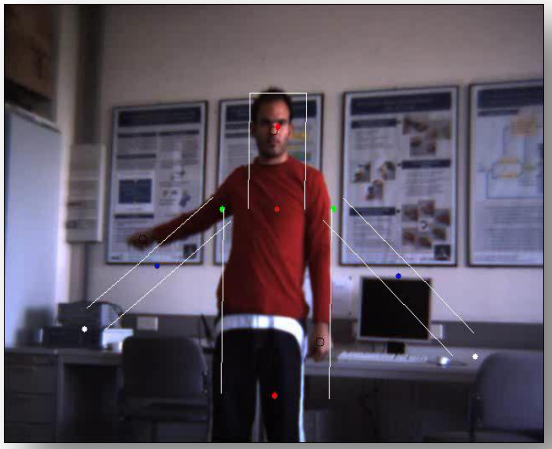
Master Motor Map (MMM)

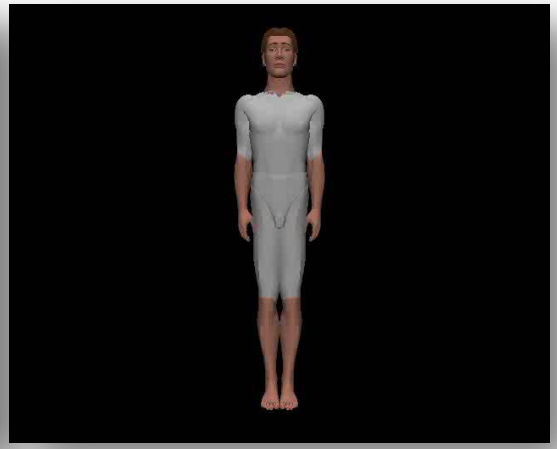
- Replacement of any module (perception, recognition, visualization, reproduction) can be guaranteed by using the MMM as the exchange format
- All perceptive module convert their output to the MMM format
- All recognition and reproduction modules convert the MMM format to their specific internal representation



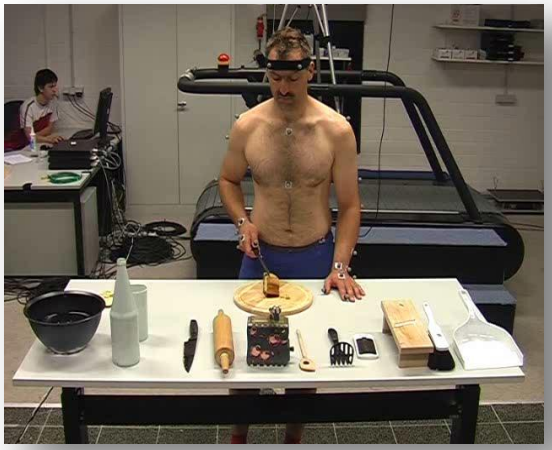
Motion reproduction using MMM

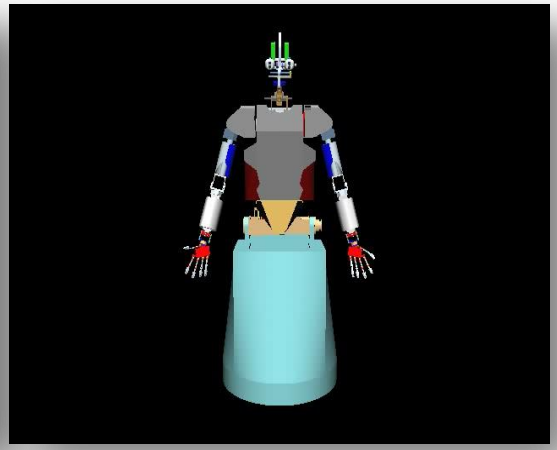
- Data from stereo-based markerless human motion capture system



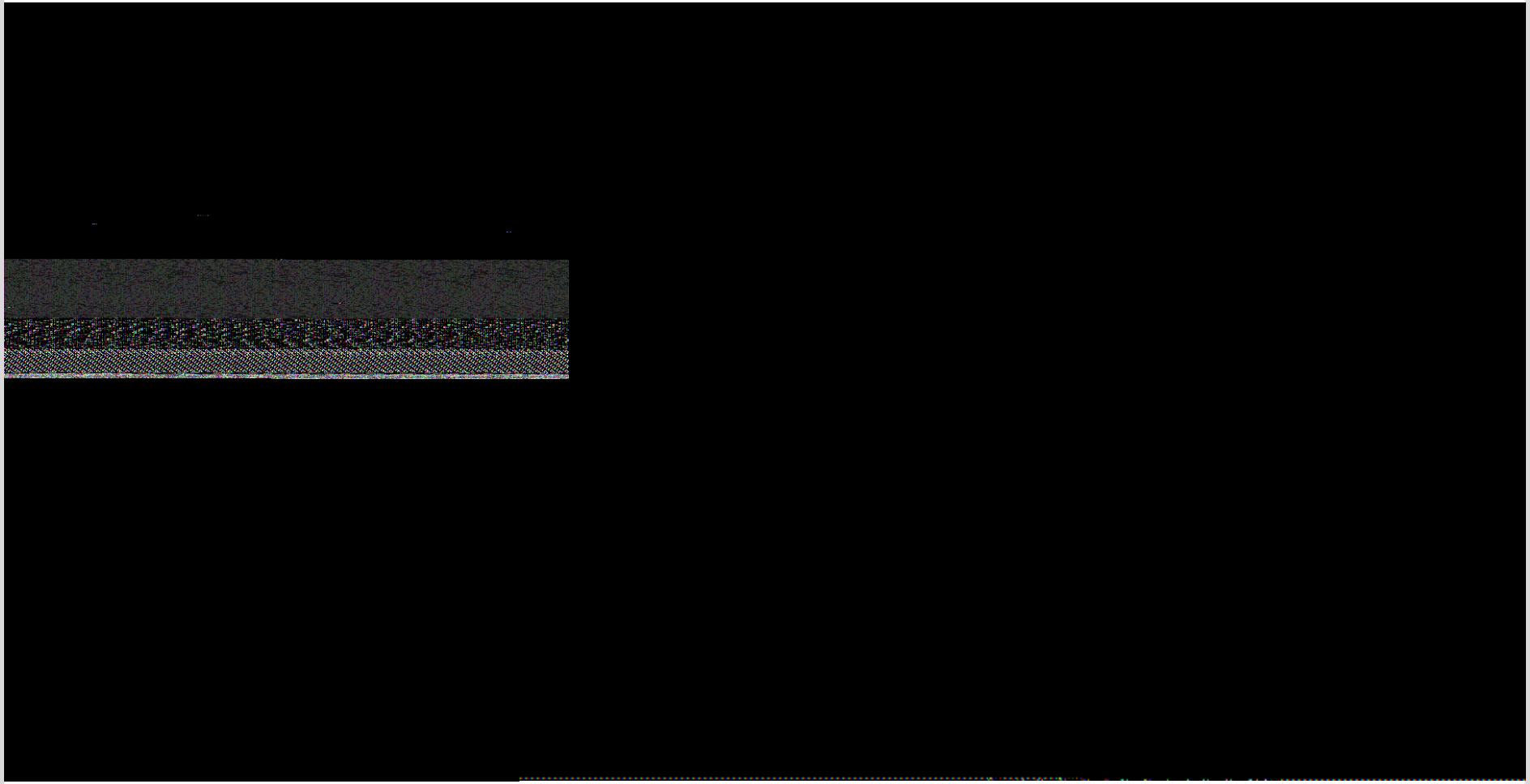


- Data from VICON system (SFB 588)



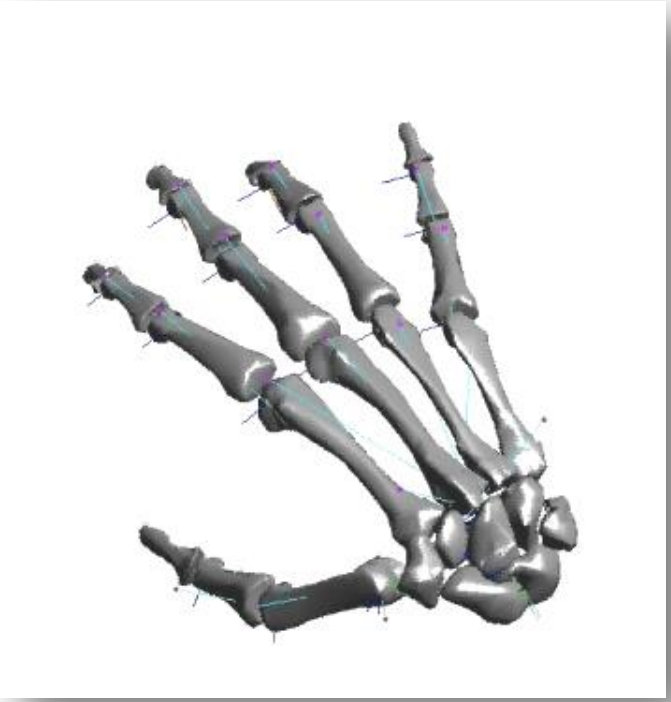


Motion Reproduction using MMM

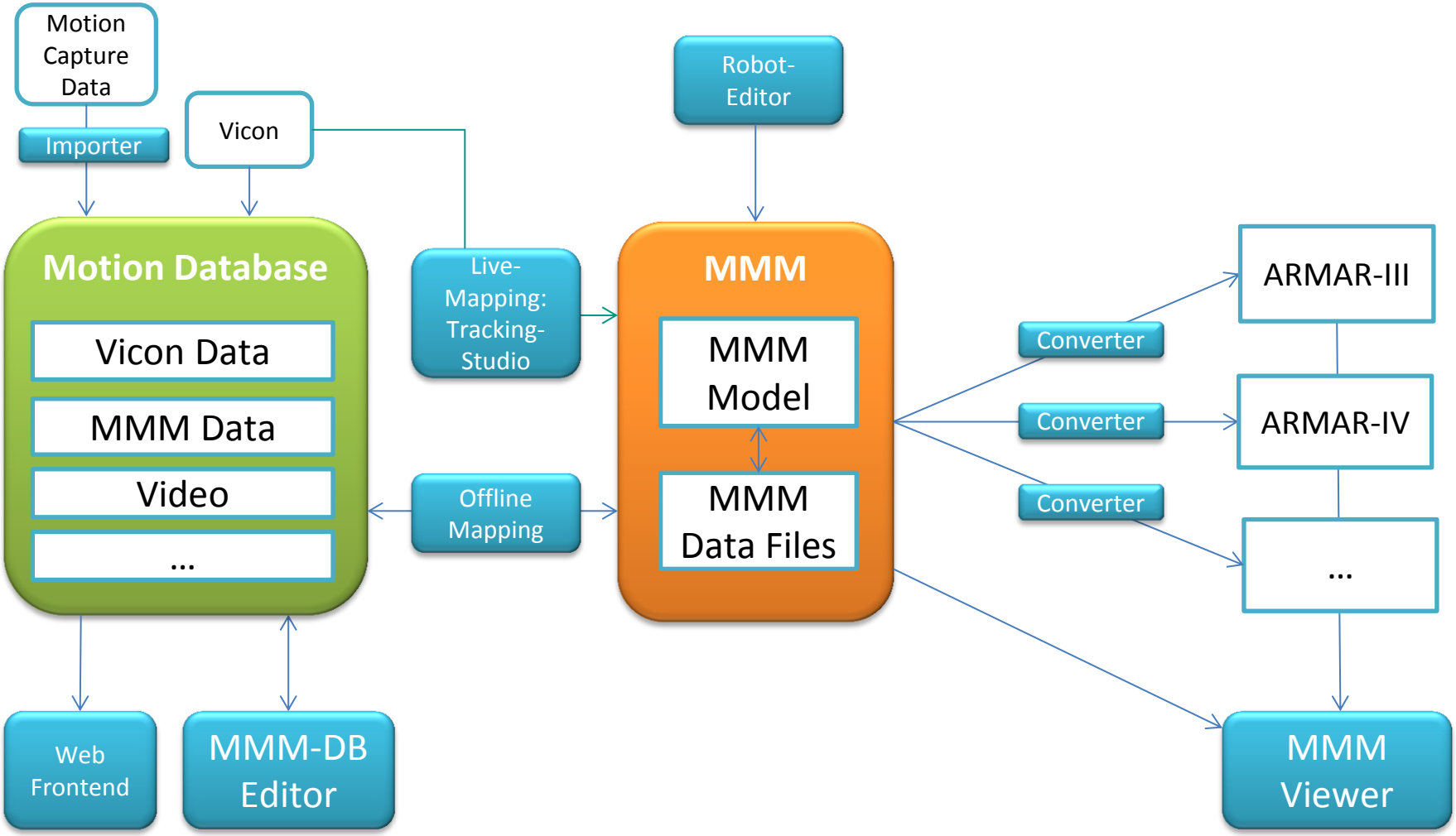


SFB 588

Motion Reproduction using MMM

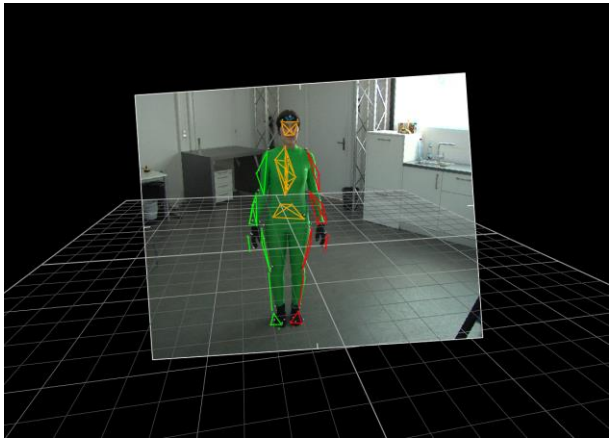


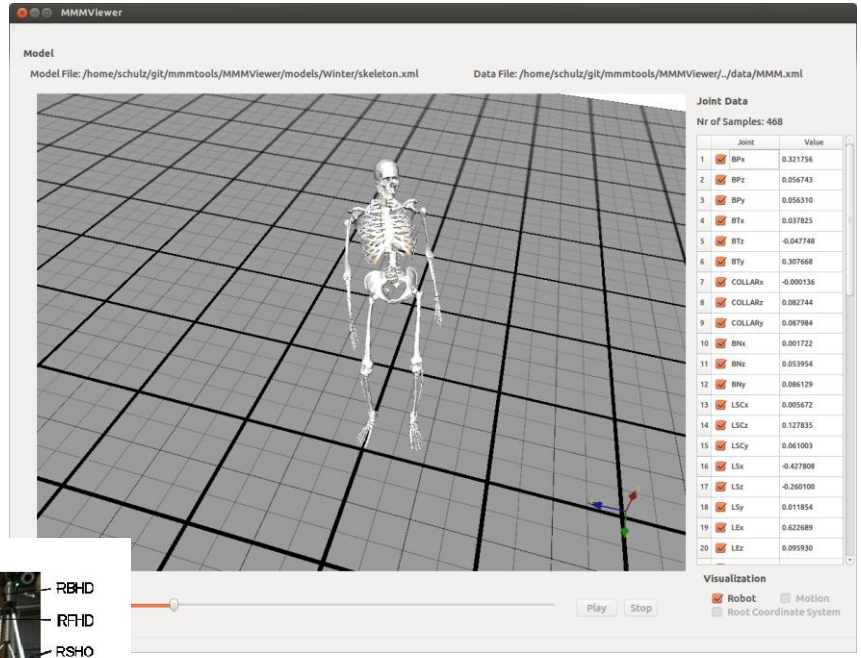
Master Motor Map - Framework

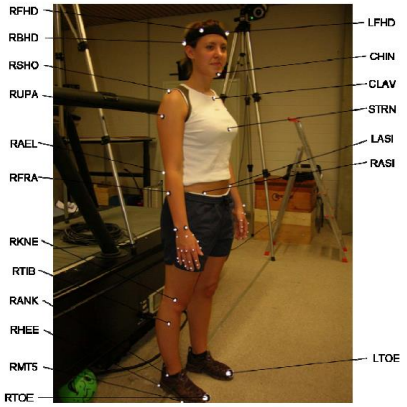


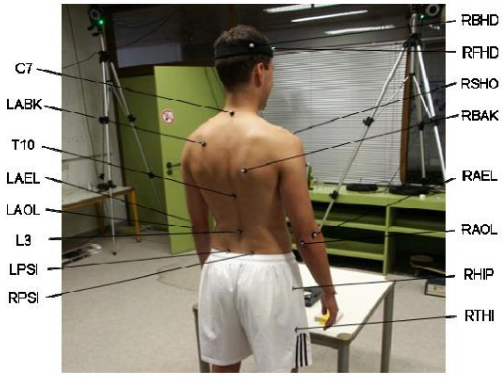
Large scale motion database & MMM

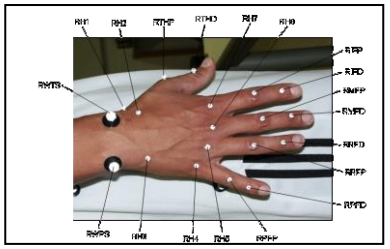
- Human motion capture using Vicon, vision, force, …
- Object and environment information





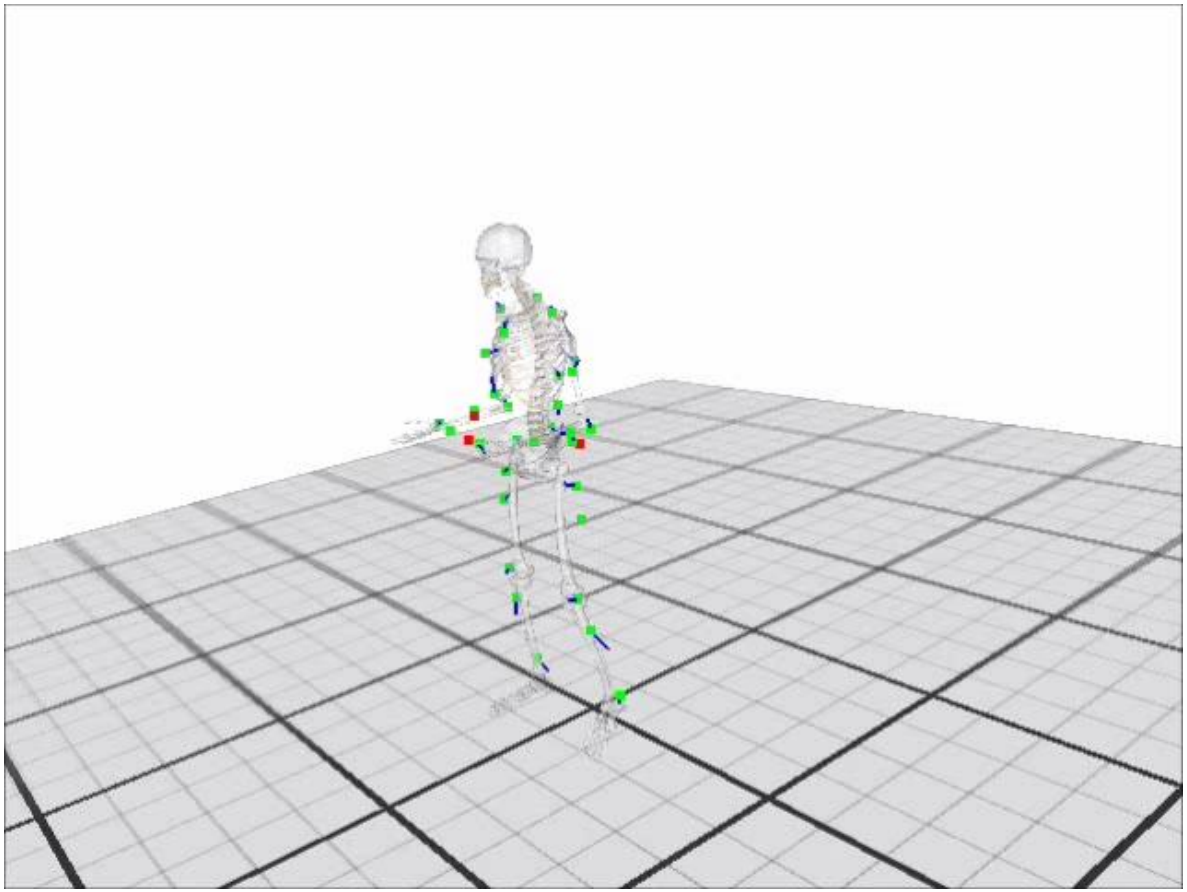




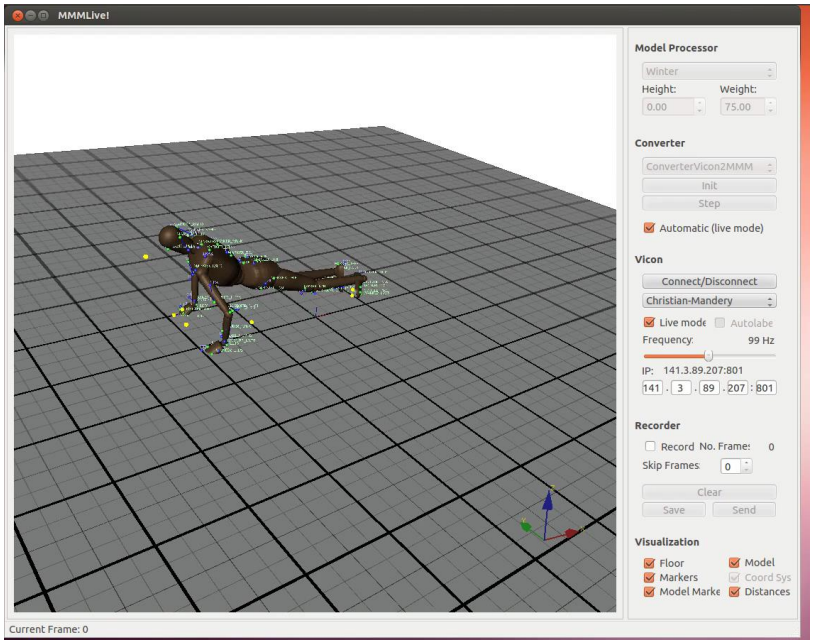


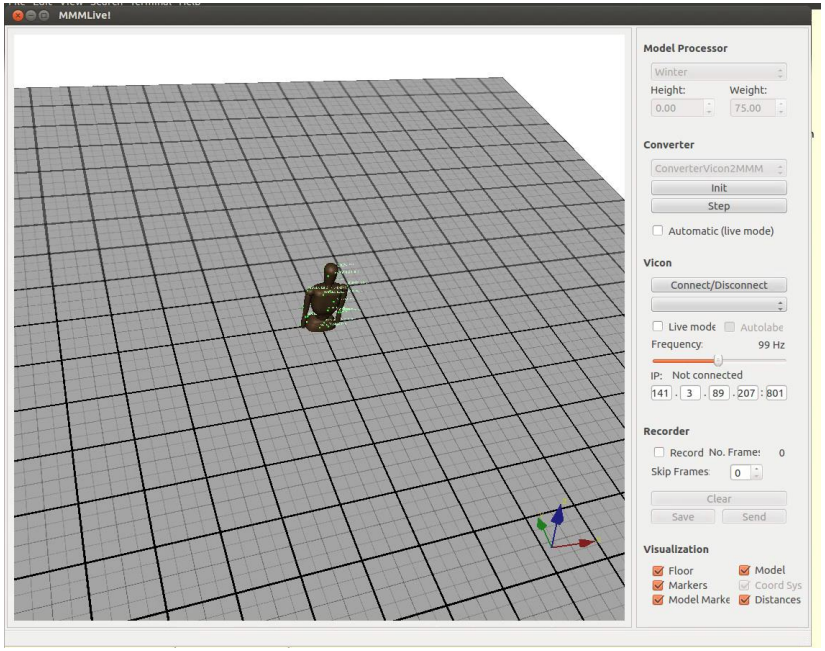
Large scale motion database & MMM

- Tracking Studio: Live mapping from human to MMM

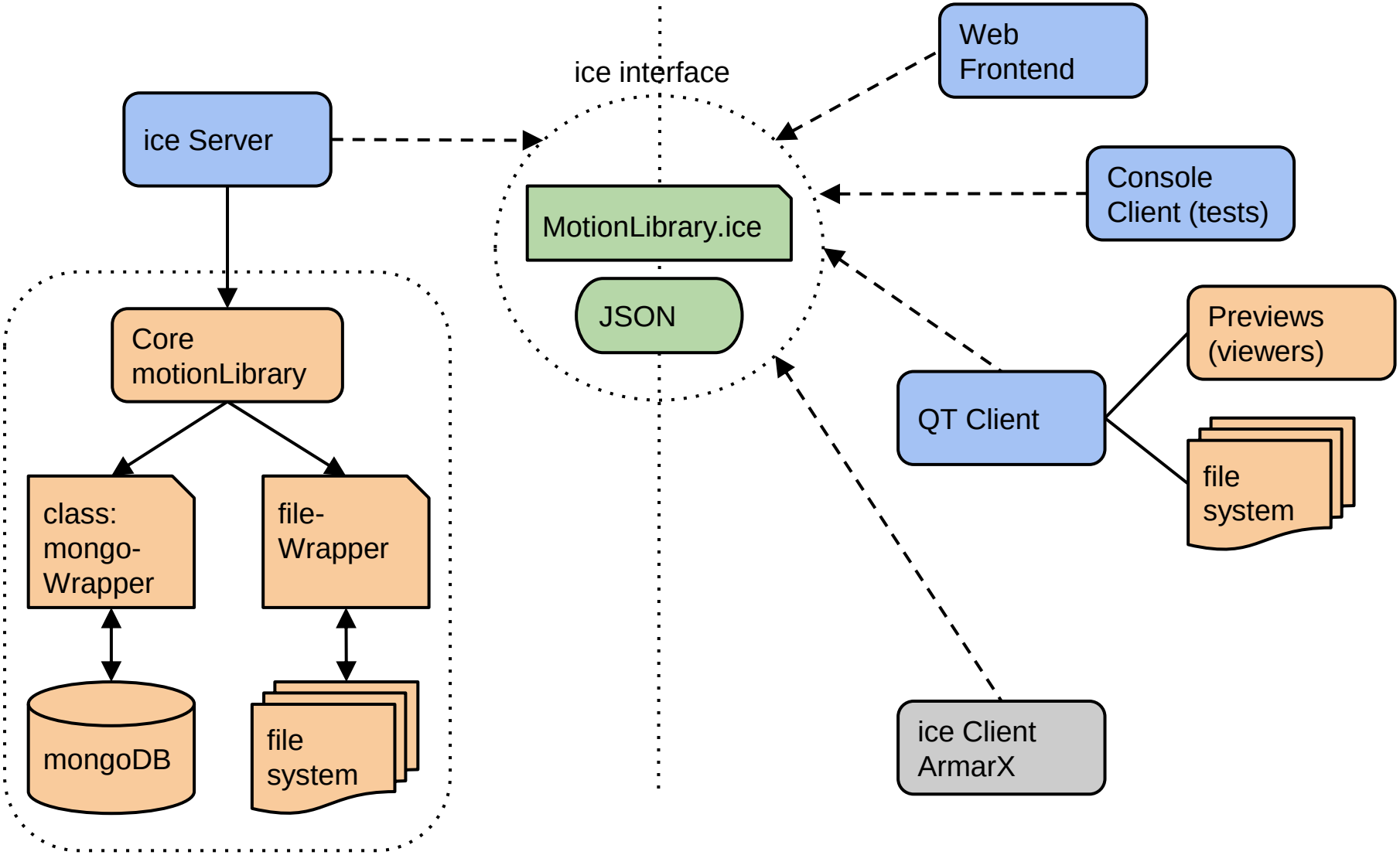


Live Motion Capture and Mapping



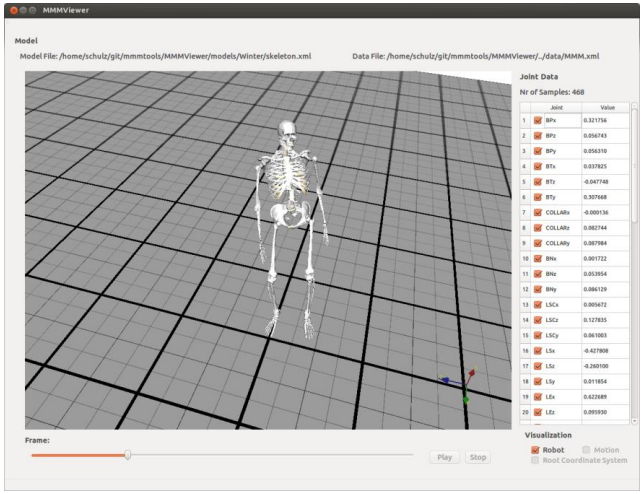


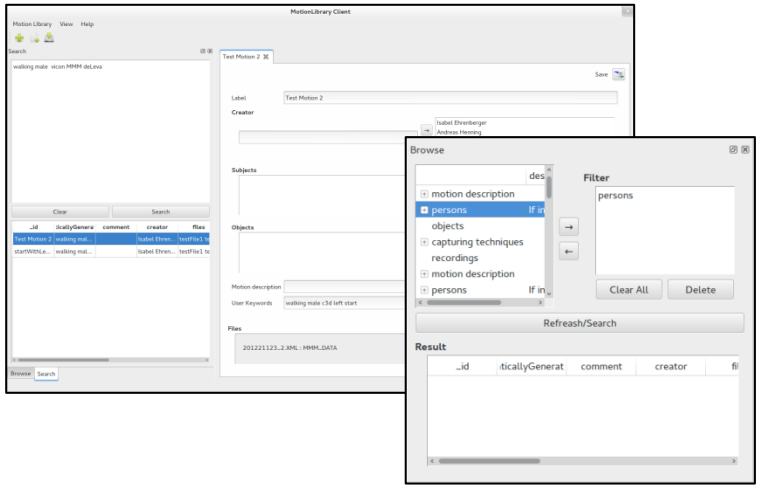
MMM Tools


ice interface
Web Frontend
ice Server
Console Client (tests)
MotionLibrary.ice
JSON
Core motionLibrary
Previews (viewers)
QT Client
file system
class: mongo-Wrapper
file-Wrapper
mongoDB
file system
ice Client ArmarX

MMM Library & Tools

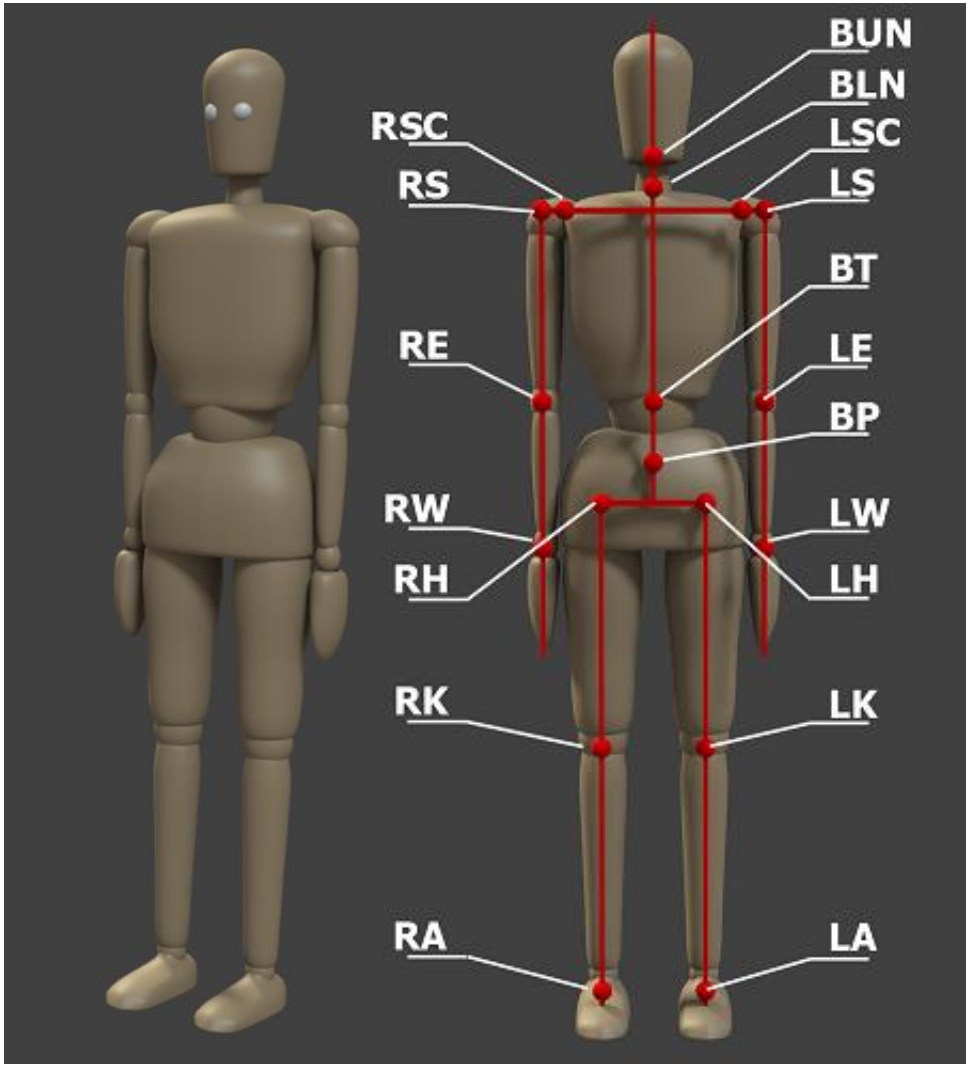
- **MMM Core**
  - C++ Library
  - I/O, XML, Raw Marker Data, Tools, Conversions
  - No dependencies (just Boost)
- **Mapping / Converter**
  - Vicon -> MMM model
  - MMM -> Robots (ARMAR III, ARMAR IV)
  - MMM -> Other robots (iCub, COMAN, HRP, …)
- **MMM Viewer**
  - 3D Model Viewer
  - MMM / Marker Data
  - Robots, Motions, Contacts, …
- **MMM Database**
  - Server
  - Client/Applications, Search, Web Frontend





MMM new visualization

- Modelled in Blender
- 50 DoF are included (out of 96)
- Scalable
  - Every segment is in relation to the total height of the model
- Includes dynamical properties for every segment
  - Weight
  - Center of Mass (CoM)
  - Inertia-tensor
  - Scales with total weight



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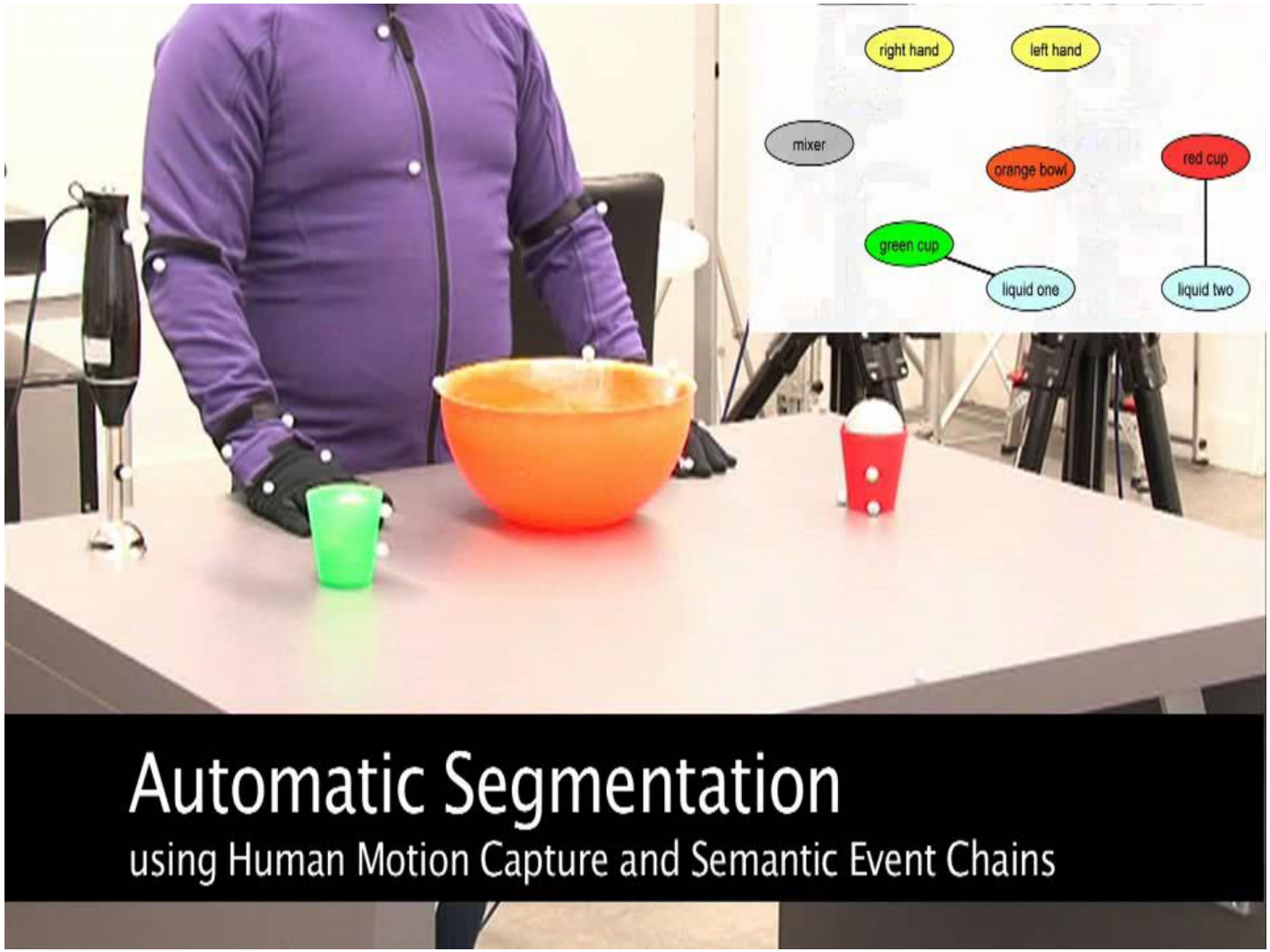
- Our previous work
  - S. Lengagne, O. Terlemez, S. Laturnus, T. Asfour and R. Dillmann, **Retrieving Contact Points Without Environment Knowledge**, IEEE-RAS International conference on Humanoid robots, pp. 841 - 846, 2012
  - S. Gärtner, M. Do, C. Simonidis, T. Asfour, W. Seemann and R. Dillmann, **Generation of Human-like Motion for Humanoid Robots Based on Marker-based Motion Capture Data**, 41th International Symposium on Robotics (ISR), pp. 1 - 8, 2010
  - Pedram Azad, Tamim Asfour and Ruediger Dillmann. **Toward an Unified Representation for Imitation of Human Motion on Humanoids**. IEEE International Conference on Robotics and Automation, 2007

- Others
  - David A. Winter. **Biomechanics and Motor Control of Human Movement**. John Wiley & Sons, Inc. 2005
  - P. de Leva, **Adjustments to Zatsiorsky-Seluyanov's Segment Inertia Parameters**, J. of Biomechanics, vol. 29, no. 9, pp. 1223 – 1230, 1996.
  - Nicolas Pronost, Georges Dumont. **Validating re-targeted and interpolated locomotions by dynamics-based analysis**. Proceedings of the 4th international conference on Computer graphics and interactive techniques in Australasia and Southeast Asia. 2006
  - Michael Gleicher. **Retargetting Motion to New Characters**. SIGGRAPH 2008

Execution on Armar III



What’s next

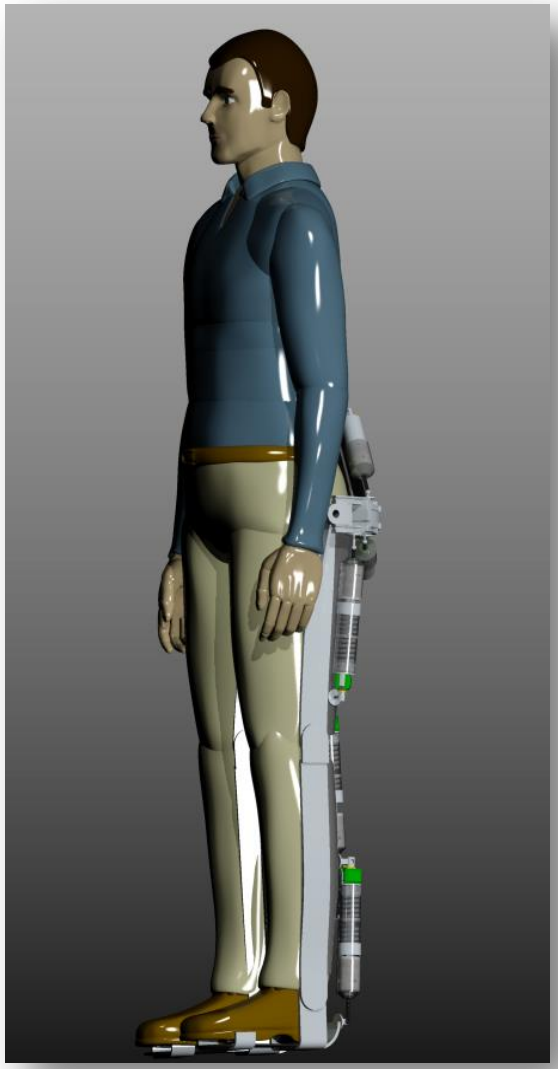
ARMAR-V

- First step towards humanoid robots with **multiple functions** and for **dual use**

Helper, Assistant and Companion

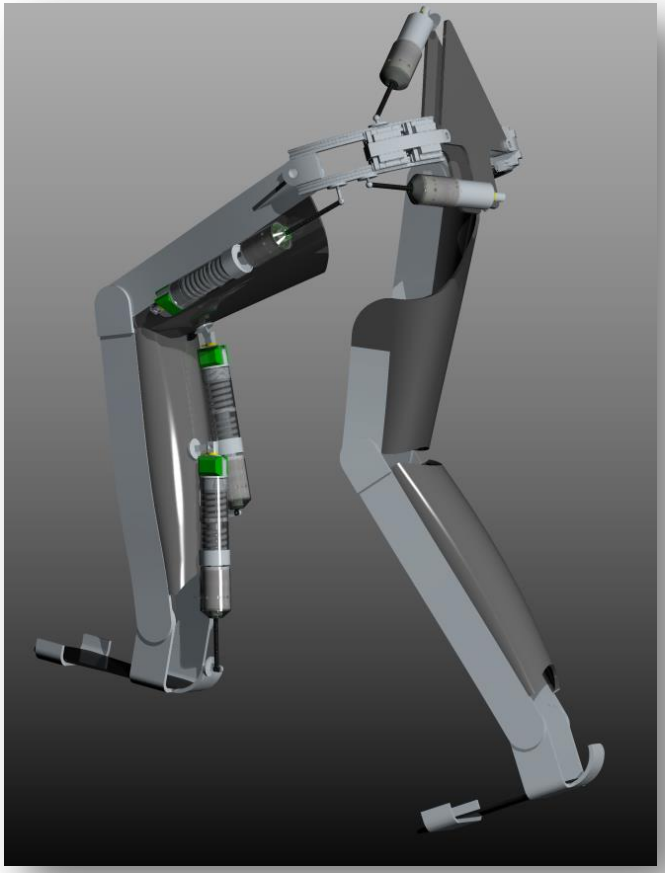
Wearable Humanoid „Body suit“

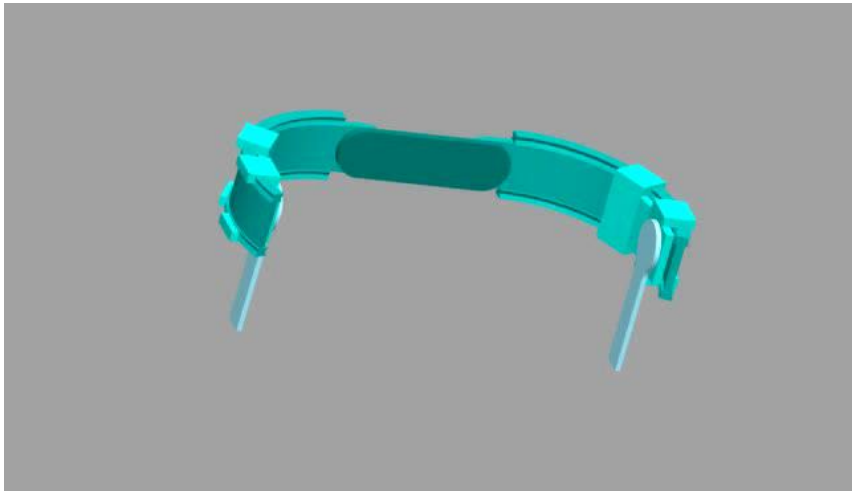
ARMAR-V: Legs



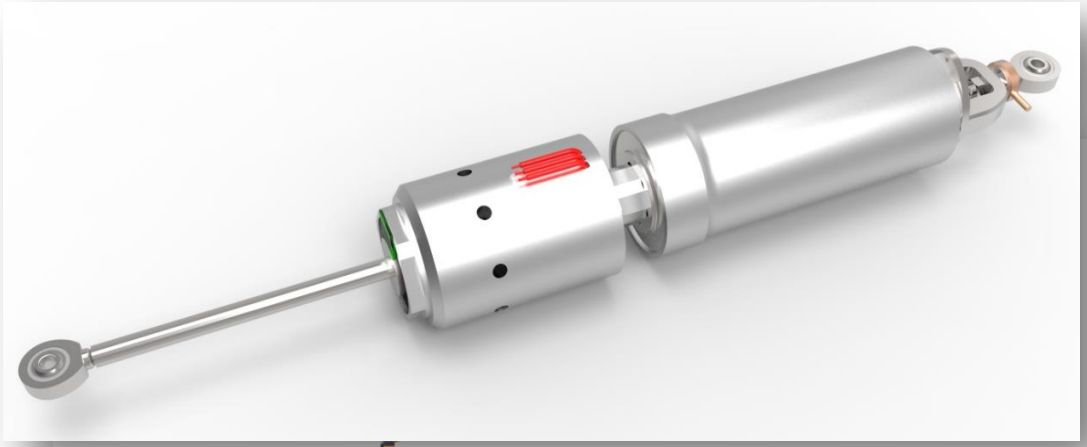
ARMAR-V Legs

- 5 actuated DOFs in total in each leg
  - 3 DOFs in the hip
  - 1 DOF in the knee
  - 1 DOF in the ankle
- Serial elastic actuation in 3 pitch – DOFs
  - Adjustment of elasticity
- Joint peak torques ~ 120 Nm

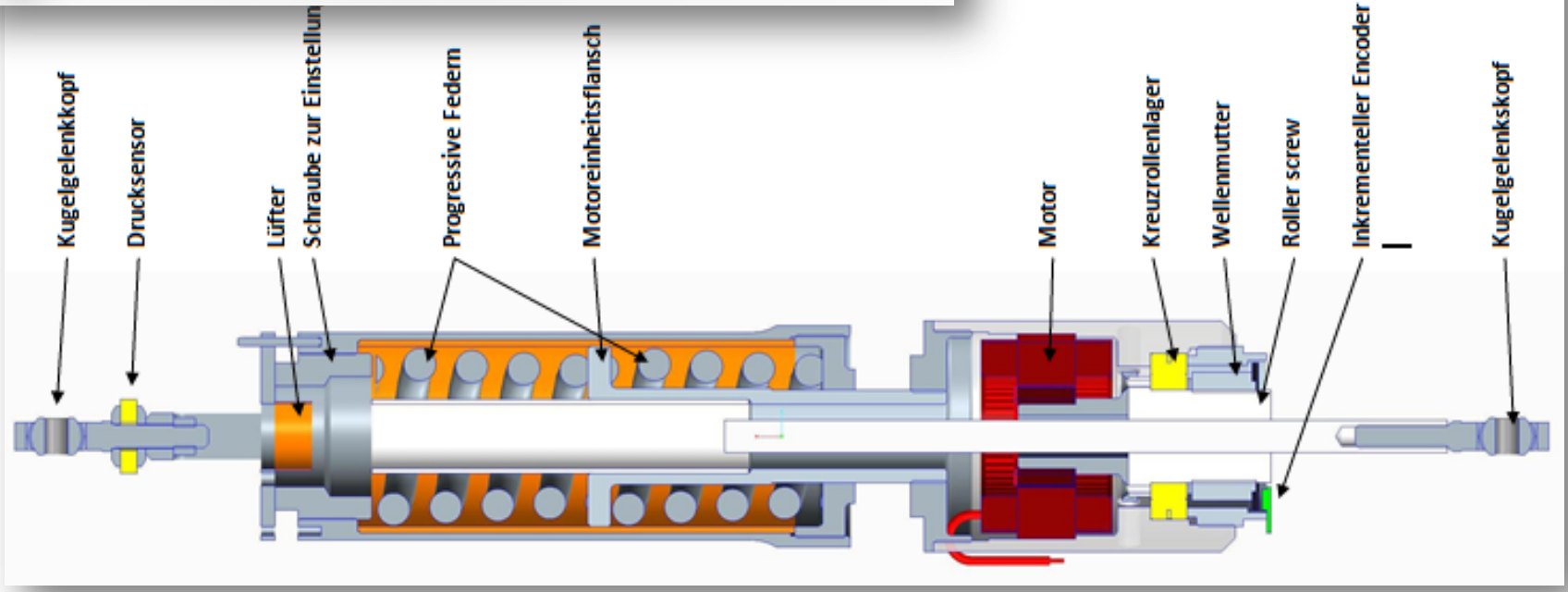




ARMAR-V Legs – New Linear Elastic Actuators

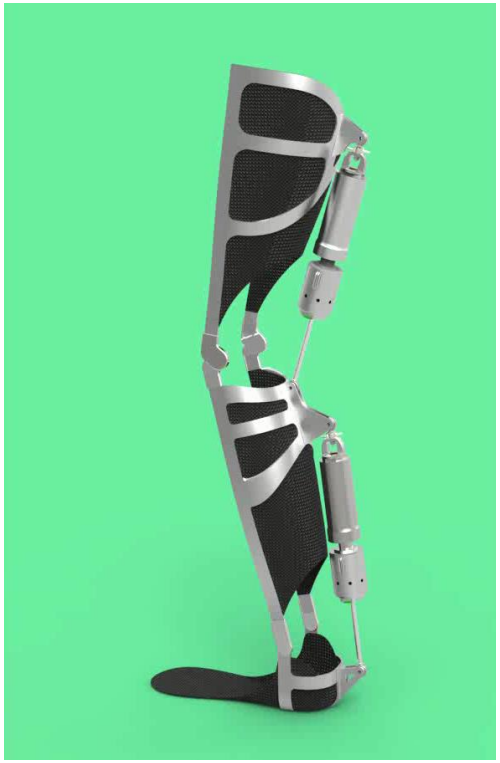


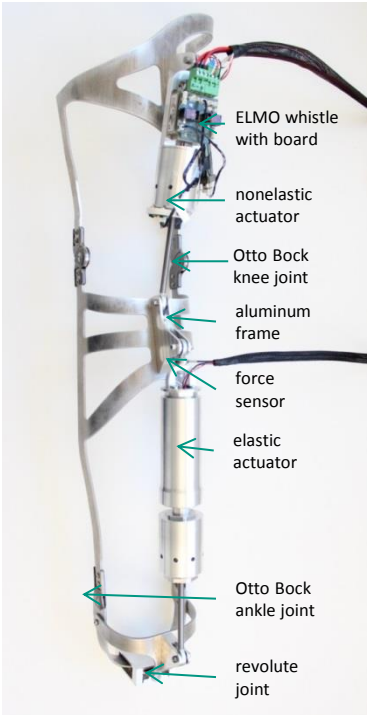
- Maximal axial force 2900 N
- Force at nominal motor torque 930 N
- Speed 300 mm/sec



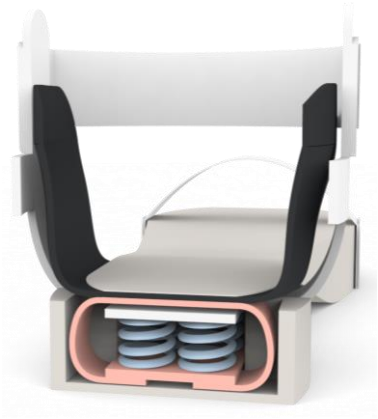
First version – with two elastic actuators

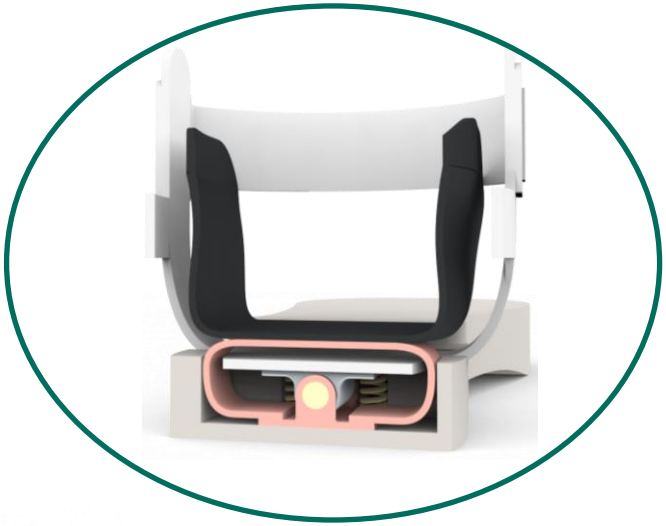
- Progressive springs integrated in the actuators for energy storage and reuse
- Serial-elastic type with 2 progressive springs
- Manually adjustable stiffness by increasing preload on springs

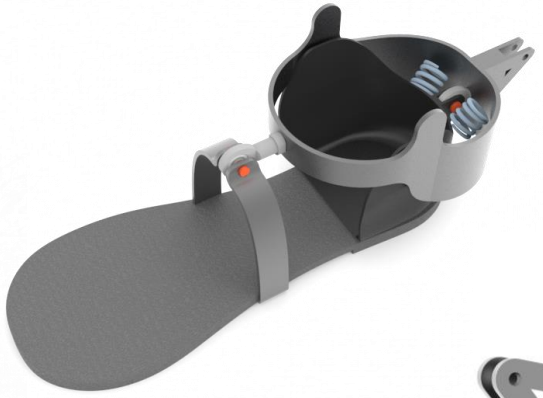


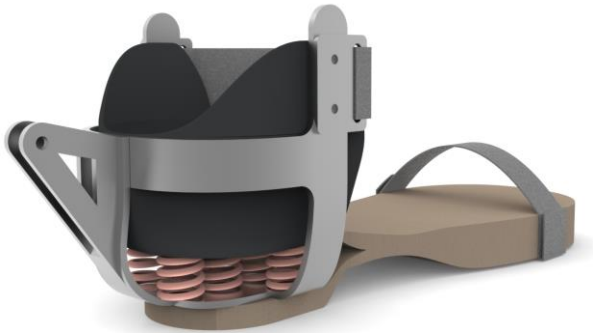


Foot and ankle joint – concepts

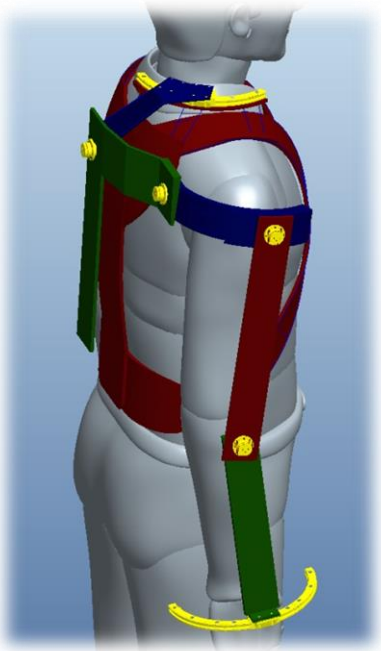


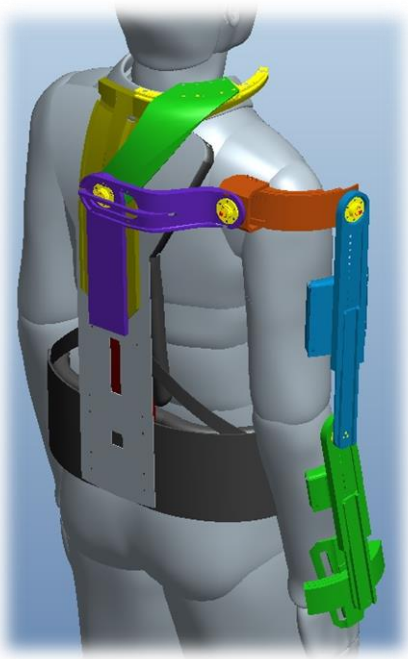


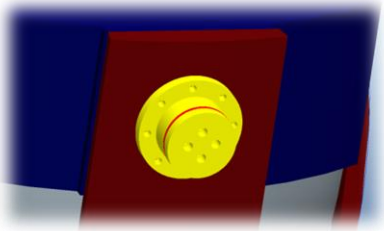


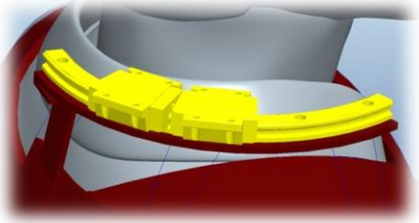


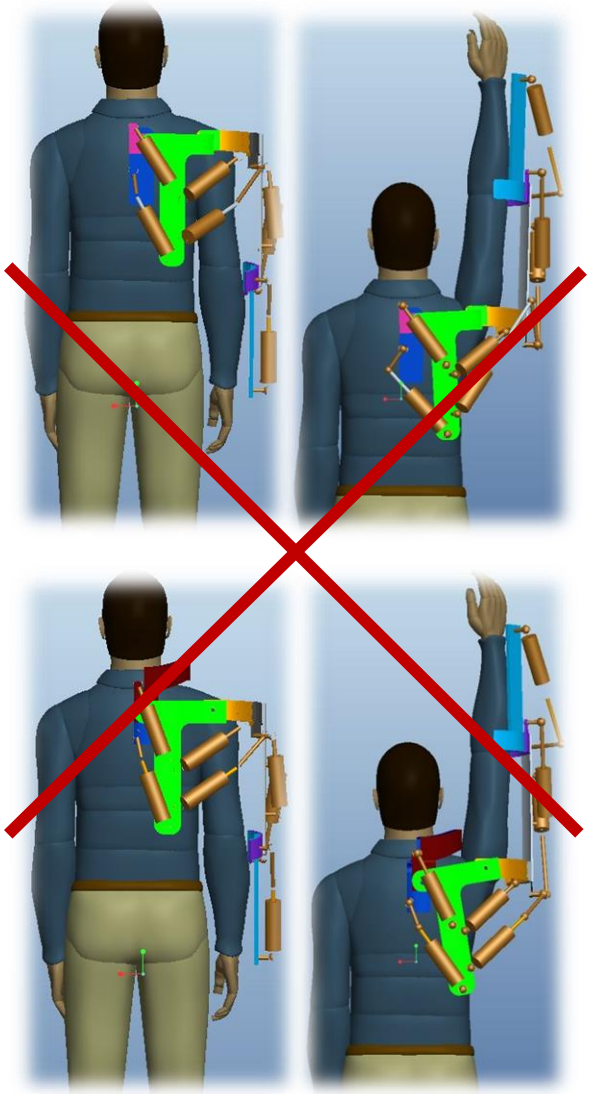
ARMAR-V: Upper body



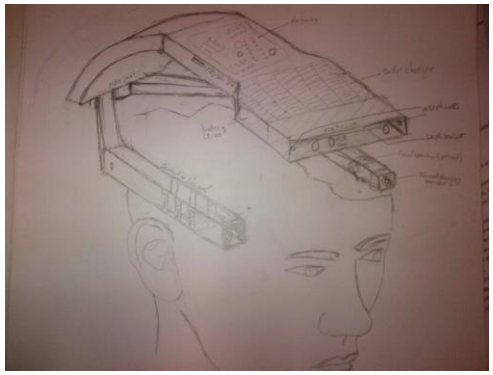


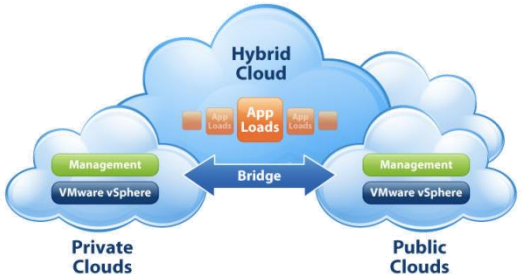






ARMAR-V: Head/ smart Helmet





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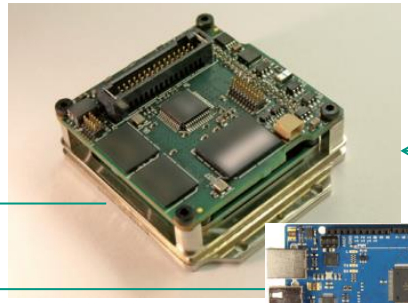
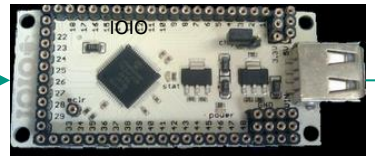
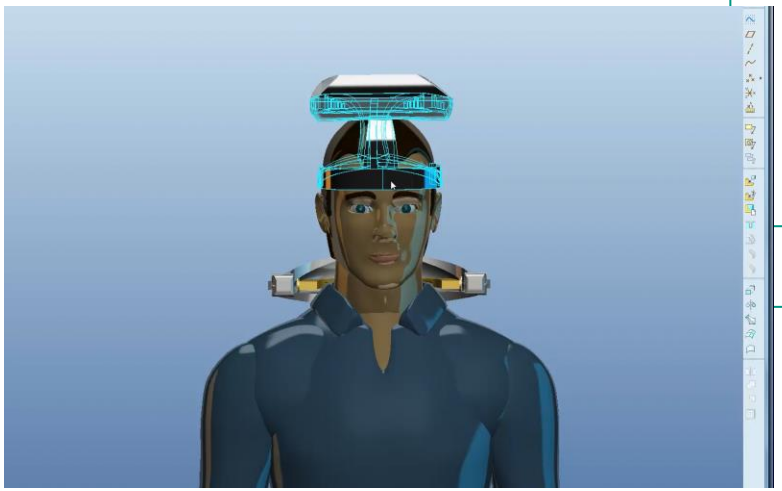


E-Nose

Vibration motors

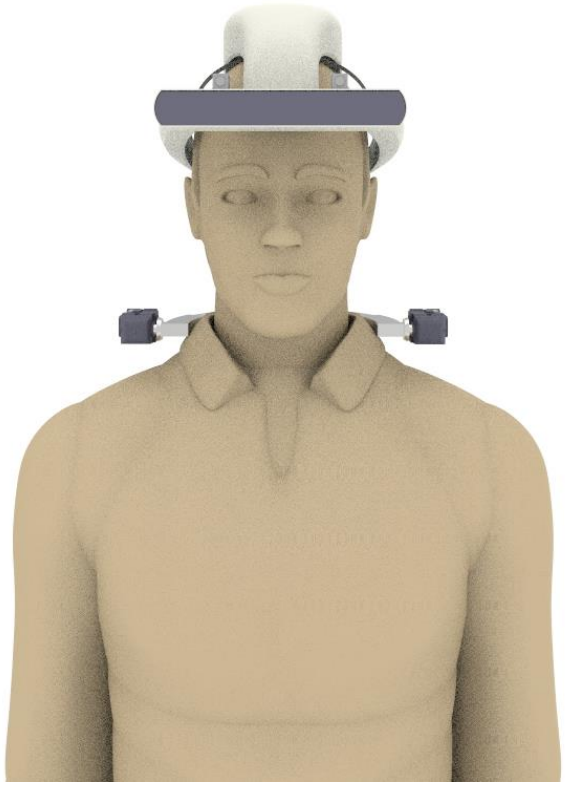


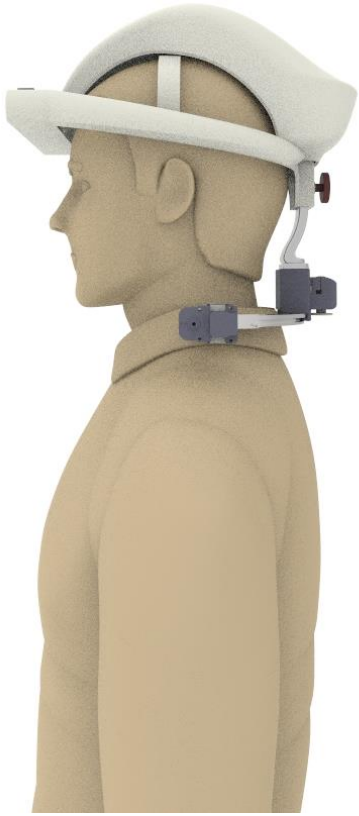


- Vision
- Audio
- Chemical
- Ultra low power thermal cameras
- Solar charger
- …

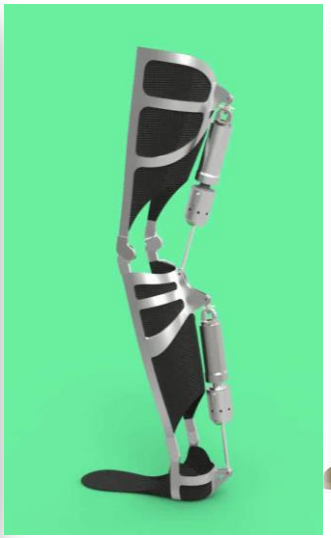
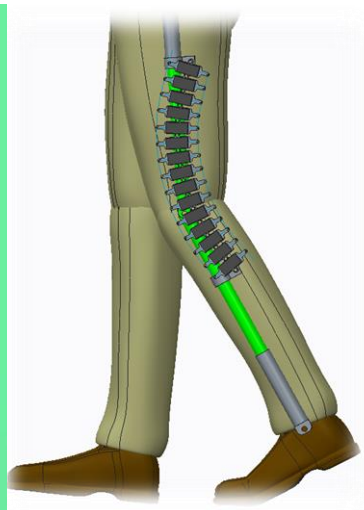
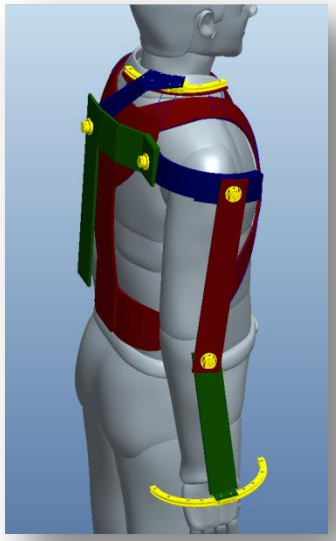
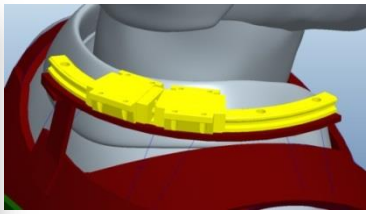
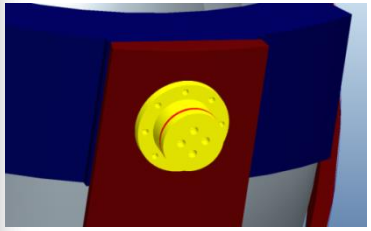
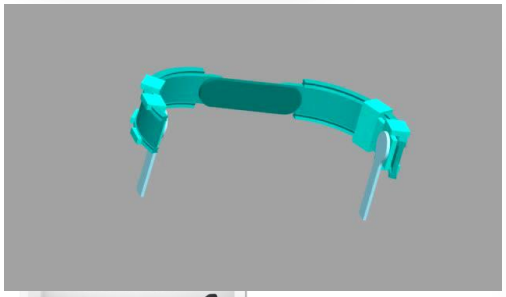
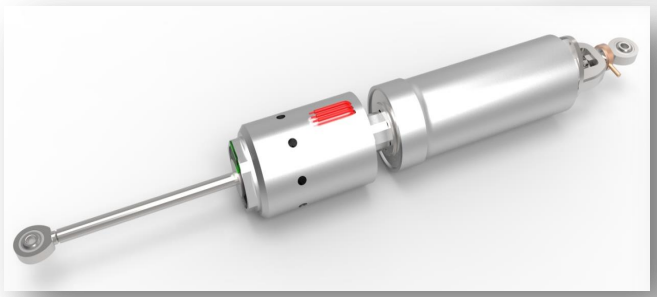
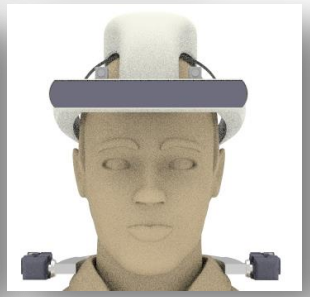
Solar charger

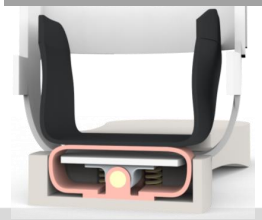
ARMAR-V: Head/ smart Helmet





ARMAR-V: Wearable Humanoid

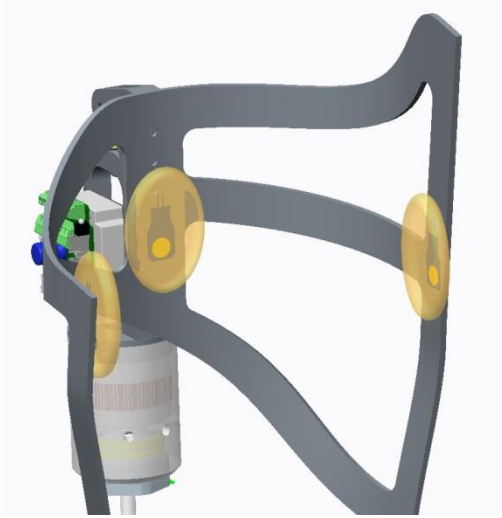


- Maximal „axial“ force 2900 N
- Force at nominal motor torque 930 N
- Speed 300 mm/sec

ARMAR V: Interface to the human body

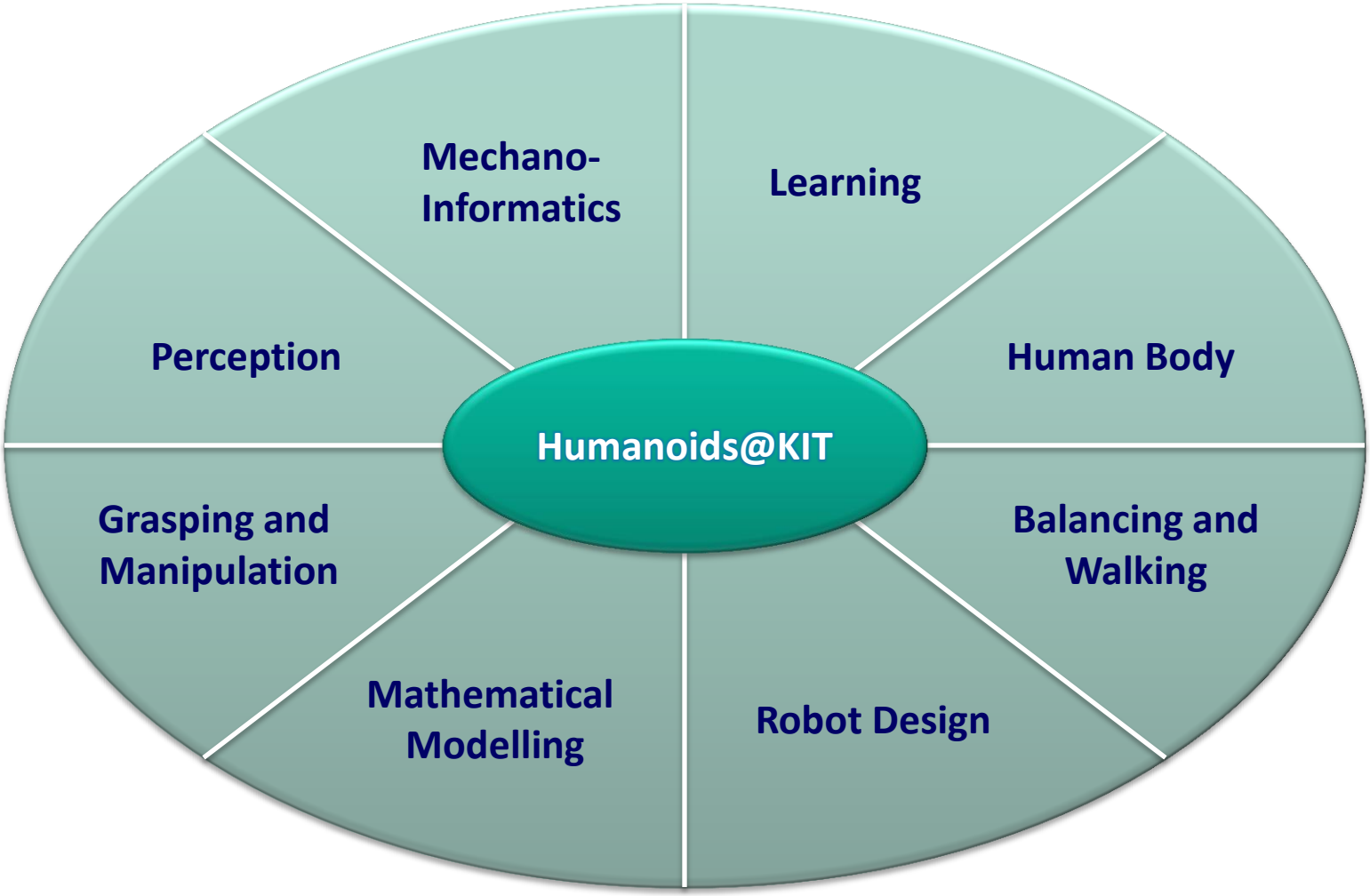
Force sensor suit

- Non-invasive, EMG-free Interface to the human body
- Learn interaction force pattern between human and suit and use them for prediction



- EMG unreliable
- EMG can only be used to train a classifier as well as to study correlations between EMG pattern and force pattern “feel the muscle activation”

Humanoids@KIT



Thanks to ...

- German Research Foundation (DFG)
  - SPP 1527 autonomous-learning.org (2010 -)
  - SFB/TR 89 www.invasic.de (2009 -)
  - SFB 588 www.sfb588.uni-karlsruhe.de (2001 - 2012)

- European Commission
  - Xperience www.xperience.org (2012-2015)
  - Walk-Man www.walk-man.eu (2013-2017)
  - KoroiBot www.koroibot.eu (2013-2016)
  - PACO-PLUS www.paco-plus.org (2006-2011)
  - GRASP www.grasp-project.eu (2008-2012)

- Karlsruhe Institute of Technology (KIT)
  - Professorship “Humanoid Robotic Systems”
  - Heidelberg-Karlsruhe Research Partnership (HEiKA)

Thanks for your attention