Napoli Colloquium on Robotics
Napoli, April 21, 2015

Humanoid Robotics: From Household Assistants to Personalized Robot Suits

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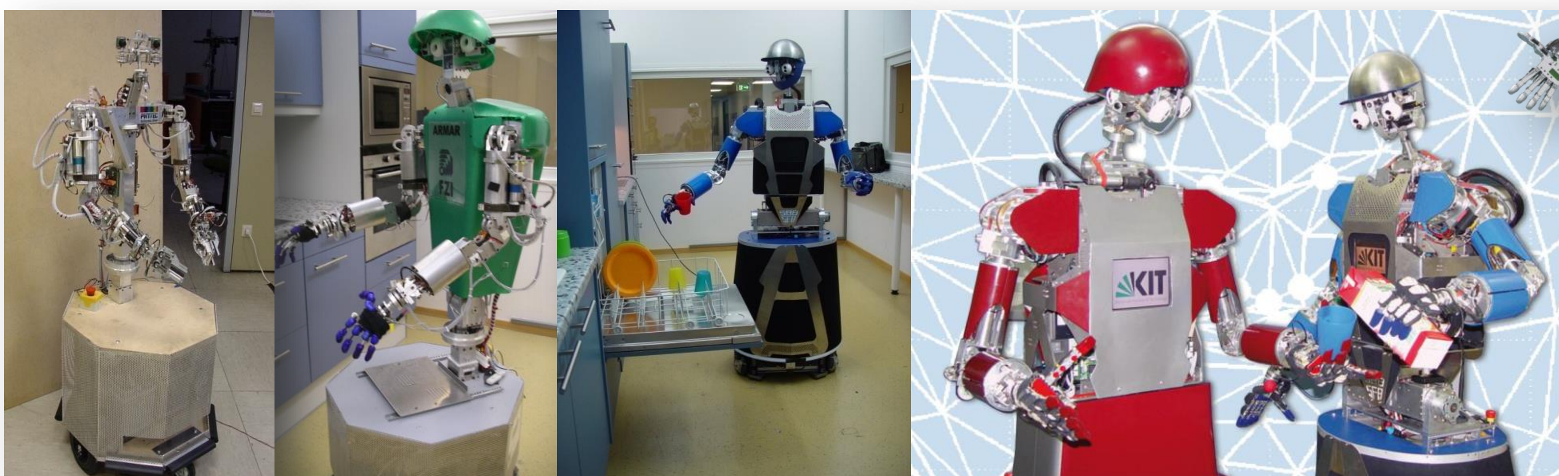
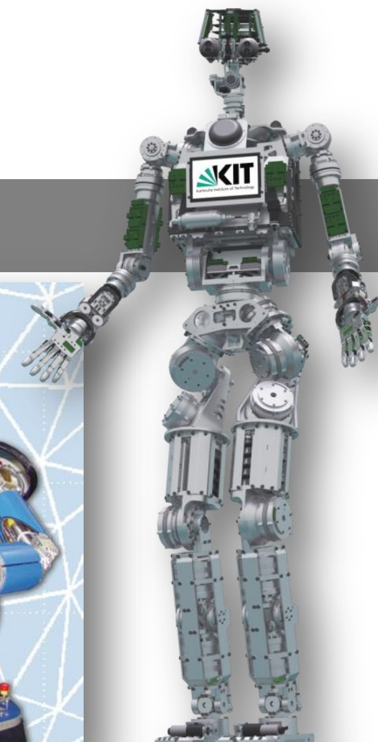
Institute for Anthropomatics and Robotics, Humanoid Robotic Systems





http://www.humanoids.kit.edu http://h2t.anthropomatik.kit.edu

My team

Humanoids@KIT

Humanoids in the real world

- Grasping and manipulation

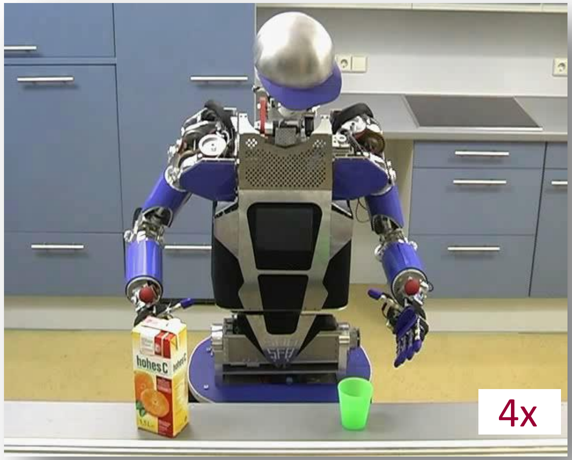
- Learning for human observation
- Natural Interaction and communication

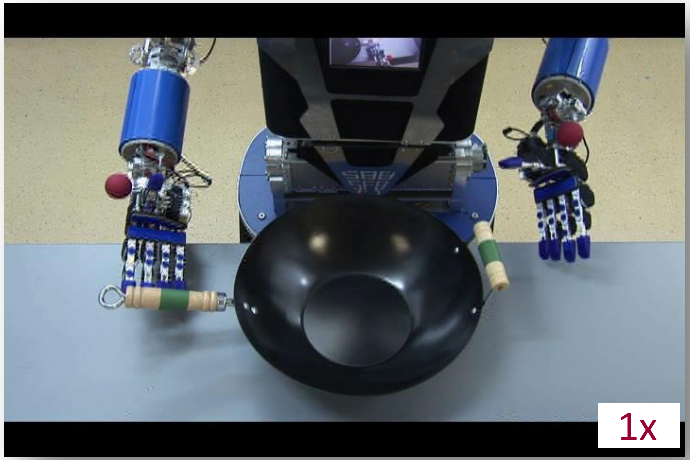
ARMAR-III in the RoboKITchen

- 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
- …

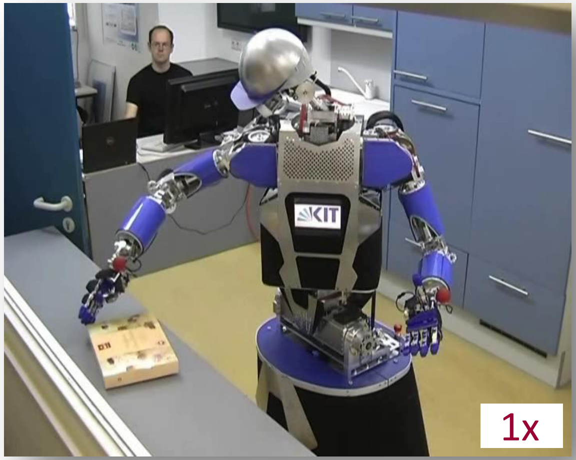
Advanced grasping capabilities

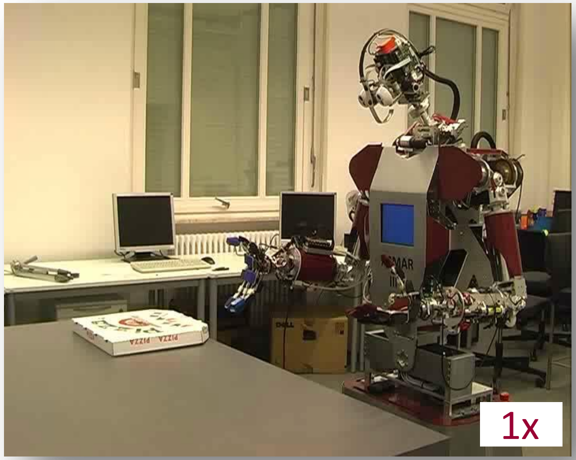
- Bimanual grasping and manipulation





- Pre-grasp manipulation





RAM 2012
IROS 2011
Humanoids 2010
Humanoids 2009
RAS 2008

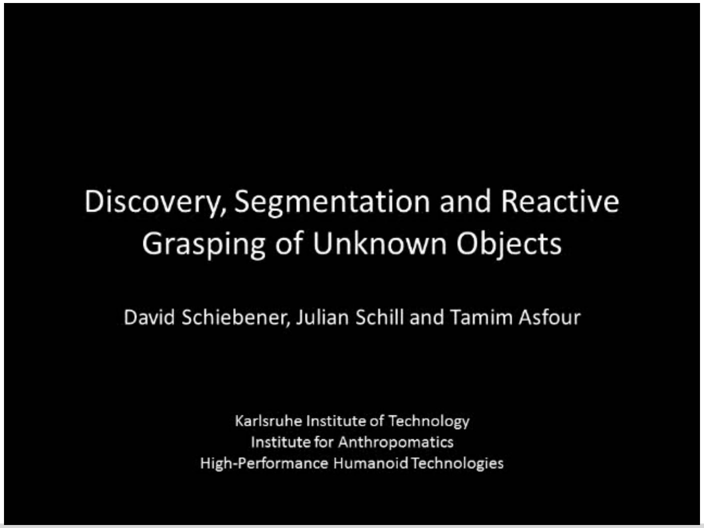
Discover, segment and grasp unknown objects

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

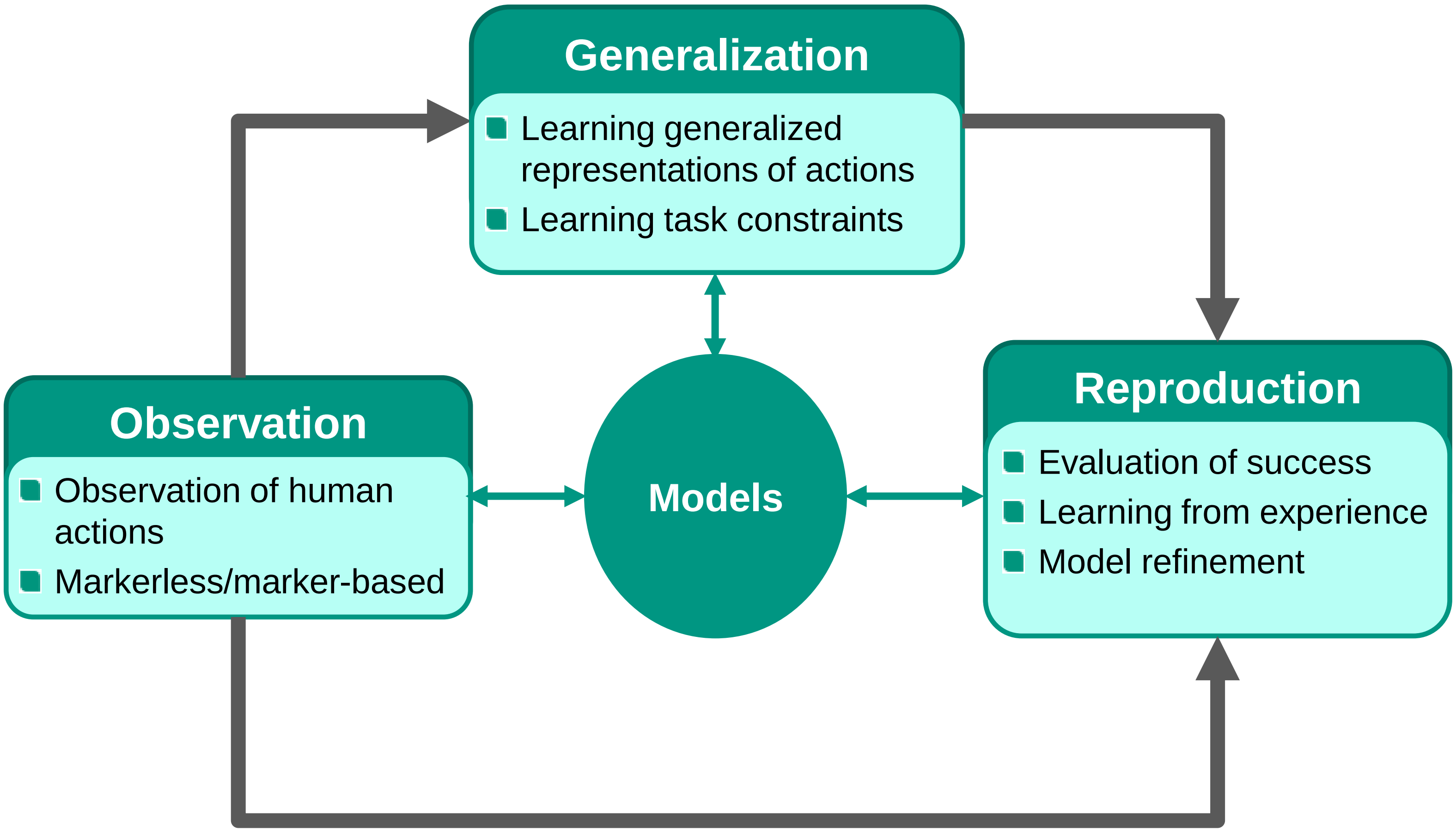
→ Reliable, correct and complete object segmentation

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

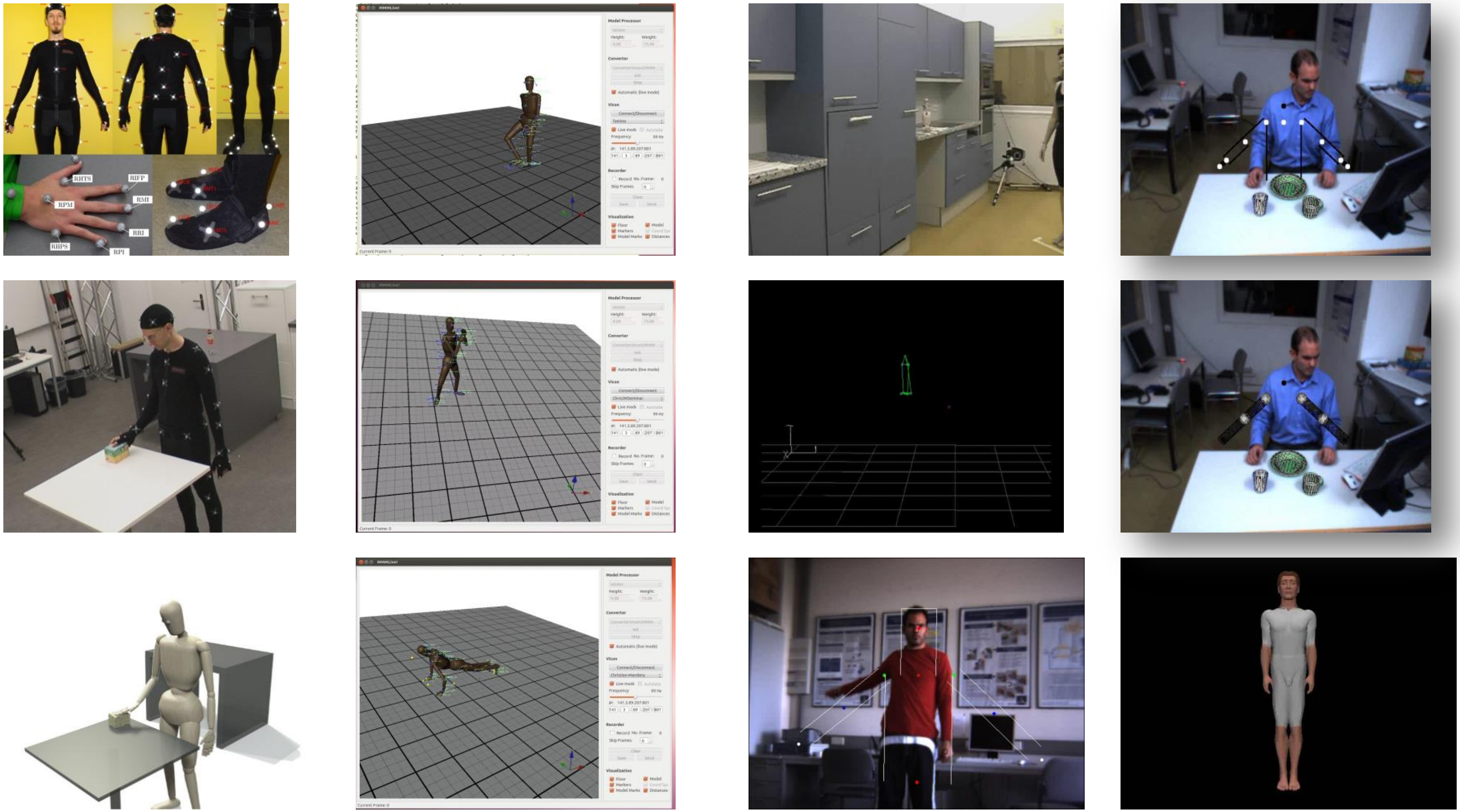
ICRA 2012, 2014,
Humanoids 2011, 2012
Adaptive Behavior 2013



Learning from human observation



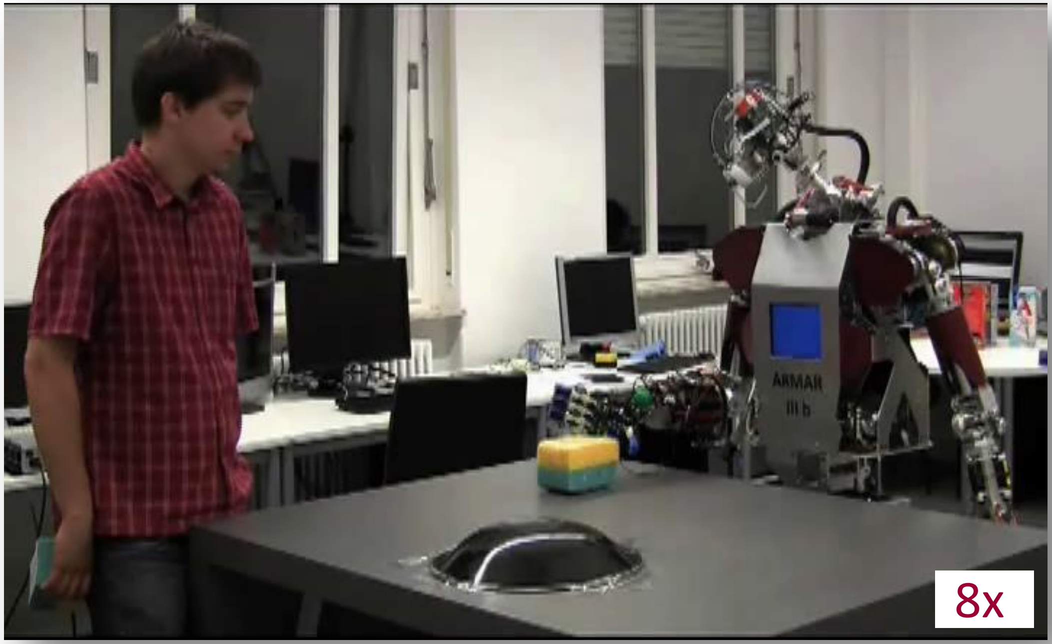
Observation: markerless and marker-based



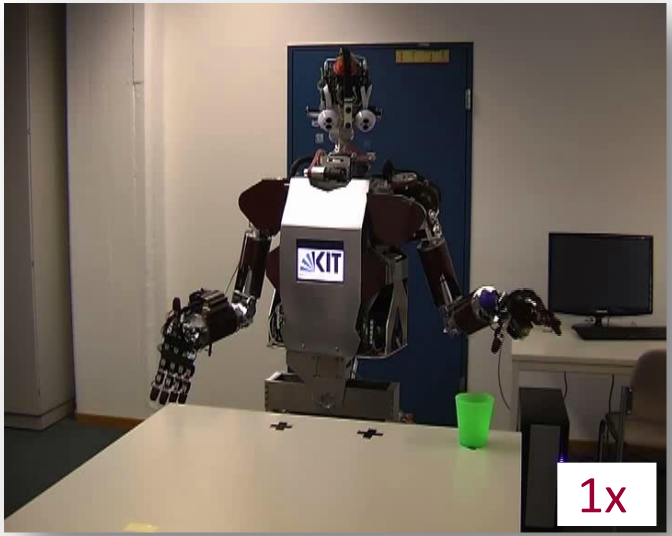
KIT motion database https://motion-database.humanoids.kit.edu

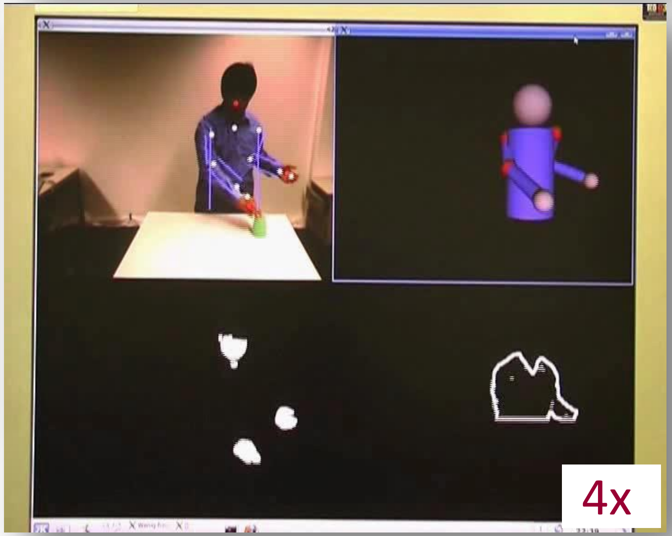
Learning from observation

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



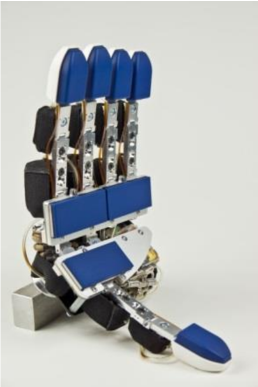
Humanoids 2006, IJHR 2008, Humanoids 2007, ICRA 2009, Humanoids 2009, TRO 2010, Humanoids 2012

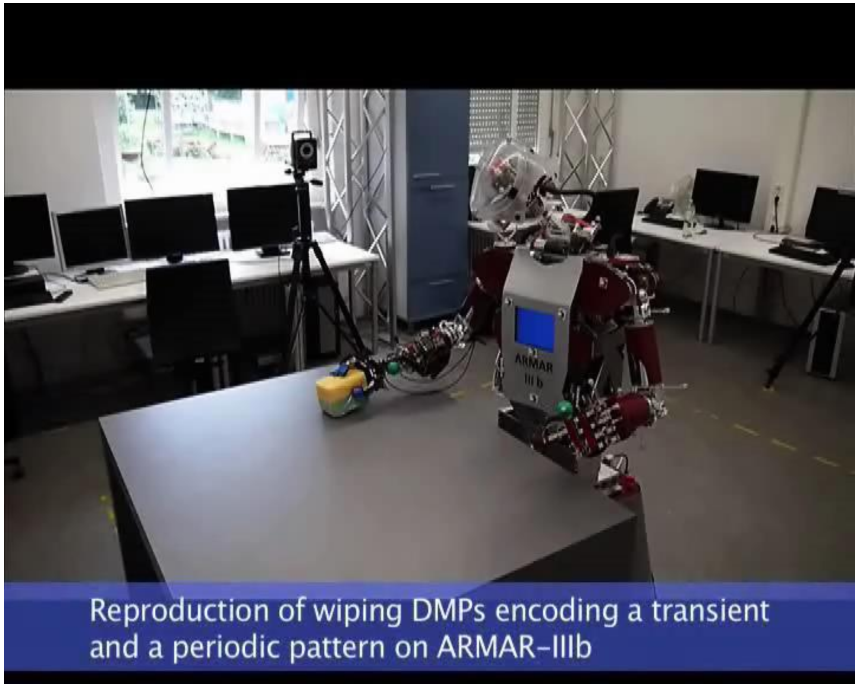


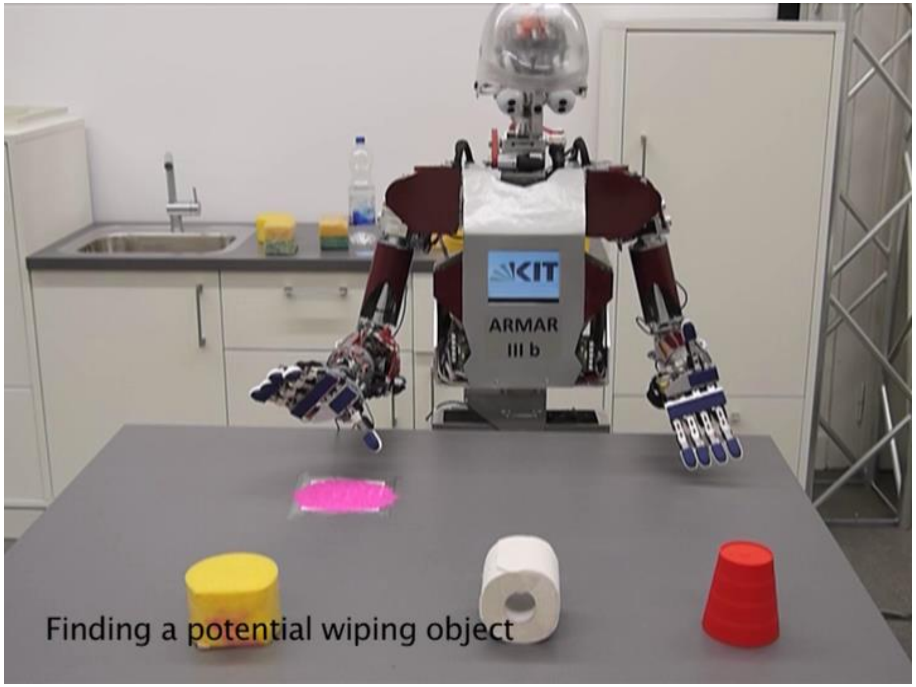


Learn to wipe

- One dynamical system for discrete and periodic motions
- Learn relations between object properties and action parameters





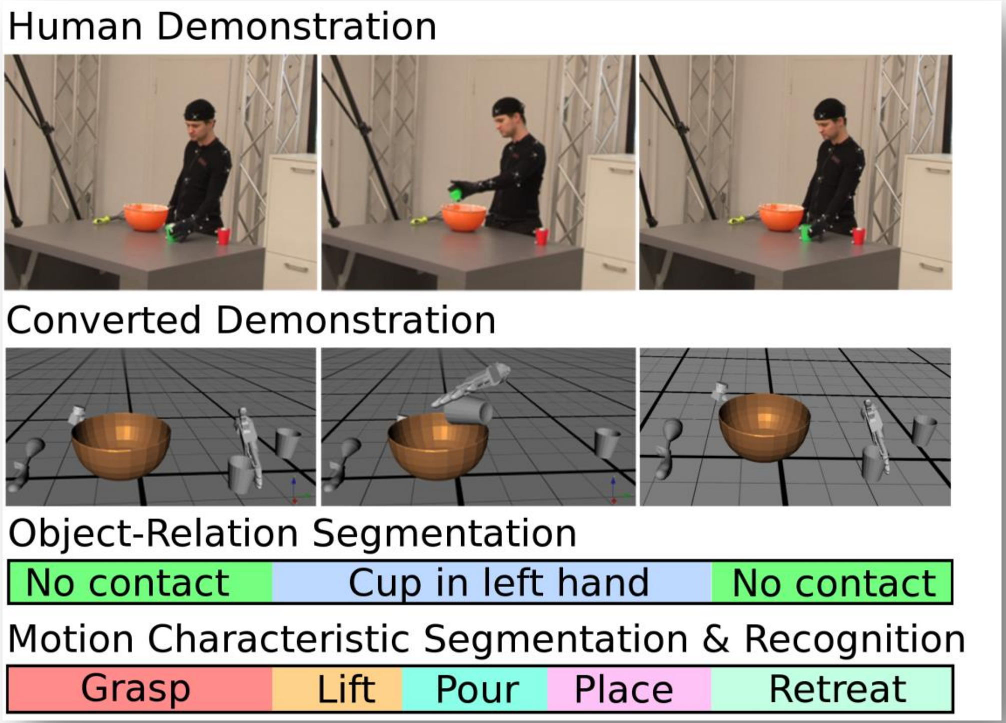


Humanoids 2012, ICRA 2014

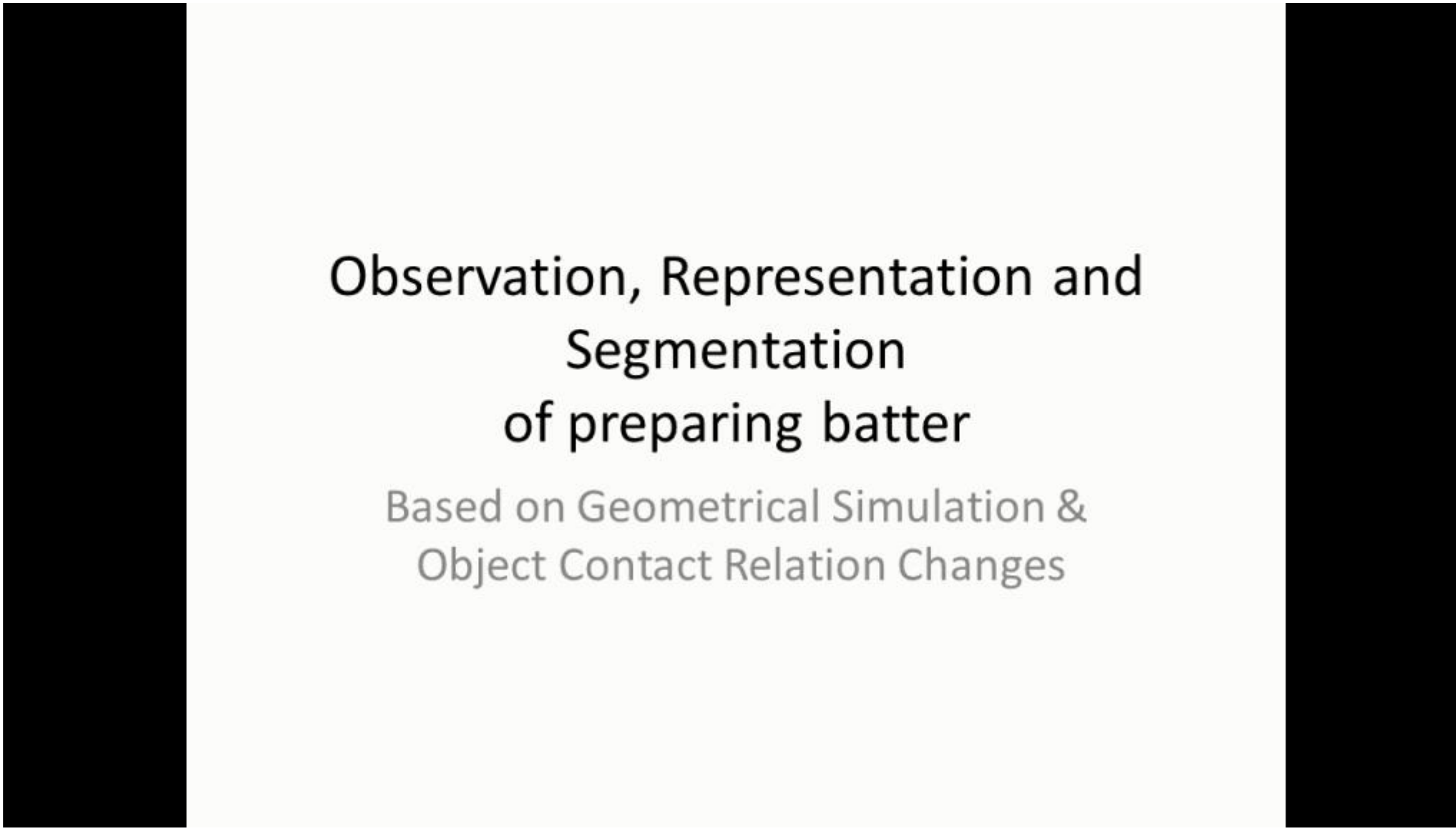
Learning from human observation – prepare the dough

Learning from human observation

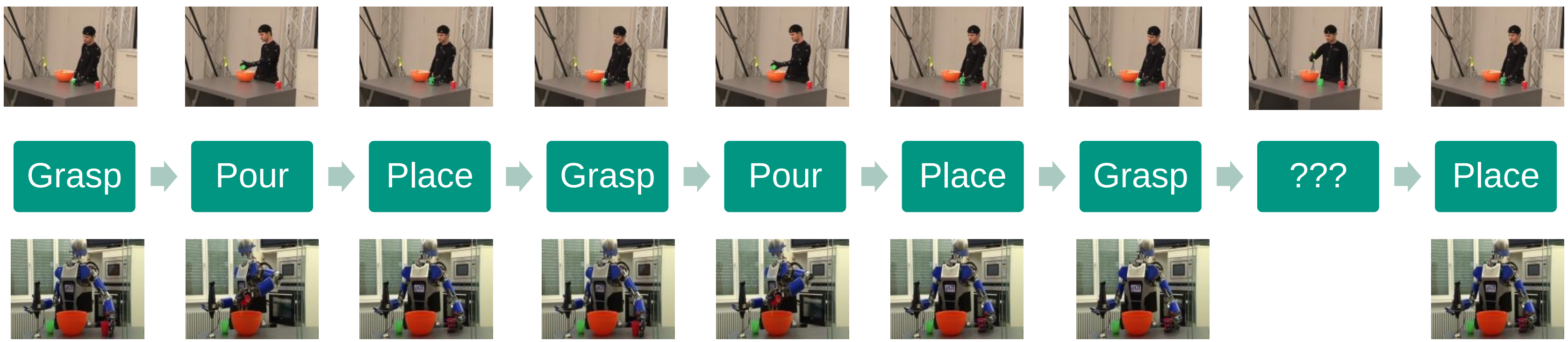
- Hierarchical segmentation approach which not only considers motion but also relevant objects
  - Semantic segmentation based on object relation
  - Motion segmentation based on trajectory characteristics

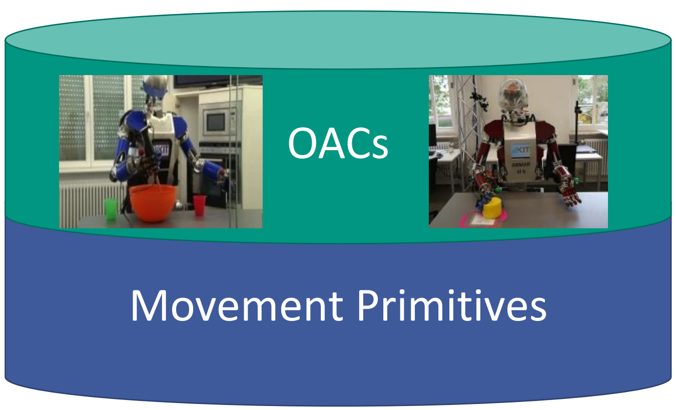


Hierarchical action segmentation

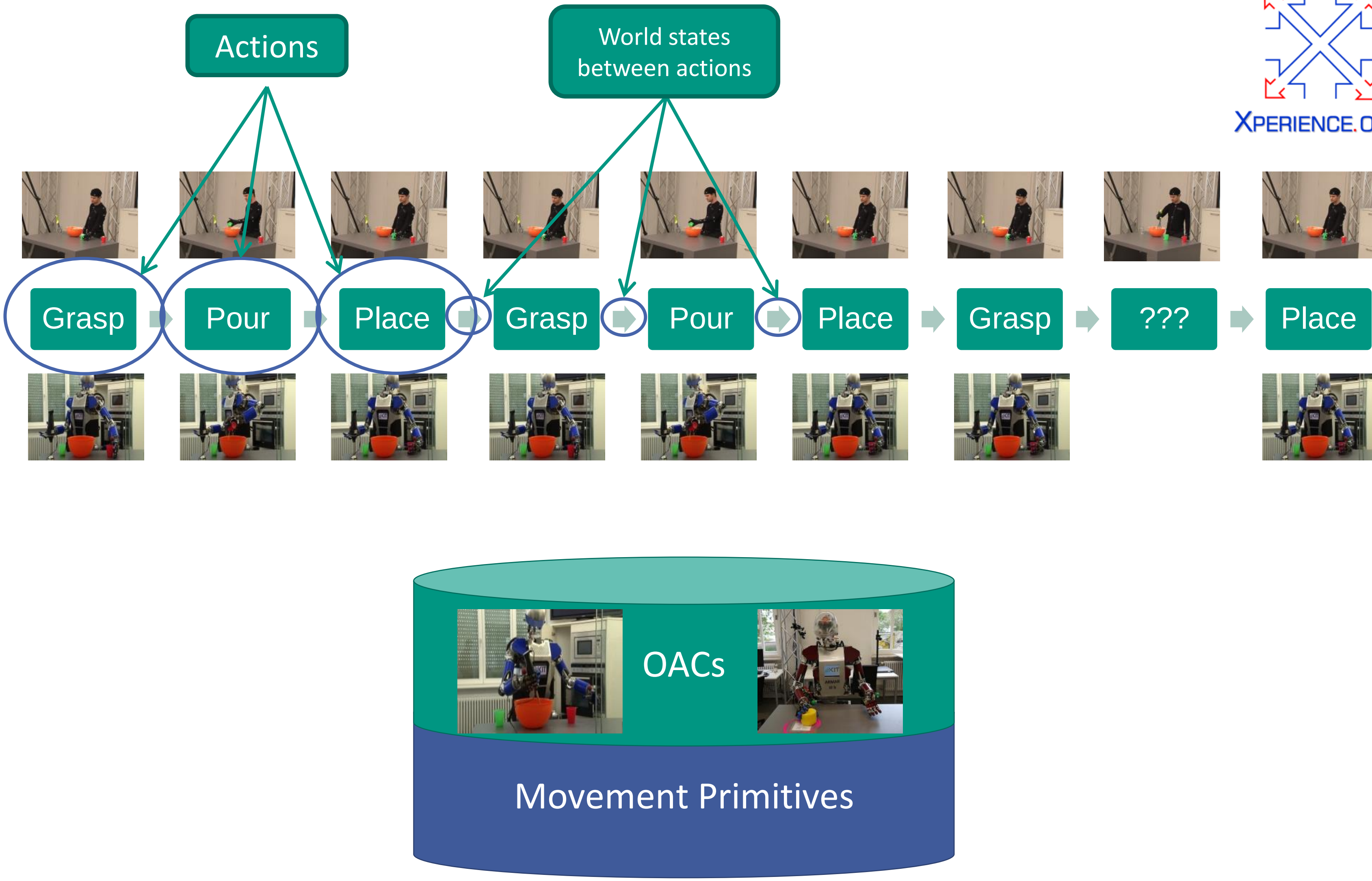


Understanding human demonstration (I)

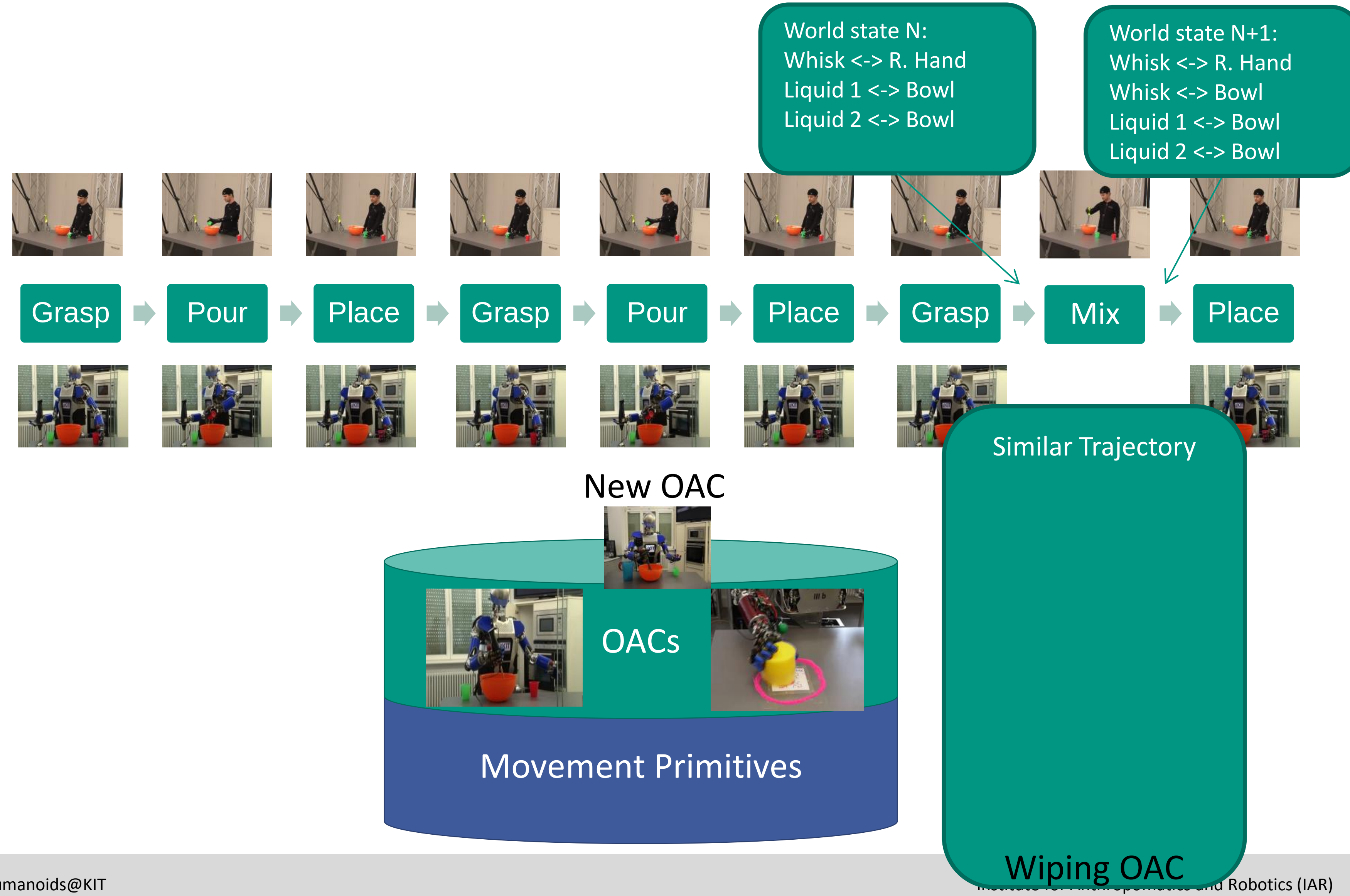




Understanding actions and their effects



Action replacement from a motion library



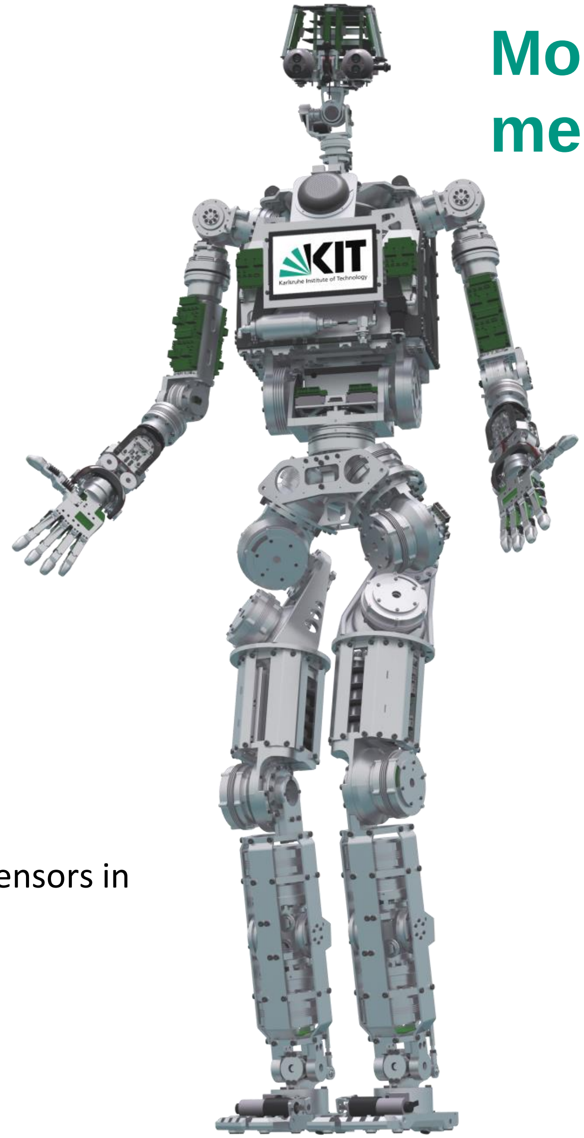
Learning from observation – prepare the dough

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

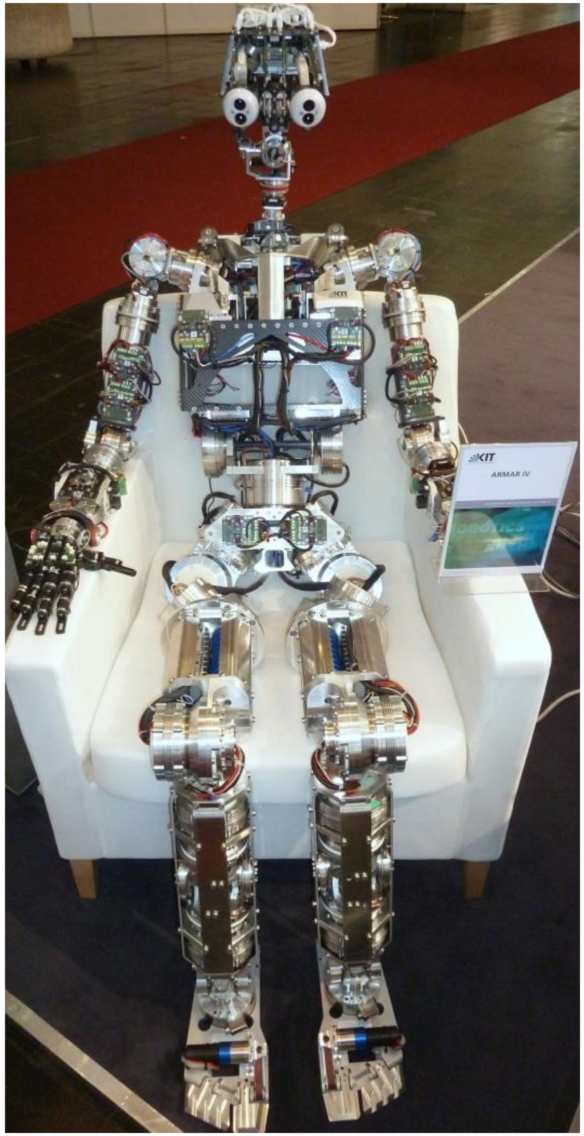
70 kg

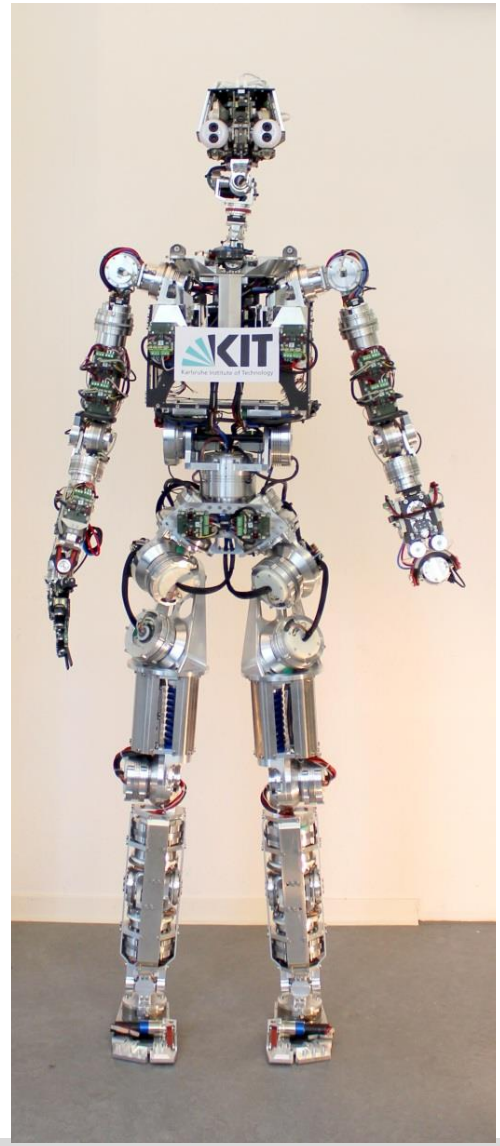
170 cm

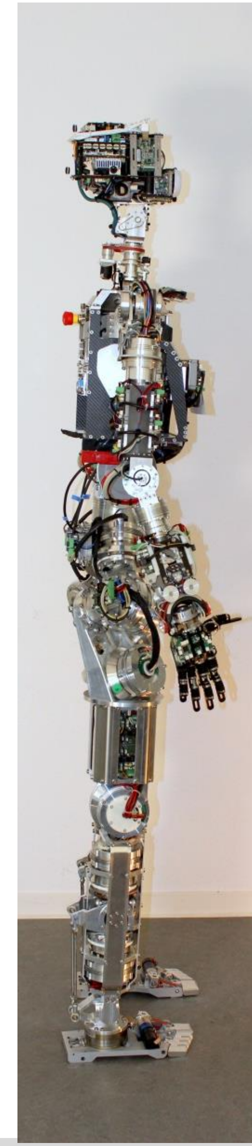
Karlsruhe Institute of Technology

ARMAR-IV

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



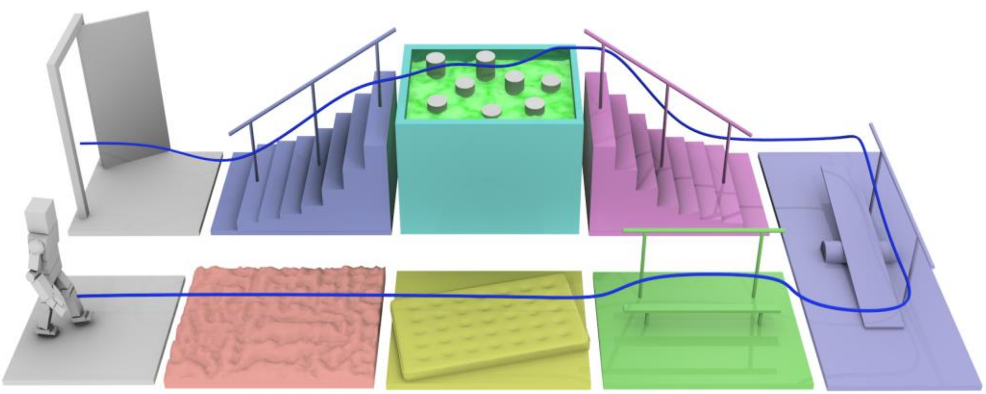




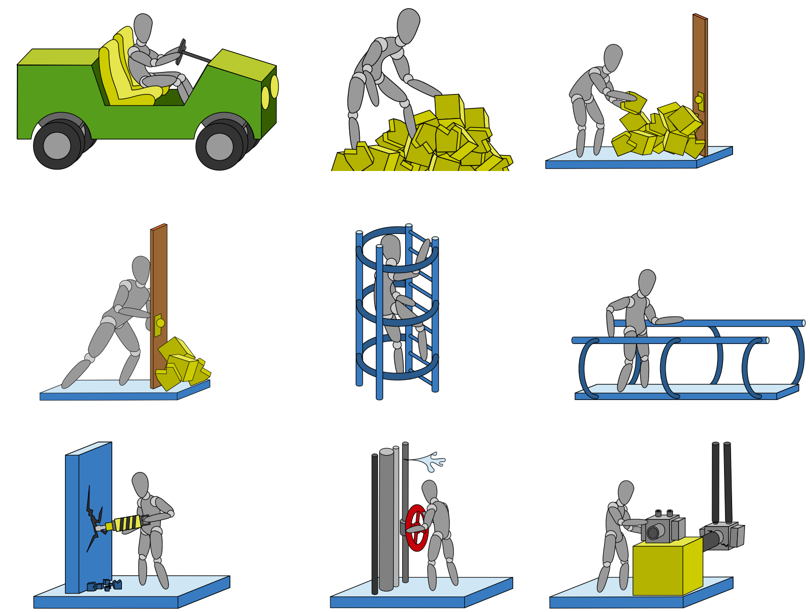
Whole body loco-manipulation tasks

- KoroiBot: 2013-2016
- WALK-MAN: 2013-2017

SEVENTH FRAMEWORK PROGRAMME



Improving walking behavior based on human walking motion



Whole-Body Loco-manipulation tasks

Generation of whole-body motion

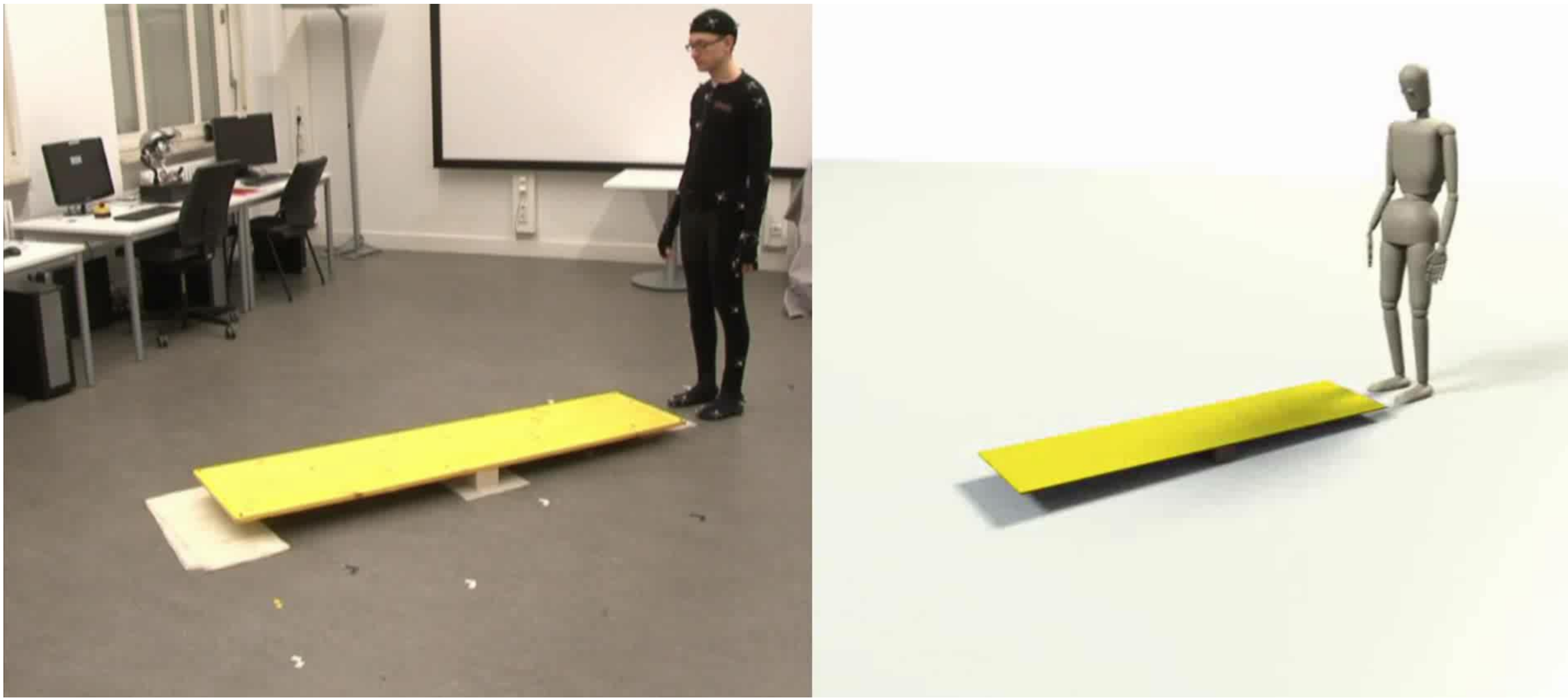
Walking on a beam

Generation of whole-body motion

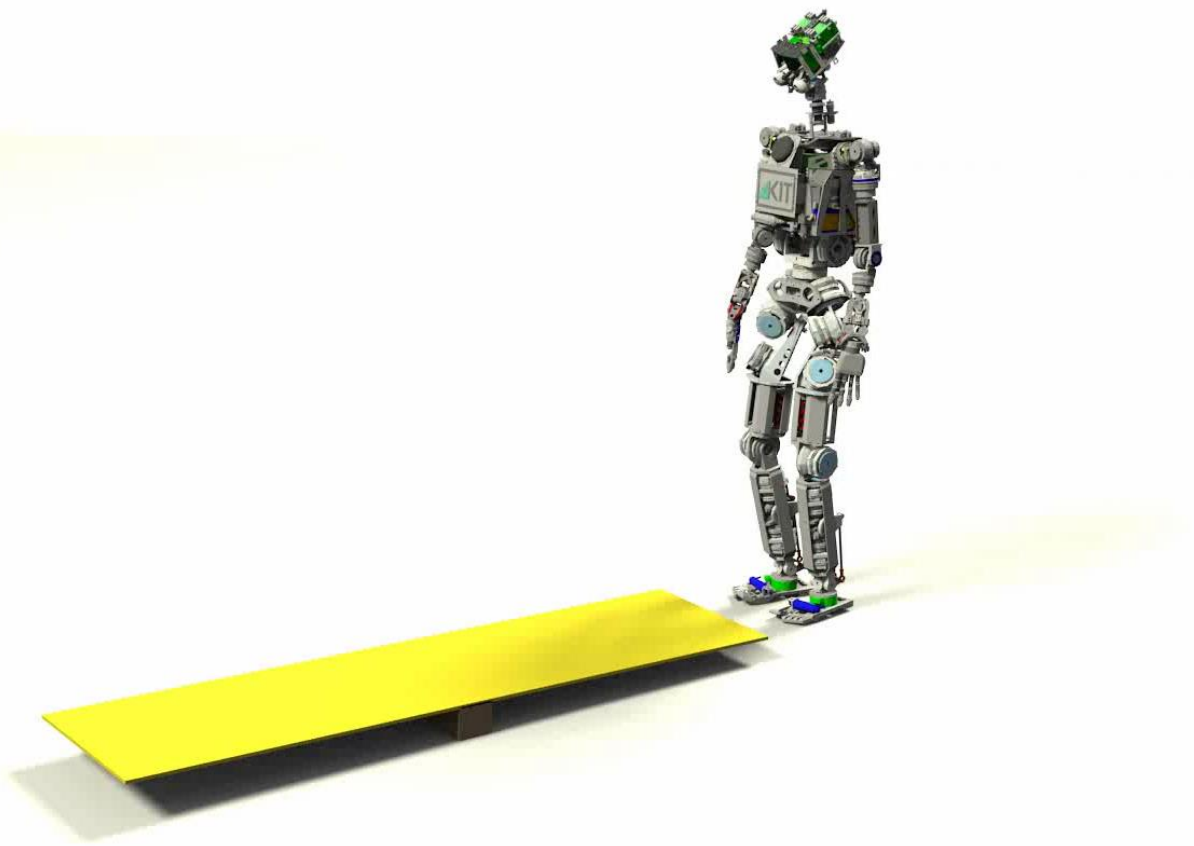
Kinematic Mapping
from recordings to robot motions

Motion generation with objects

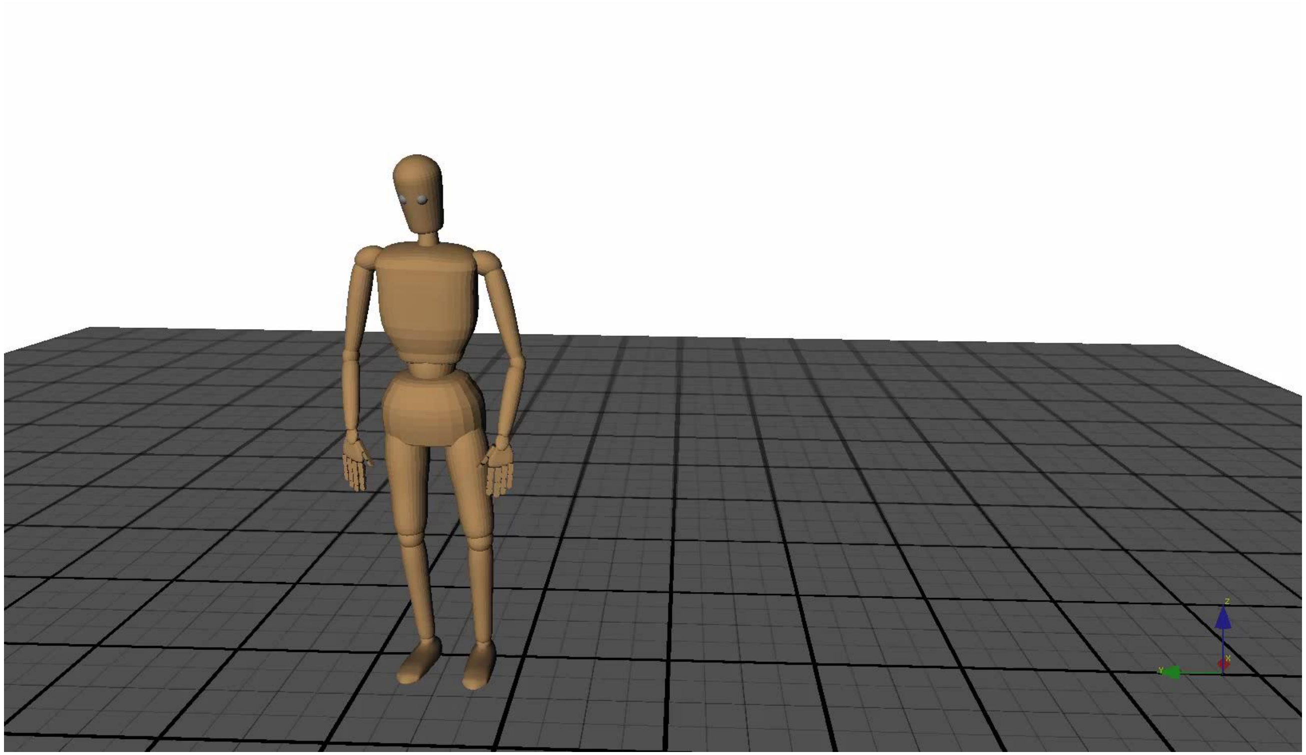
Motion generation with objects



Motion generation with objects

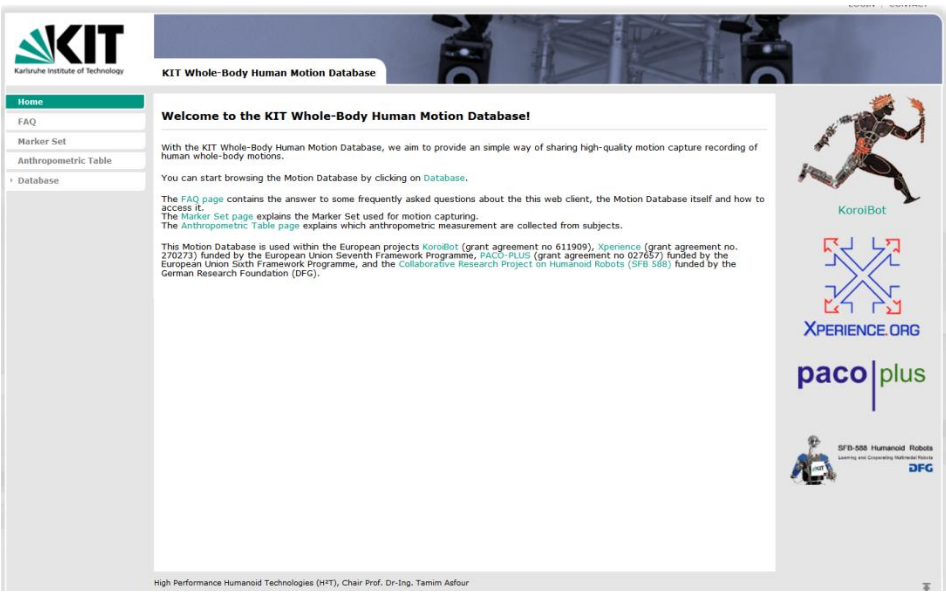


Motion generation for push recovery



KIT Whole-body human motion database

- Publicly available at:
  https://motion-database.humanoids.kit.edu/

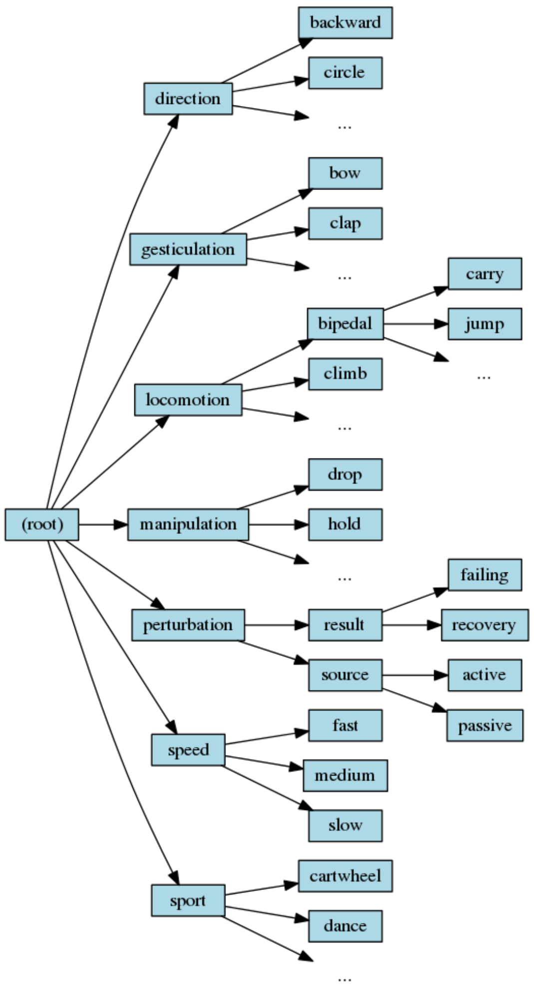


> 300 recording sessions
> 4000 recorded motion clips
> 20 GB of data
~ 10h of motion data

Motion Description Tree

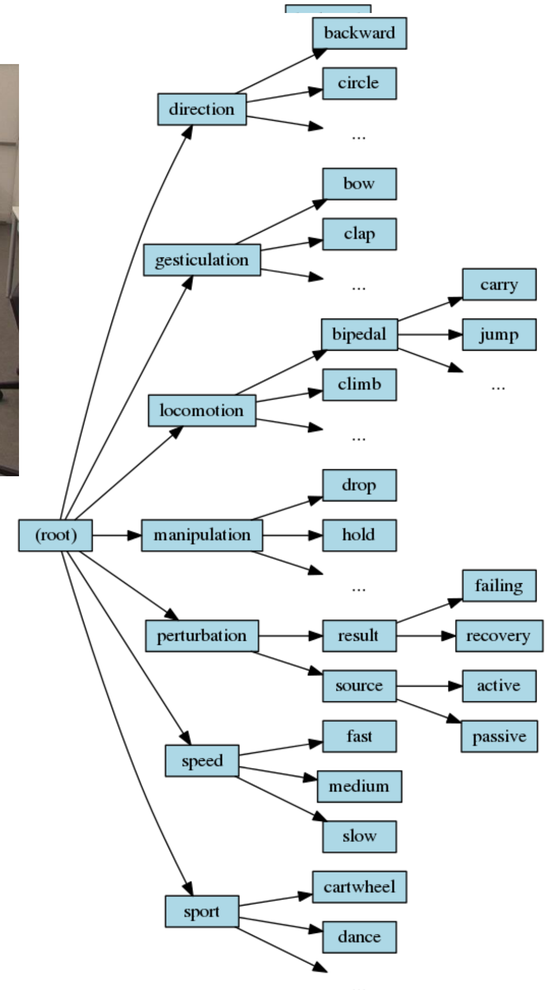
- **Classification system** for human whole-body motions
- **Hierarchical** tag declaration describing motion type and other parameters (speed, stability, …)
- Allows **efficient search** for motions of a certain type in the database
- Creation of the tree structure is based on the **lexical database WordNet**

→ motion semantics which support action segmentation and sequencing



“From motion to text/language and back”

A person walks fast forward. During walk, she/he is pushed, but she/he recovers from the push without falling



Classification in the Motion Description Tree:

direction → forward

locomotion → bipedal → walk

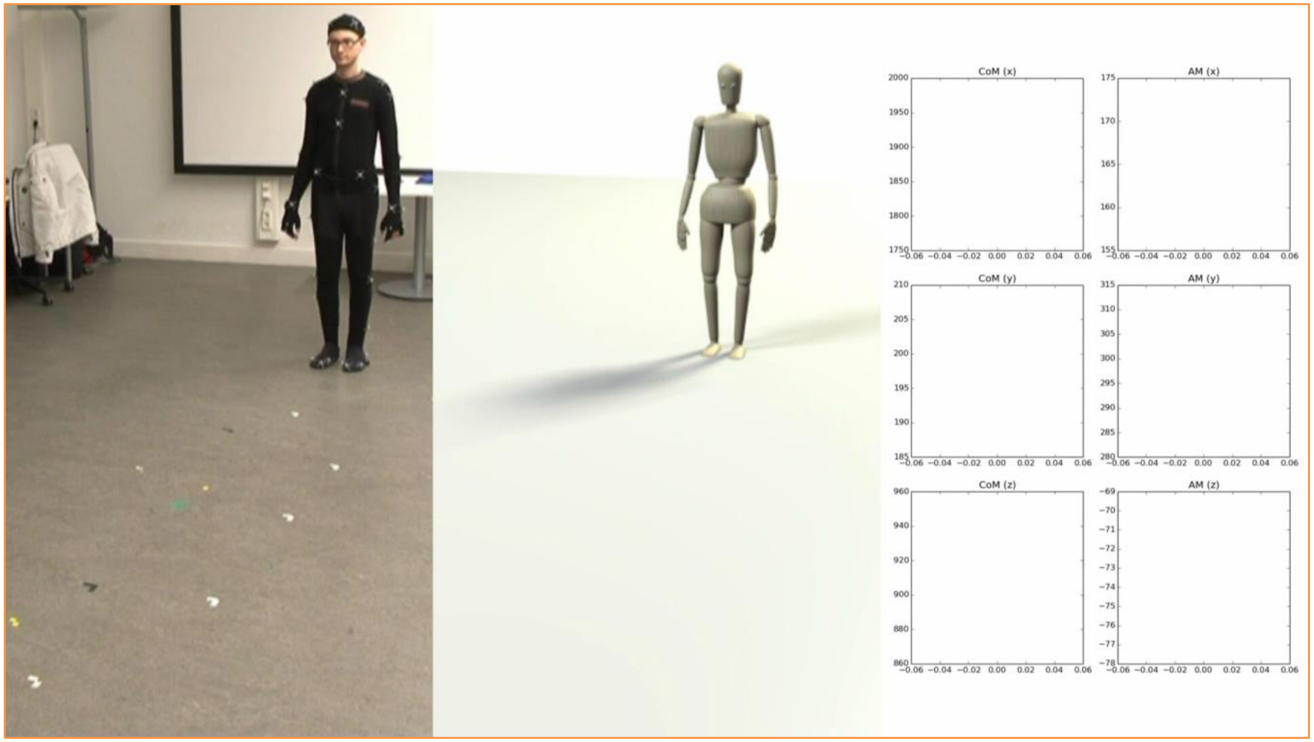
pertubation → result → recovery

pertubation → source → active

speed → fast

CoM and AM computation …

- automatically for all recordings in the database
- Code is part of the MMM tools

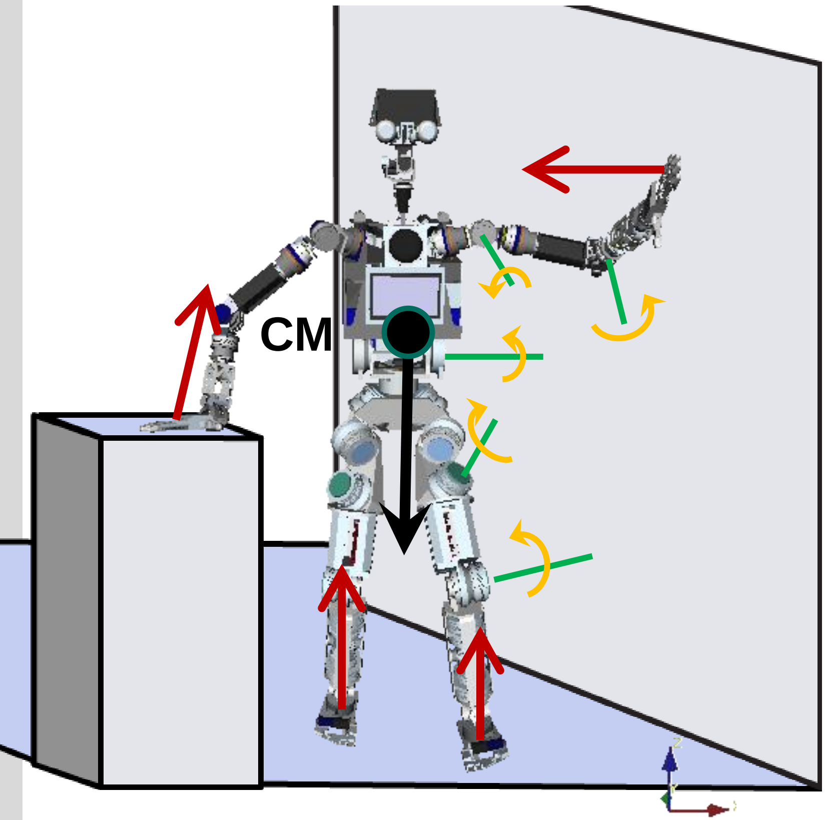


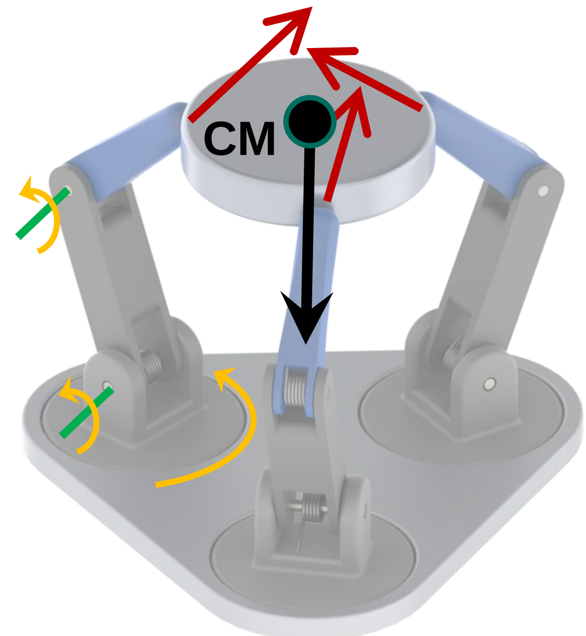
From grasping to balancing

- A stable whole-body configuration of a humanoid robot can be seen as a stable grasp on an object.
- Association of whole-body actions with objects and environmental elements?

From grasping to balancing

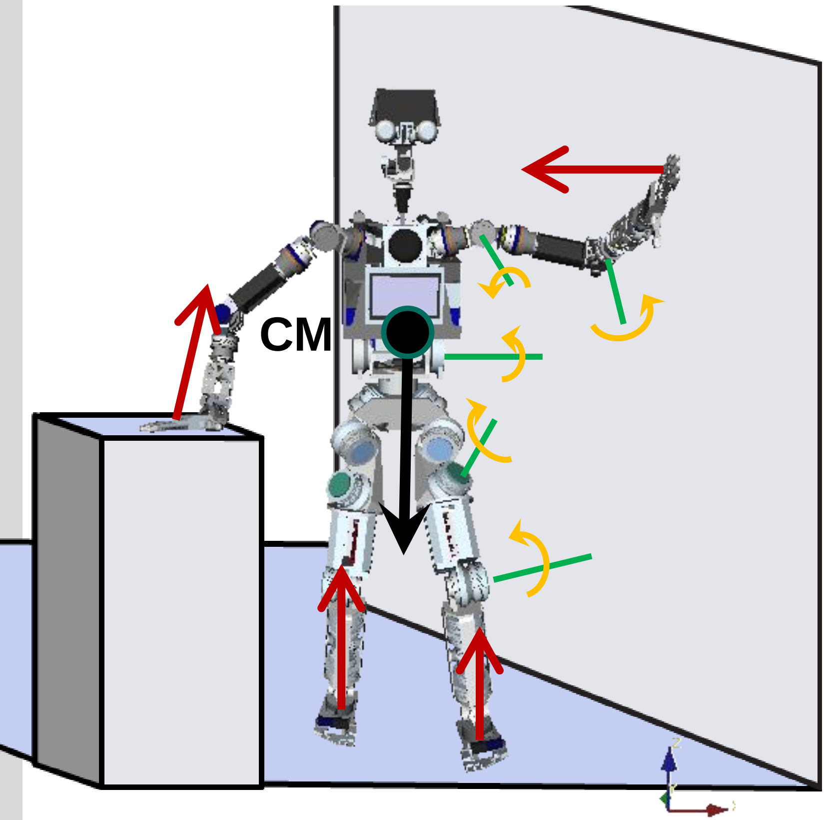
Equilibrium is reached by balancing similar sets of forces





Ground reaction forces	↔	Fingertip forces
Weight of the body (CM)	↔	Weight of the object (CM)
Torques on the joints	↔	Torques on the joints

From grasping to balancing



Concepts of grasping can be applied to loco-manipulation

$$\mathbf{G}^T\mathbf{T} = \mathbf{J}_H\dot{\Theta}$$

$$\mathbf{J}_H^T\lambda_f = \tau$$

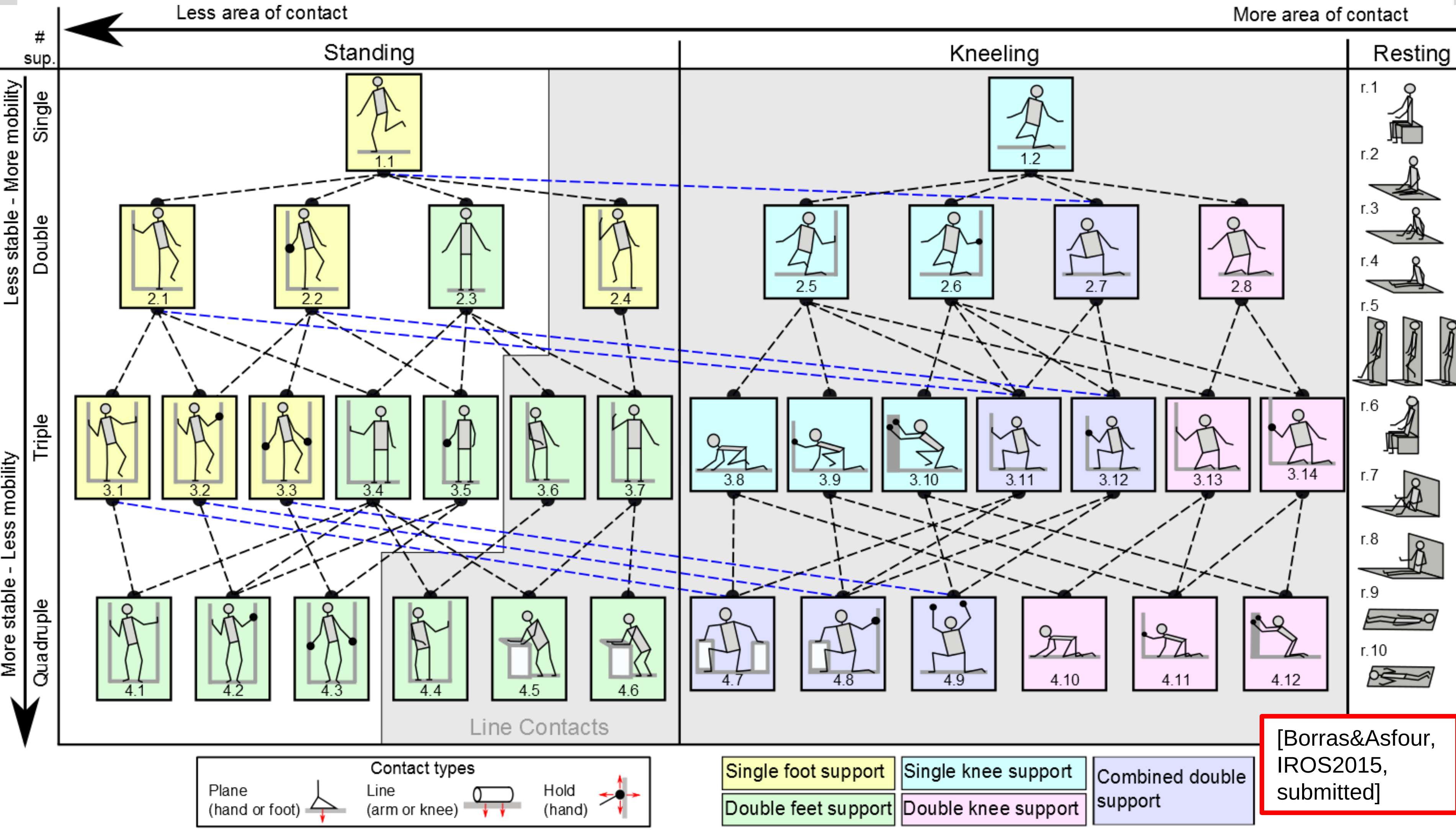
$$-\mathbf{G}\lambda_f = \mathbf{W}$$

$$\lambda_f \in \mathscr{F}$$

Balance ⟷ Stable grasp

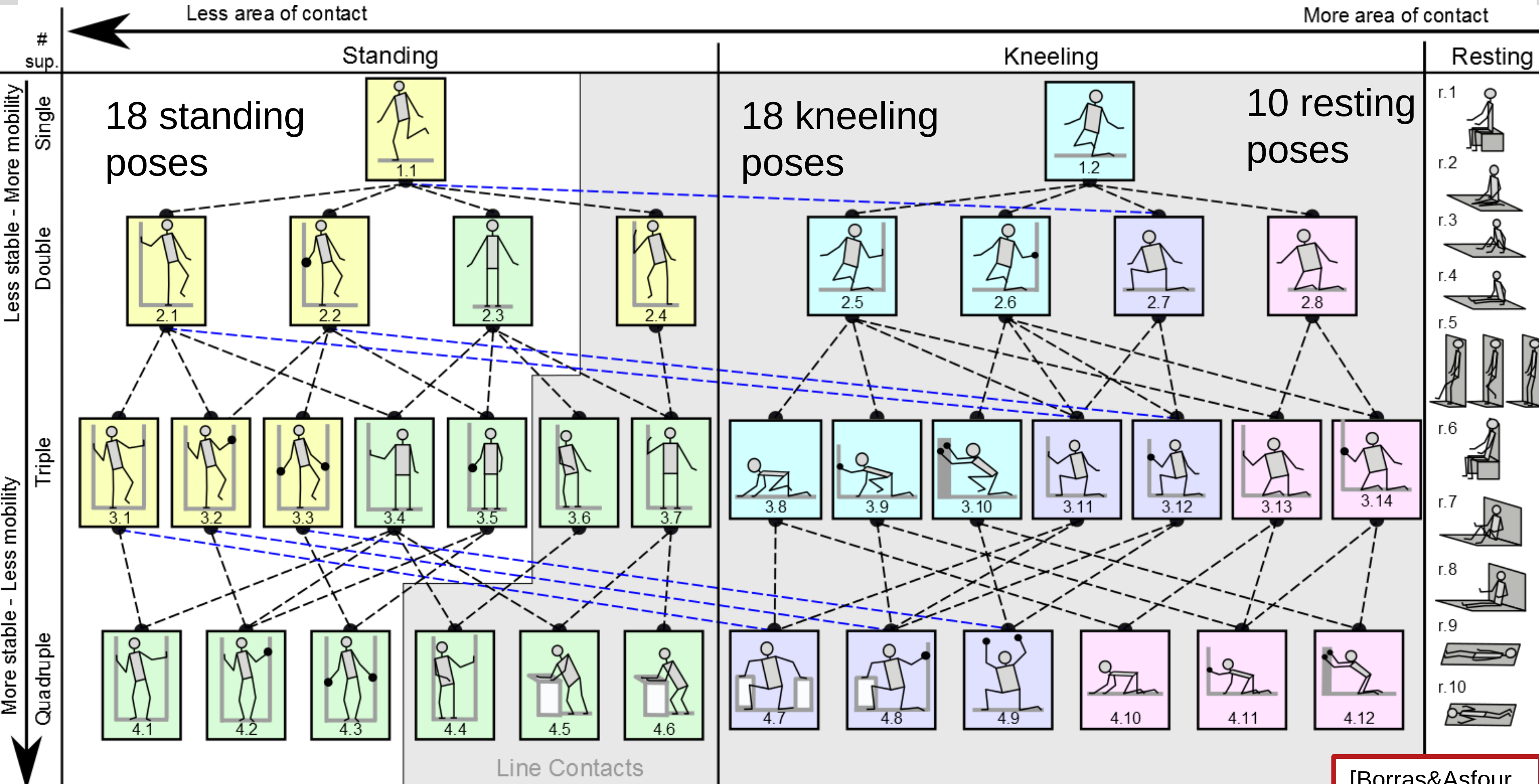
Step planning ⟷ Grasp synthesis

Taxonomy of whole-body poses for loco-manipulation tasks



[Borras&Asfour, IROS2015, submitted]

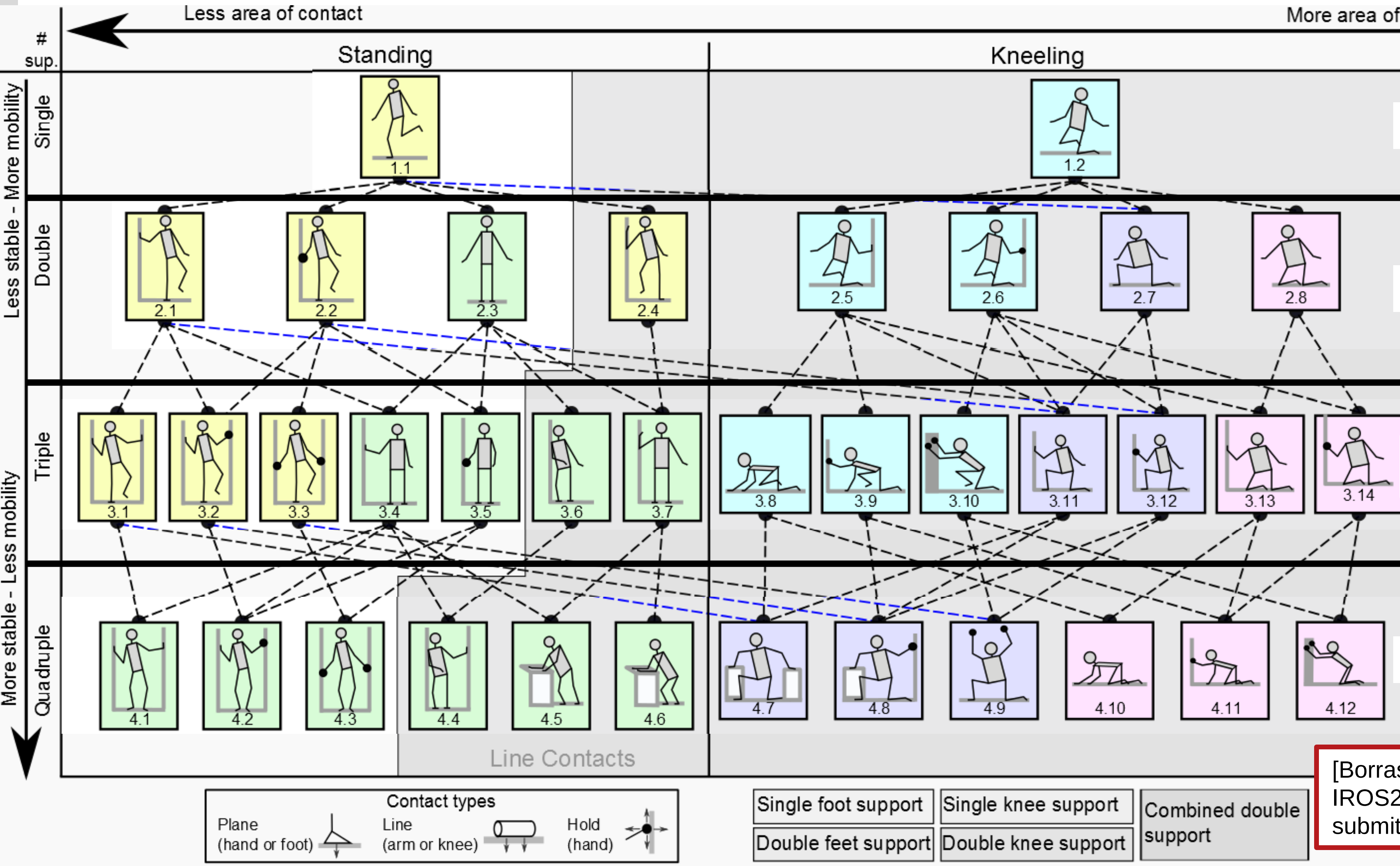
Taxonomy of whole-body poses for loco-manipulation tasks



Total: 48 classes

[Borras&Asfour, IROS2015, submitted]

Taxonomy of whole-body poses for loco-manipulation tasks



1 contact

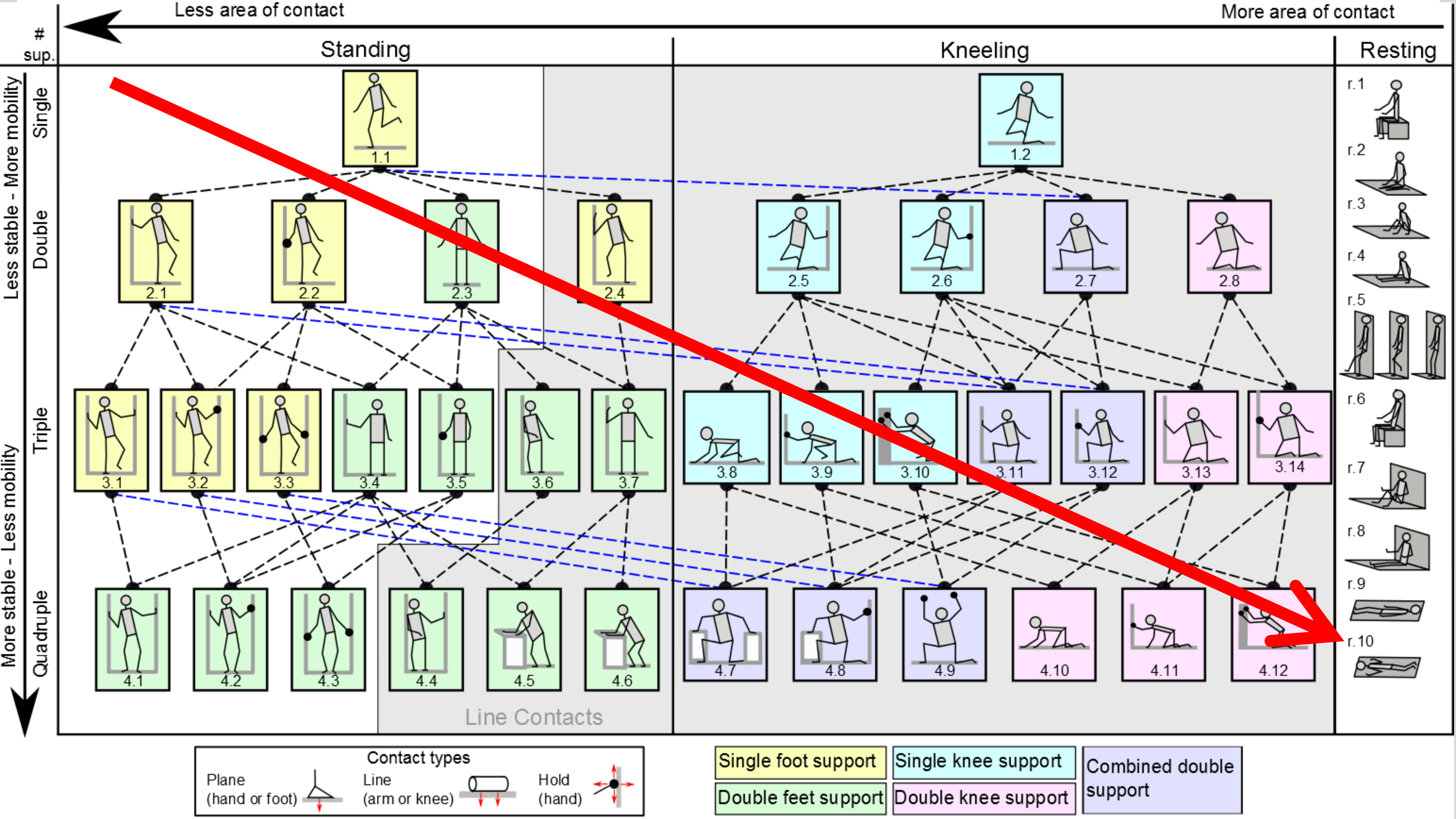
2 contacts

3 contacts

4 contacts

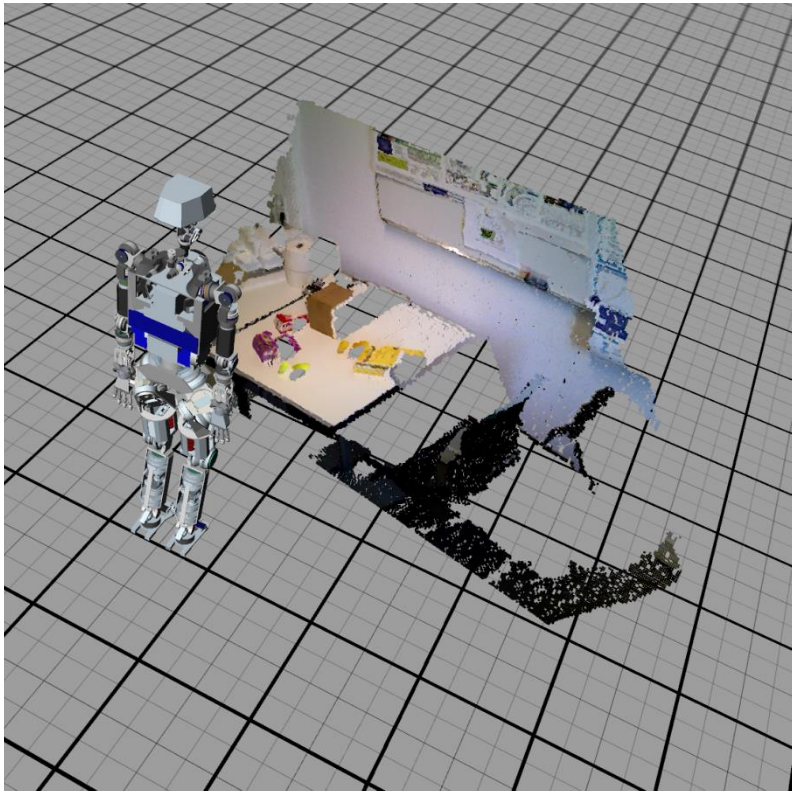
[Borras&Asfour, IROS2015, submitted]

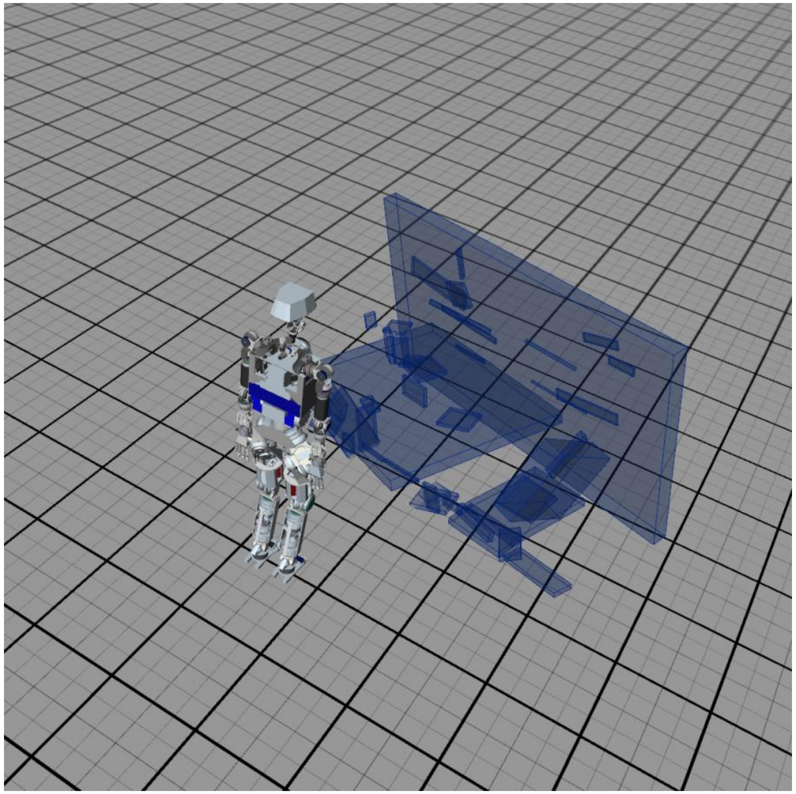
Taxonomy of whole-body poses for loco-manipulation tasks



Generation of whole-body „grasps“

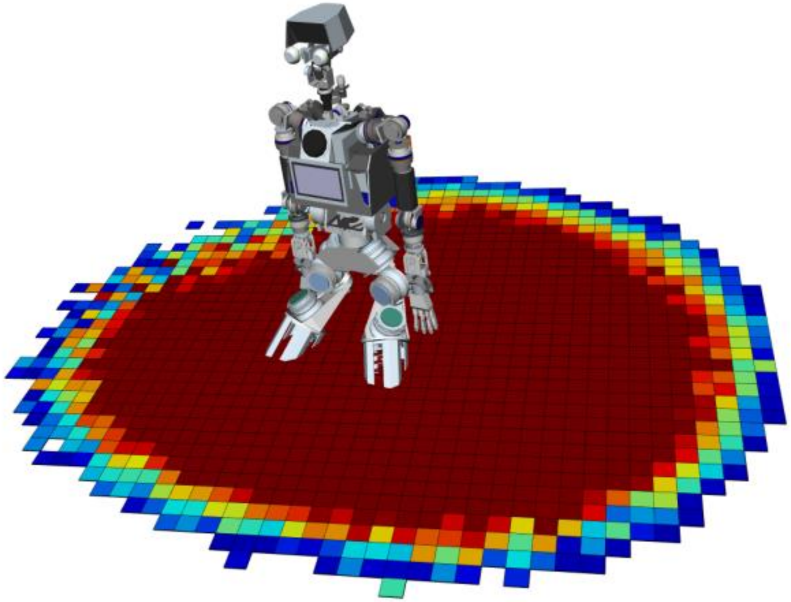
Detection of 3D primitives based on RGBD images



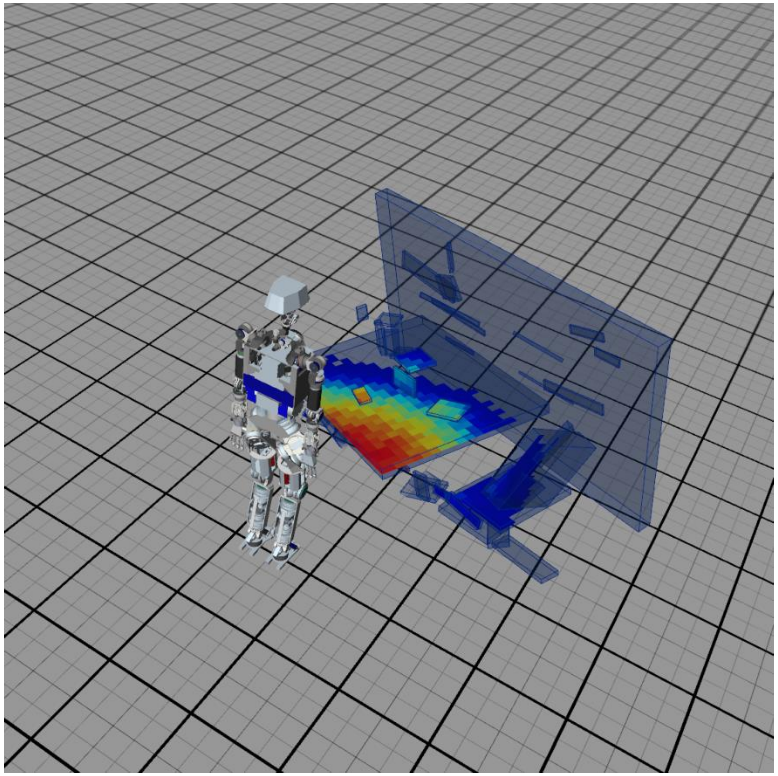


„Reachable“ and „stabile“ primitives

Exploit reachability and stability information to determine usable affordances



Cut through the Stability Distribution
(leg, hip, and arm/hand)



Vahrenkamp and Asfour, Representing the Robot's Workspace through Constrained Manipulability Analysis, Autonomous Robots, 2014

Assignment of affordances to 3D primitives

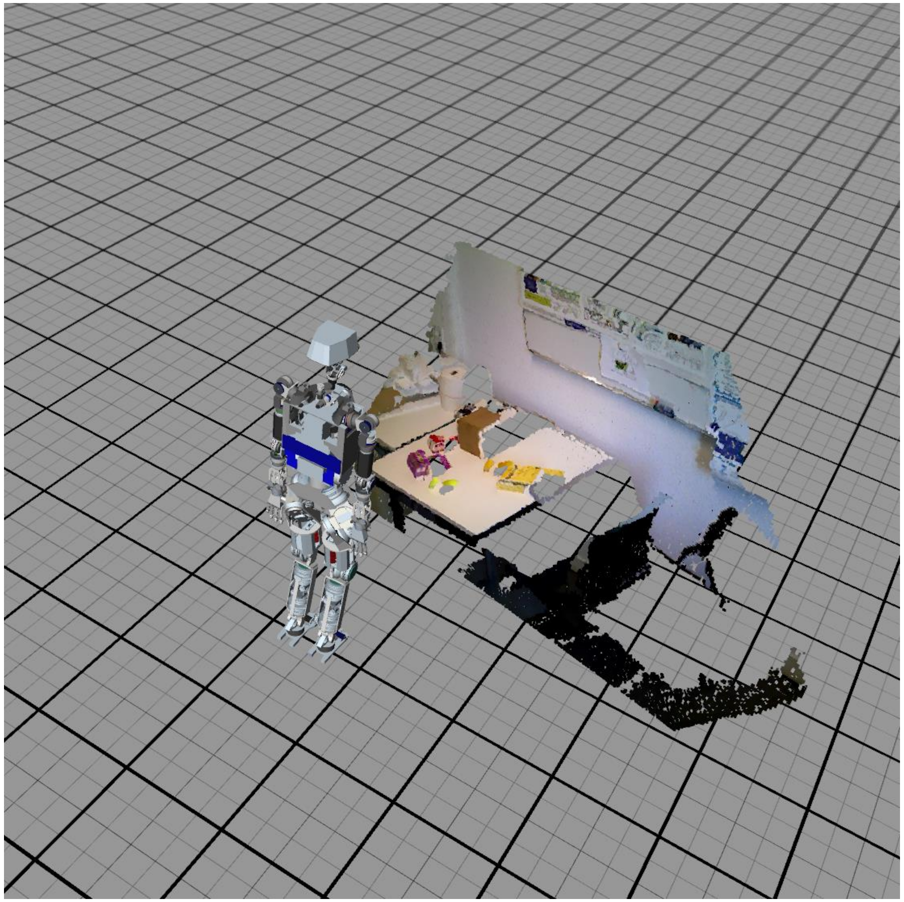
Rule-based affordance assignment based on the type of primitve and its parameters

Type of Primitve	Conditions/parameters	Affordance
Plane	Horizontal, Large enough, In reach	support
Plane	Vertical, Large enough, In reach	lean
Box	Large/small enough, In reach	grasp
Cylinder	Small radius, Short, In reach	grasp
Cylinder	Small radius, Long, In reach	hold

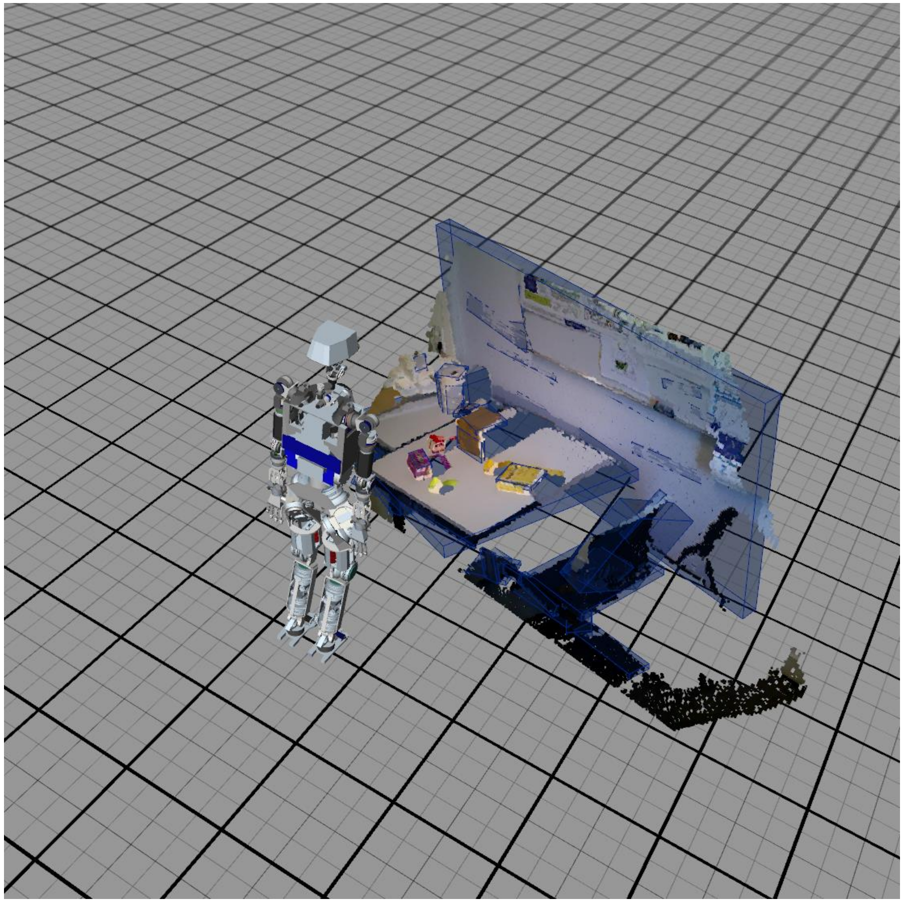
Implemented in the current examples

Future work

From primitives to affordances

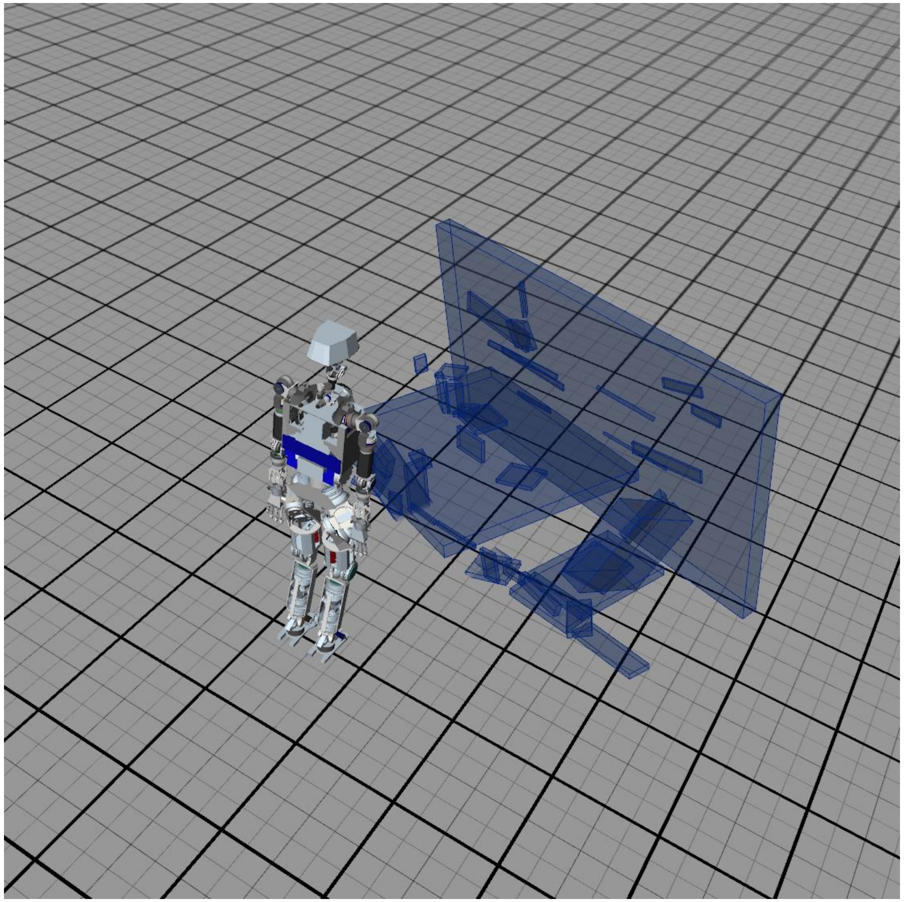


Raw point cloud data (Table in front of the robot, wall in the back, chair to the right)

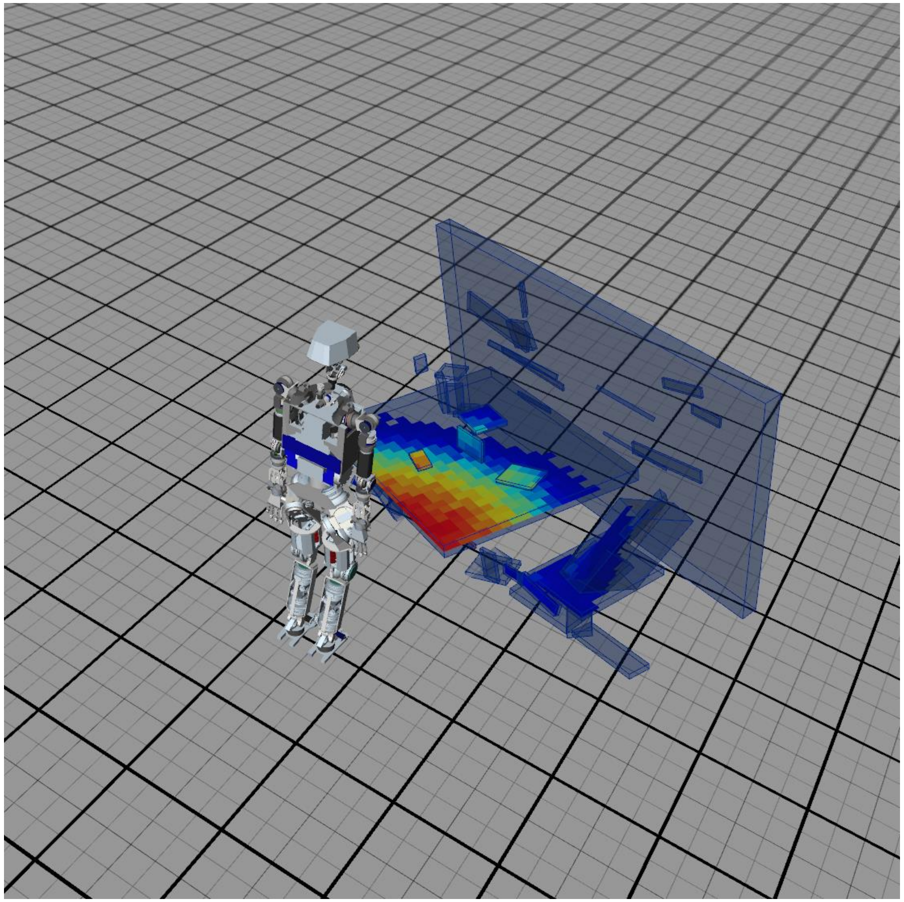


Extracted 3D shape primitives (polytopes)

From primitives to affordances

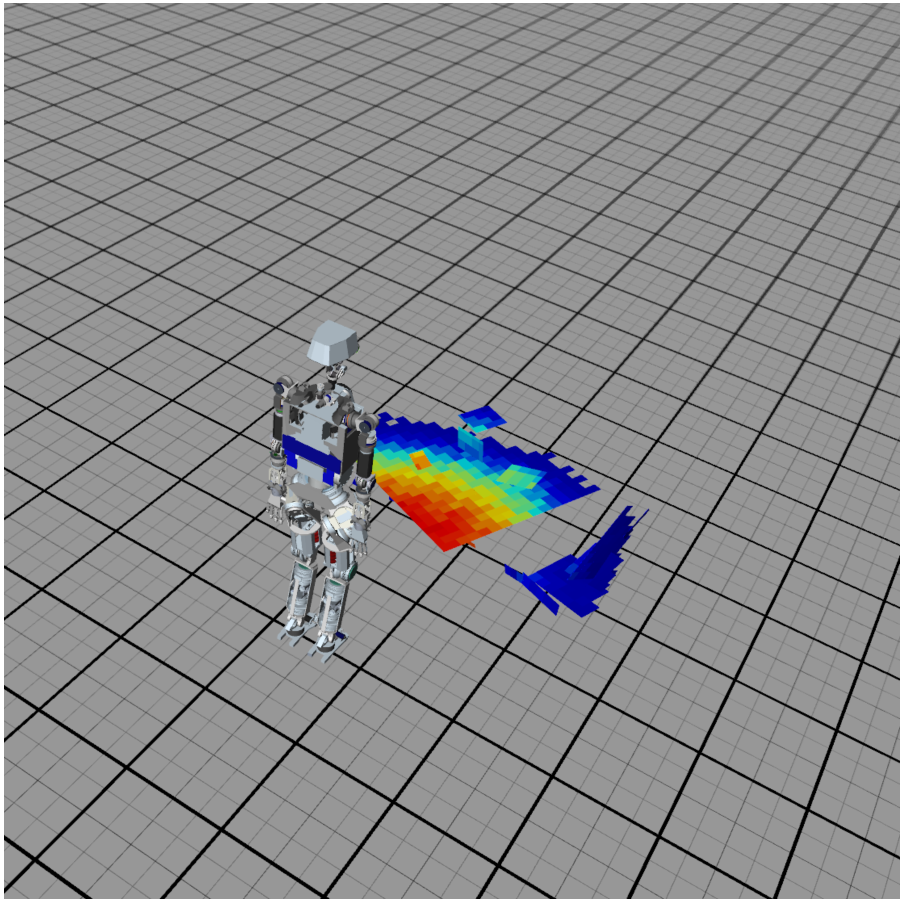


Extracted primitives without point cloud

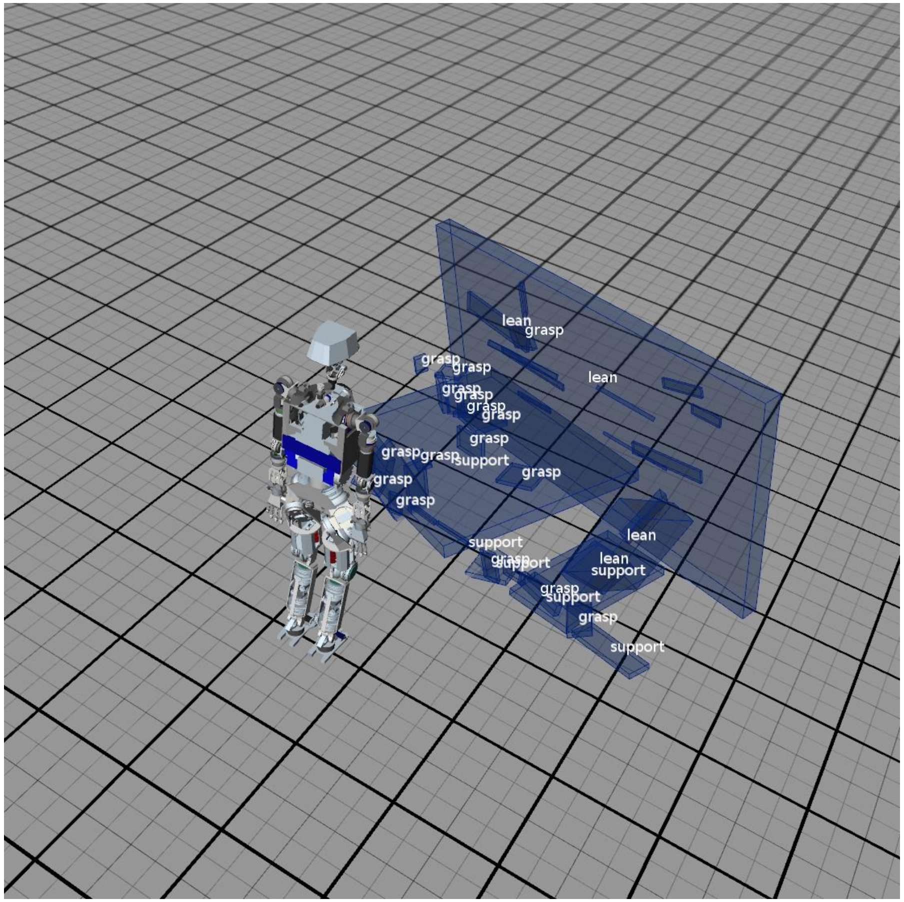


Extracted primitives together with reachability information (Based on reachability maps)

From primitives to affordances

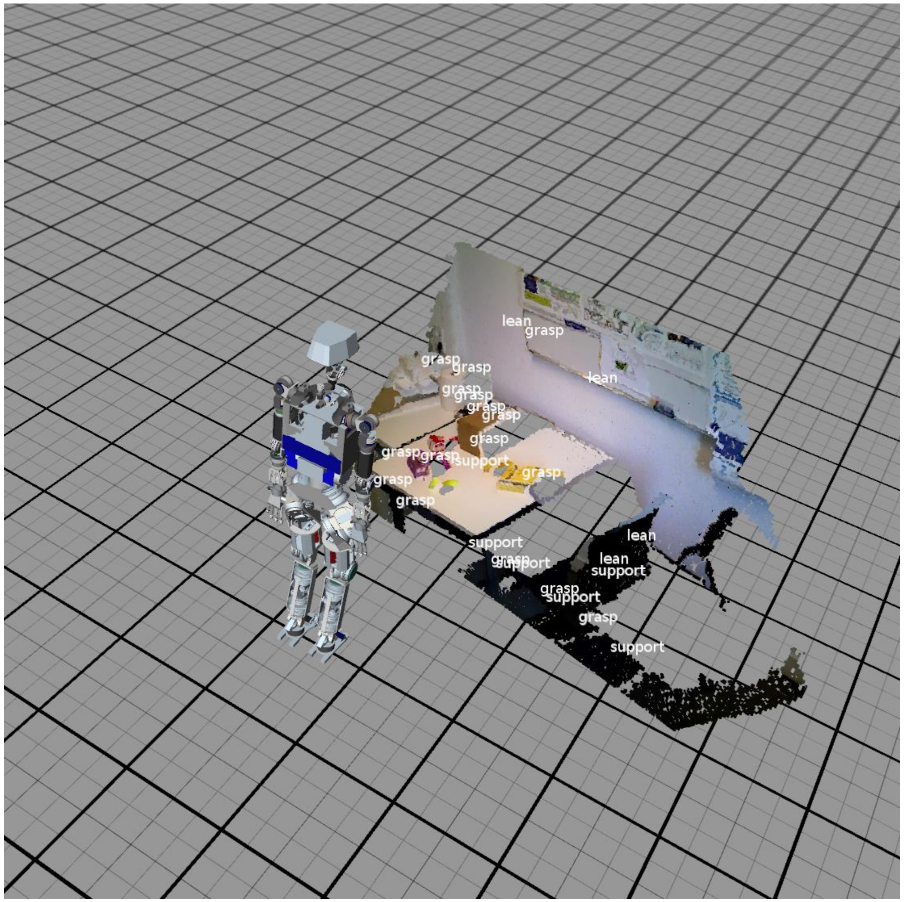


Only reachable surfaces without primitives

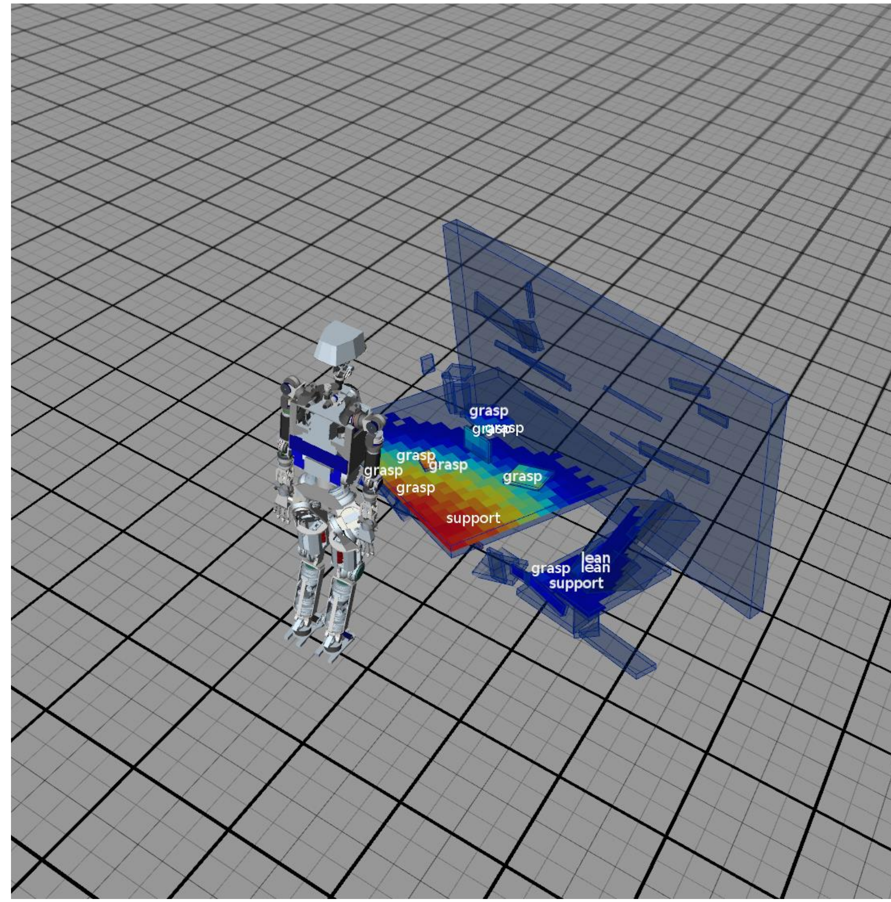


Affordances assigned based on rules

From primitives to affordances

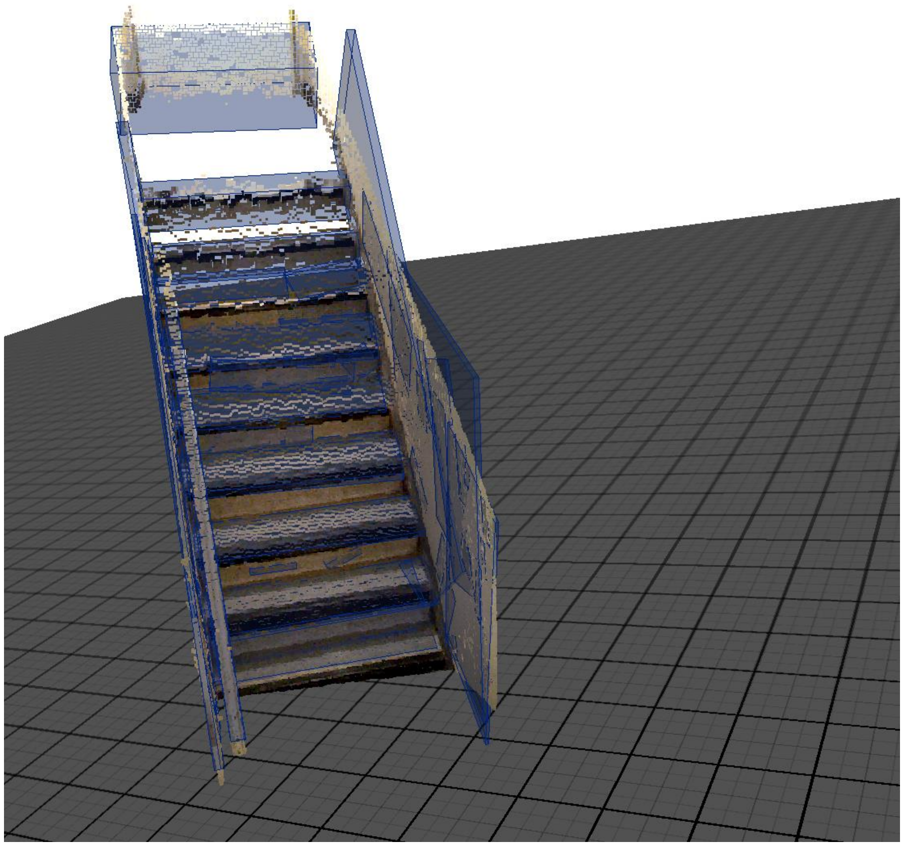


Assigned affordances in point cloud

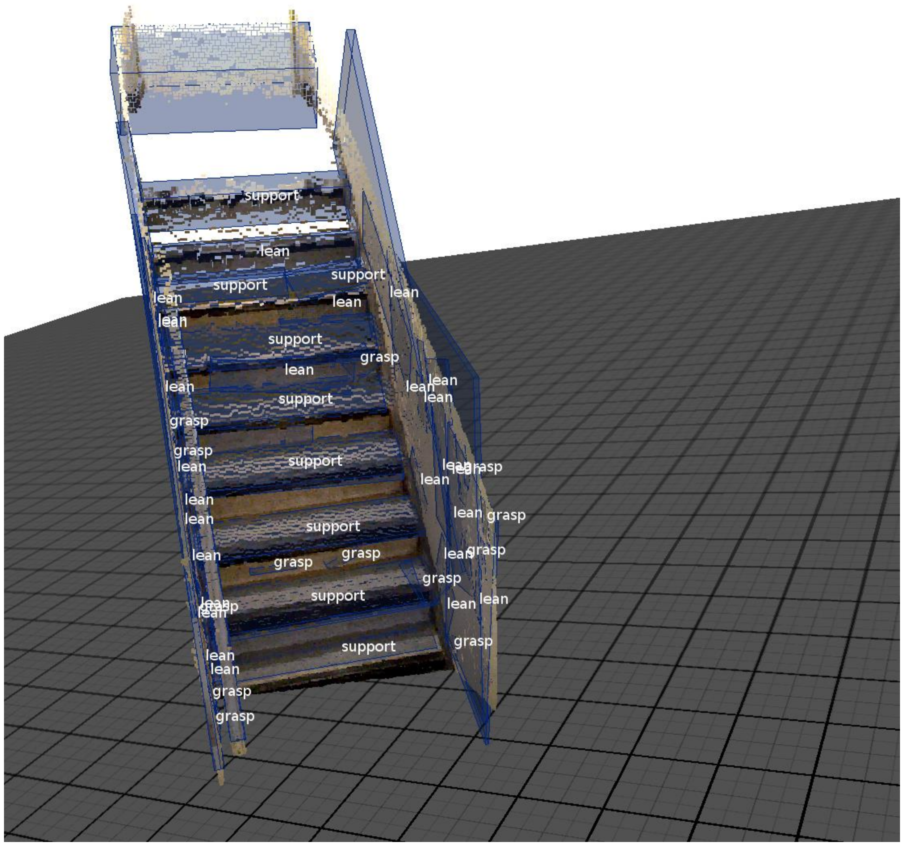


Only reachable affordances. The label is moved to the „reachability/stability hot spot“

From primitives to affordances



Point cloud of a stairs together with extracted primitives



Assigned affordances for stairs (each step has a support affordance)

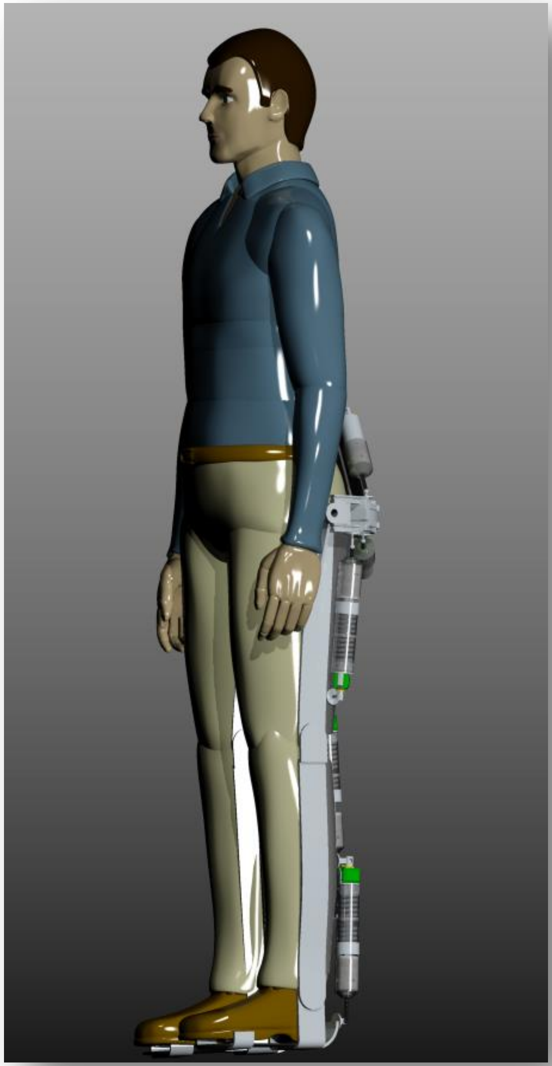
ARMAR-V

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

Helper, Assistant and Companion

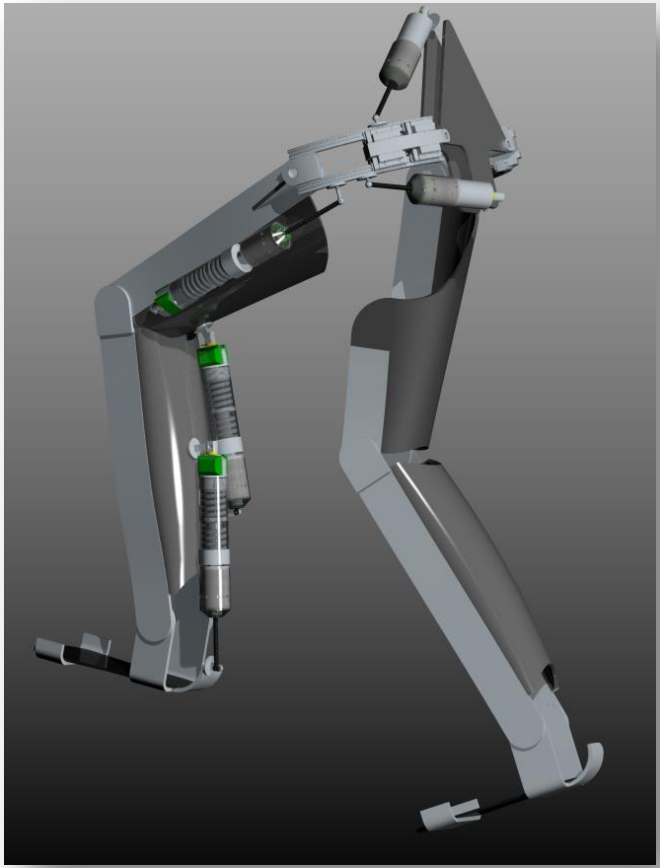
Wearable Humanoid „Body Suit“

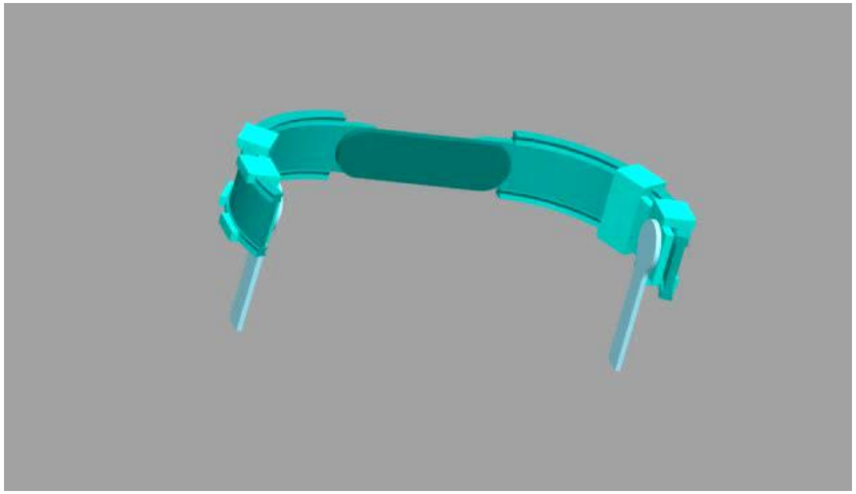
ARMAR-V: Legs



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





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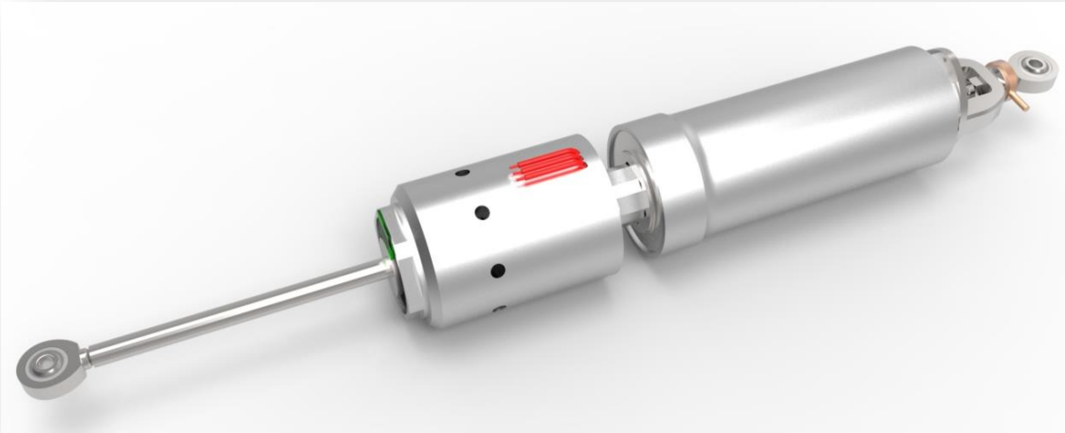
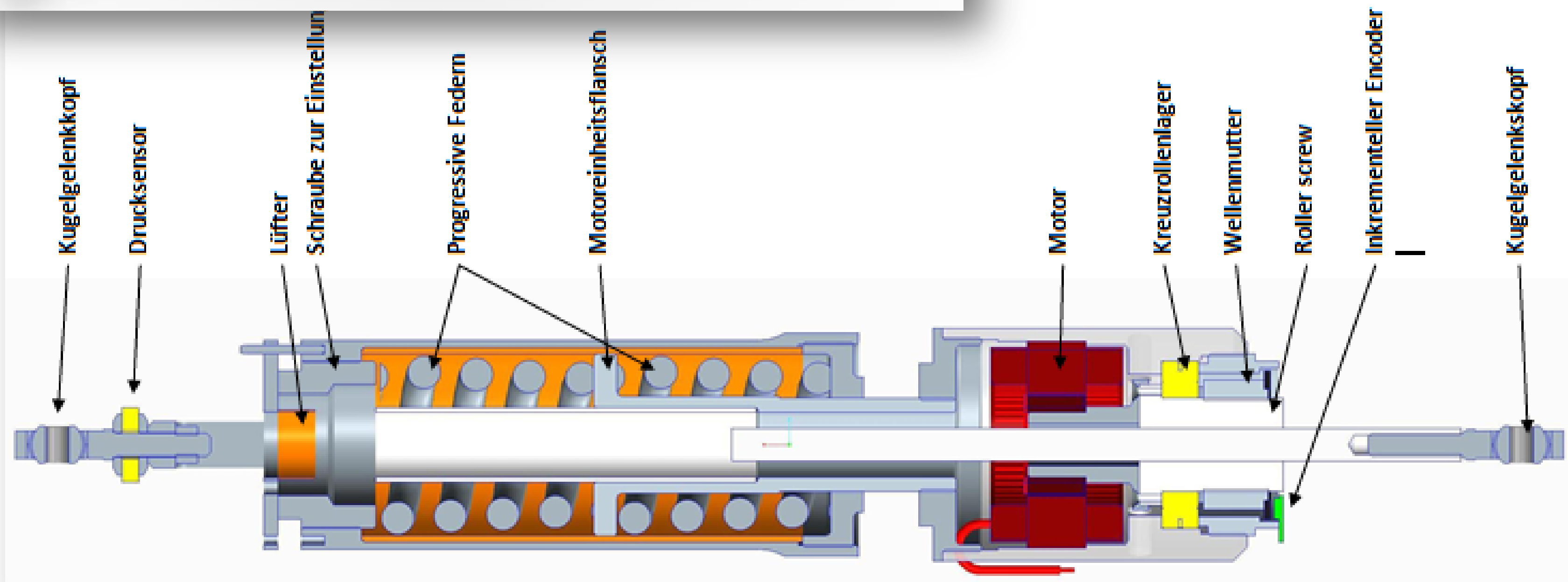
ARMAR-V Legs – New Linear Elastic Actuators

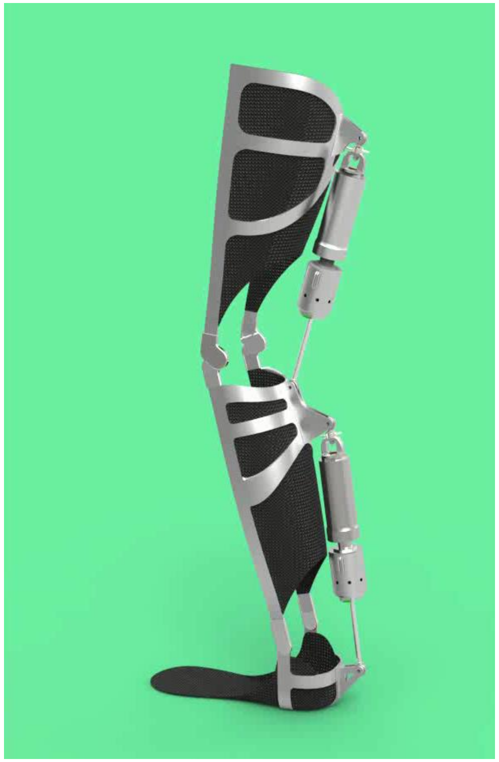


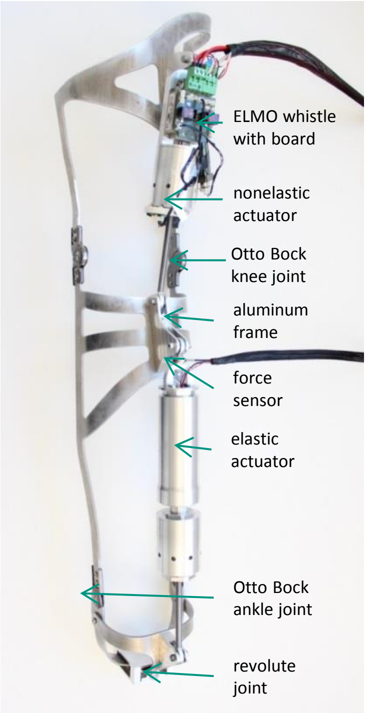
- Maximal axial force 2900 N
- Force at nominal motor torque 930 N
- Speed 300 mm/sec



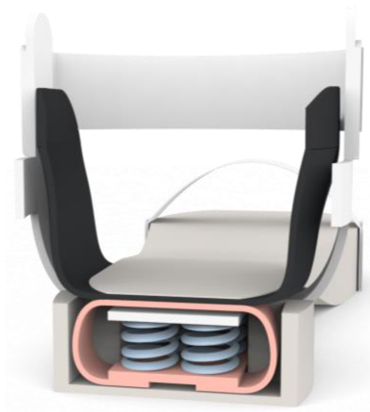
First version – with two elastic actuators

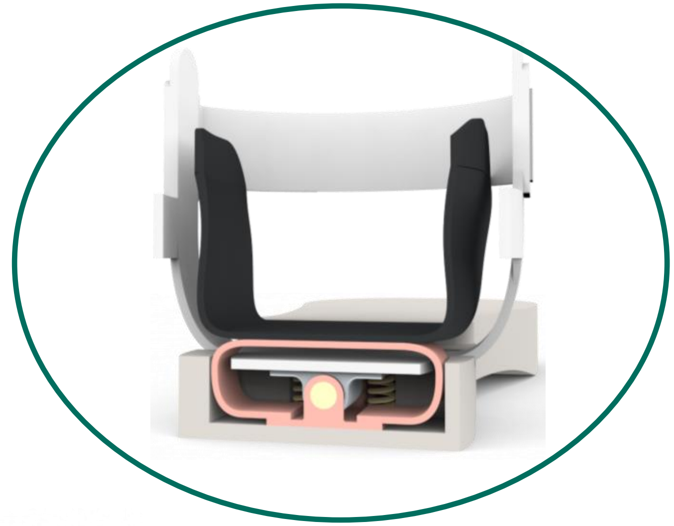
- Progressive springs integrated in the actuators for energy storage and reuse
- Serial-elastic type with 2 progressive springs
- Manually adjustable stiffness by increasing preload on springs

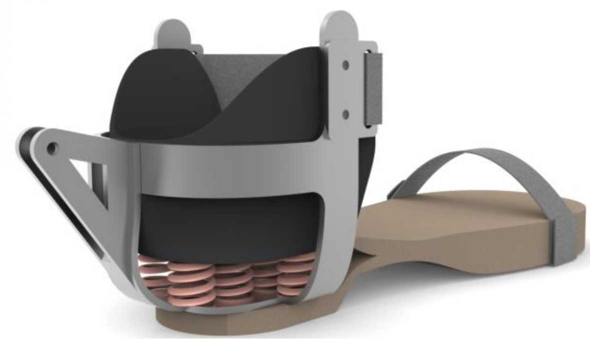




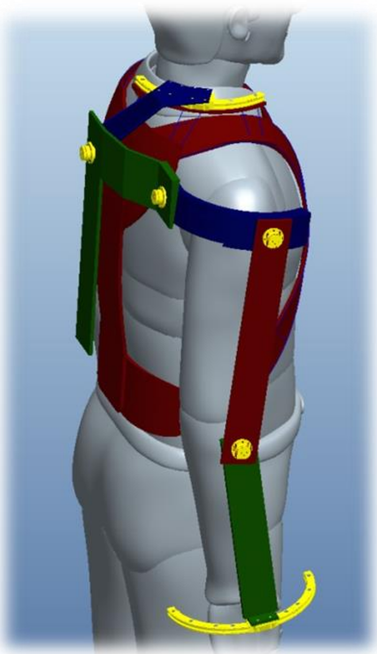
Foot and ankle joint – concepts

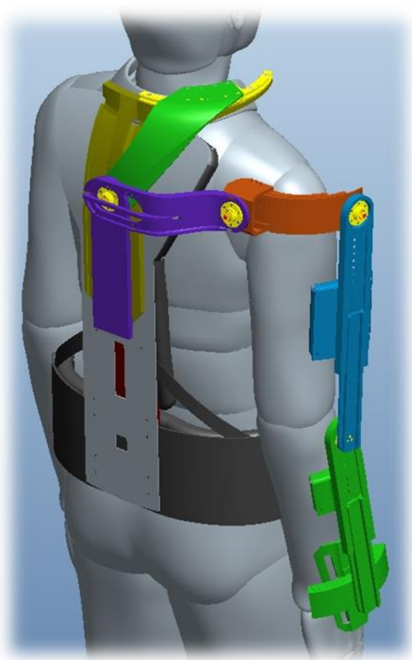


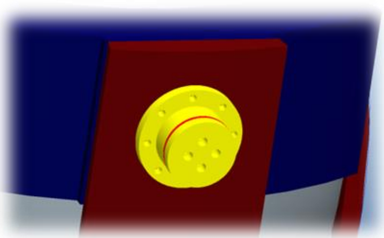


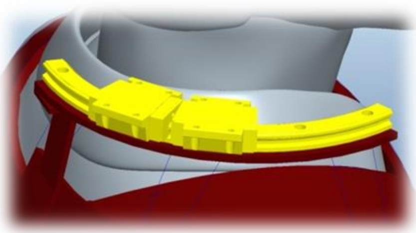


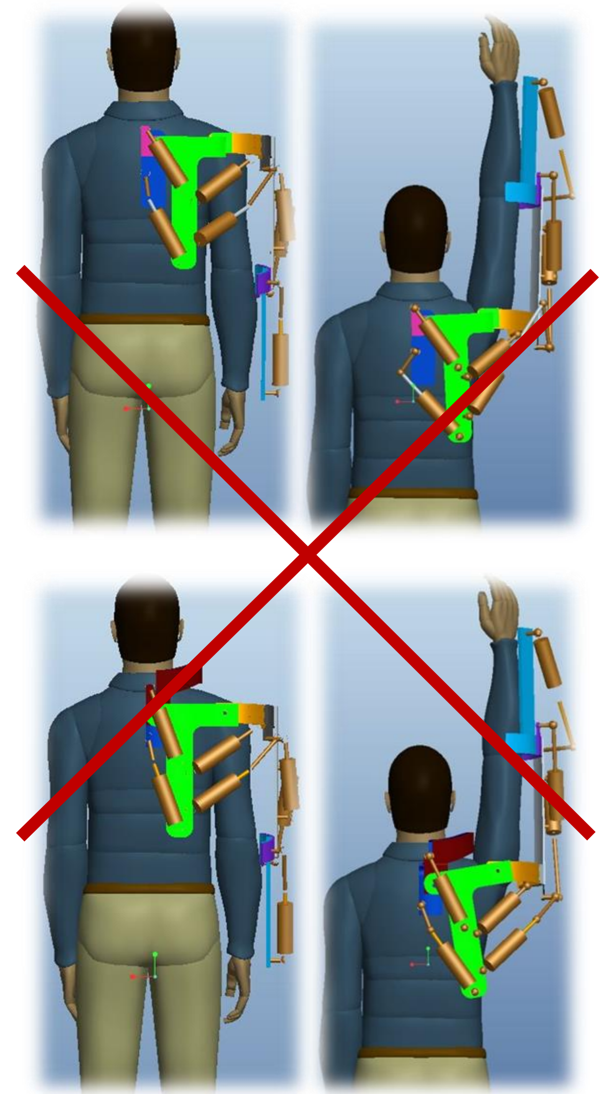
ARMAR-V: Upper body



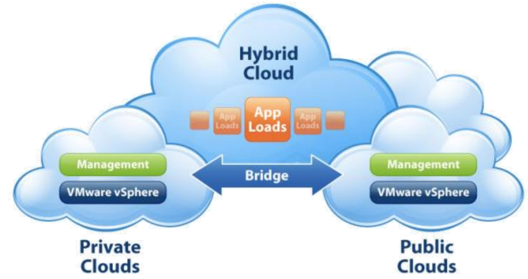


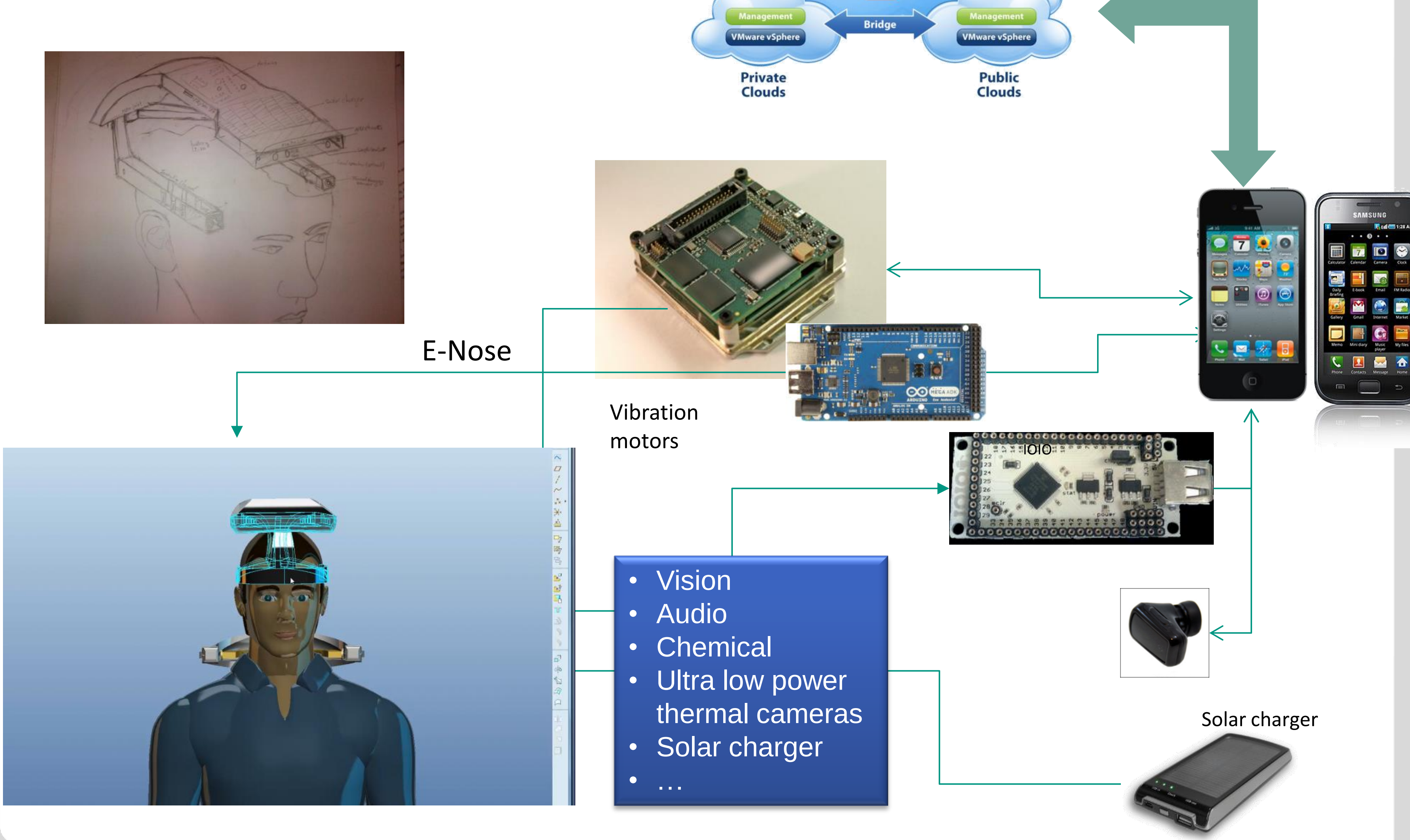




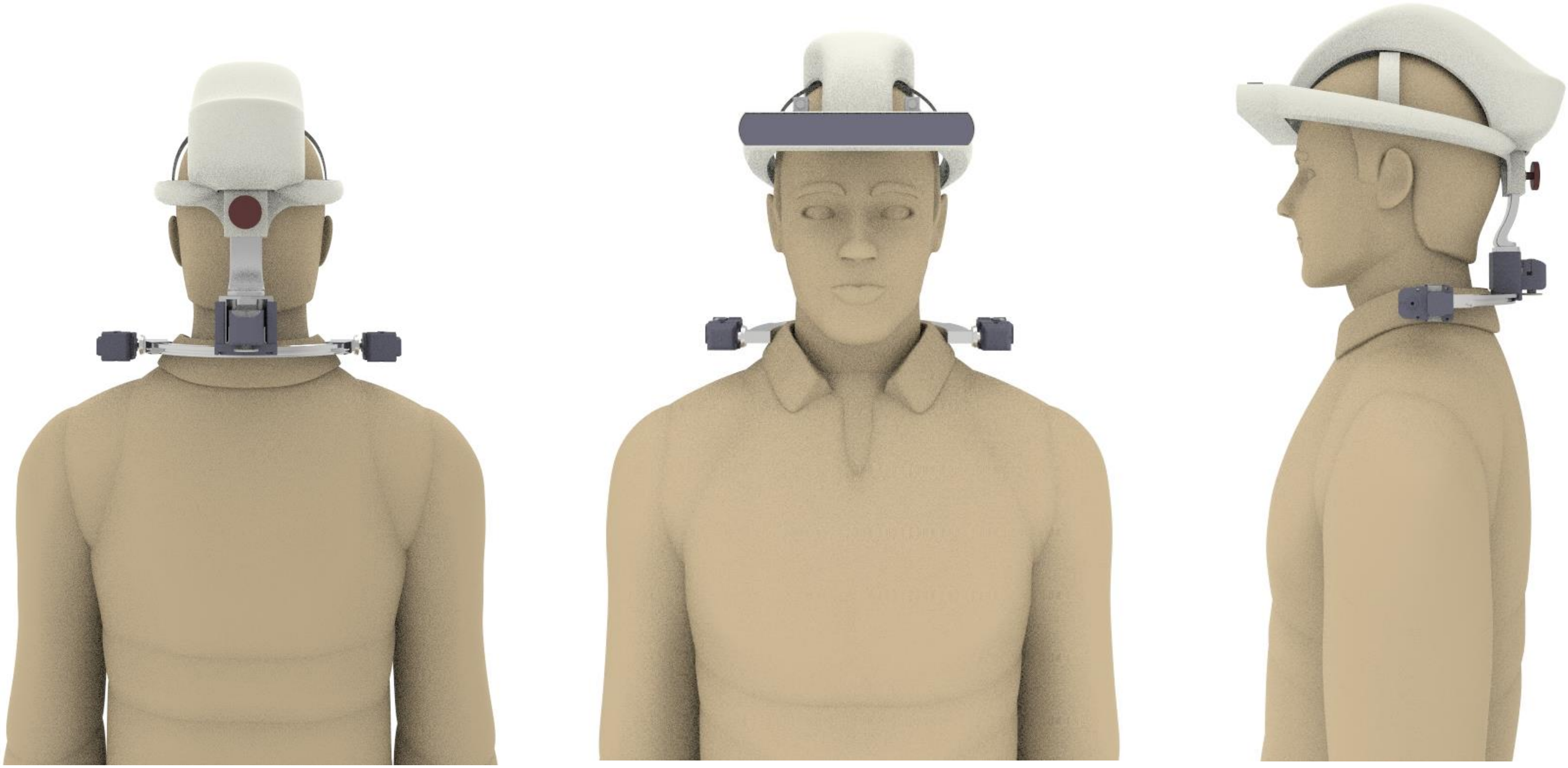


ARMAR-V: Head/ smart Helmet



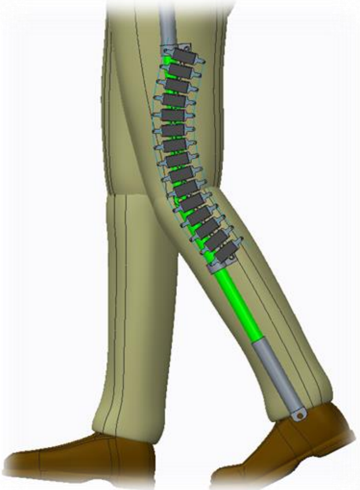
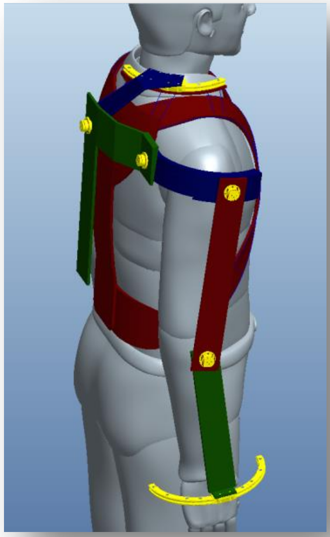
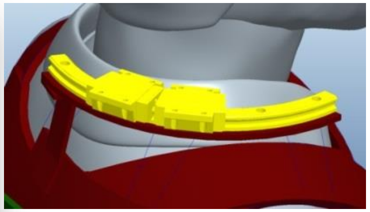
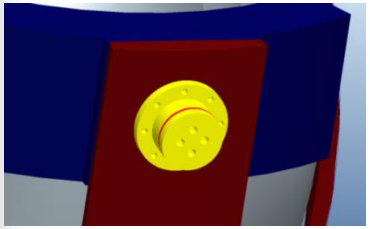
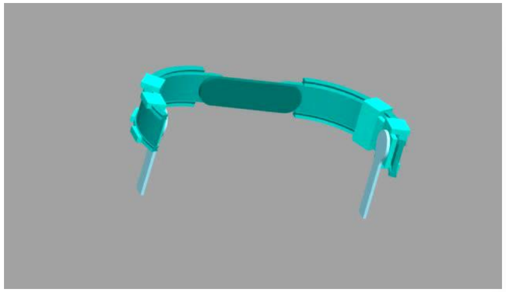
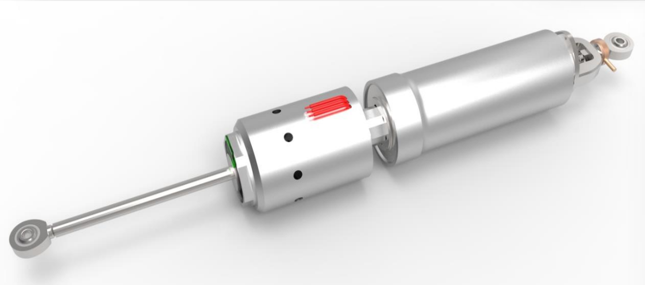
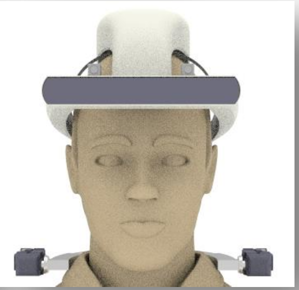


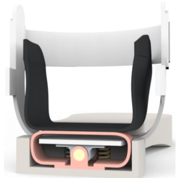
ARMAR-V: Head/ smart Helmet



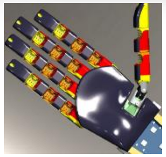
Wearable Humanoid ARMAR-5



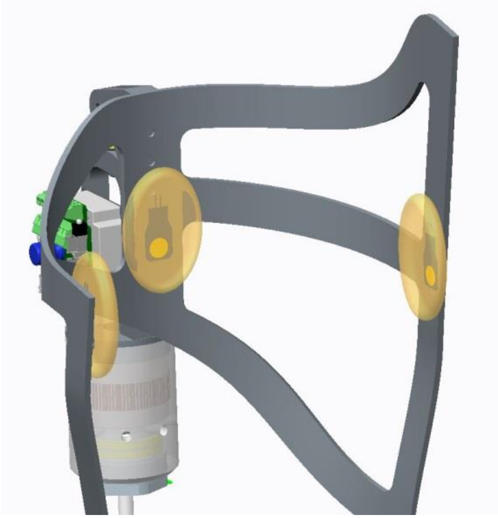



- Maximal „axial“ force 2900 N
- Force at nominal motor torque 930 N
- Speed 300 mm/sec

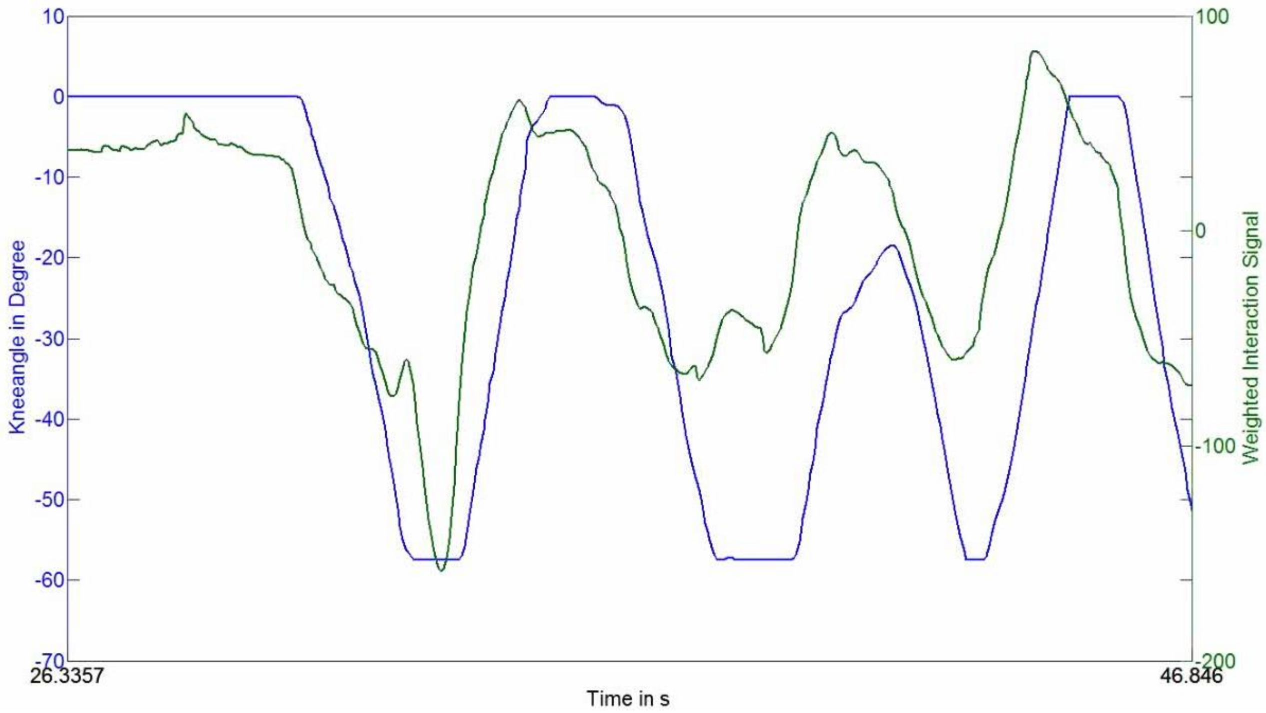


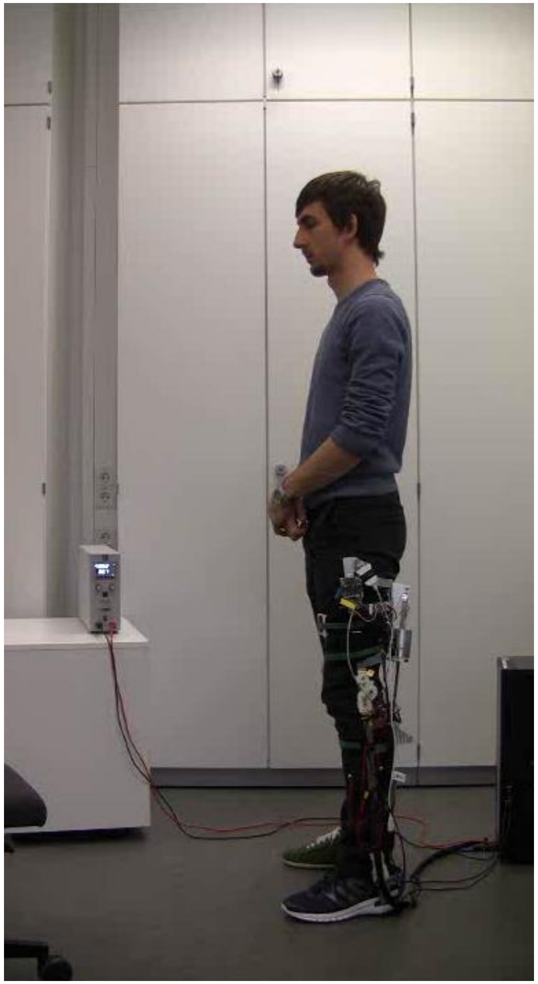
ARMAR V: Interface to the human body

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

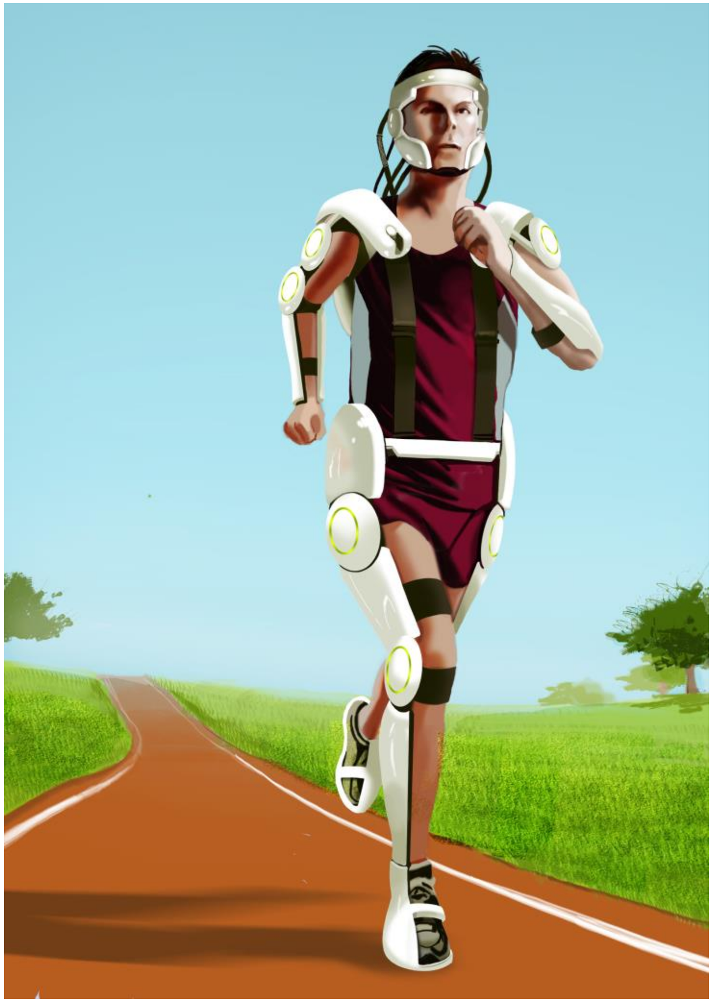


Interaction force based control



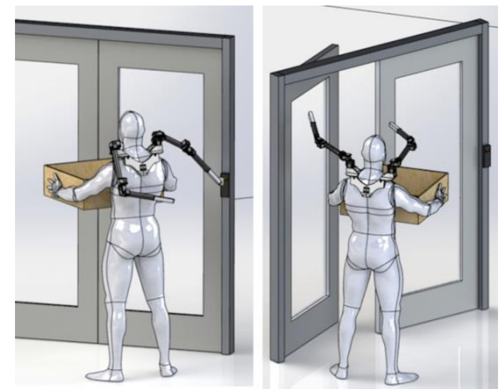


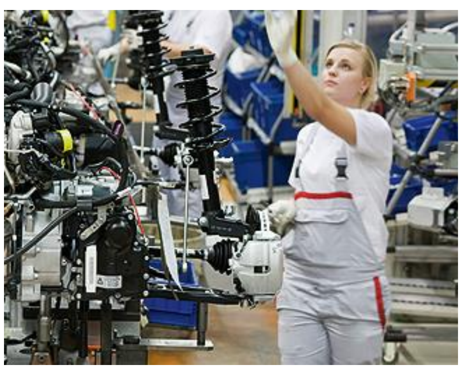
Why wearable humanoid technologies?

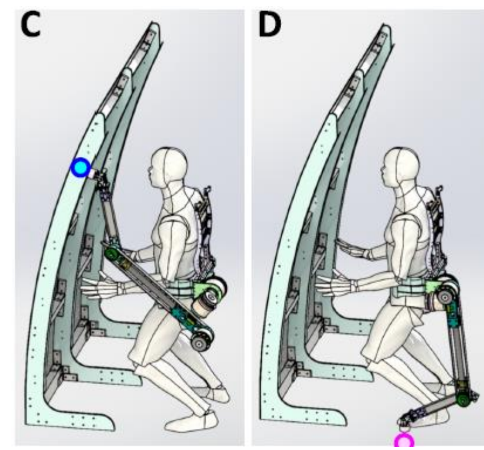


Why wearable humanoid technologies?

- Augmentation of human capabilities in working environments

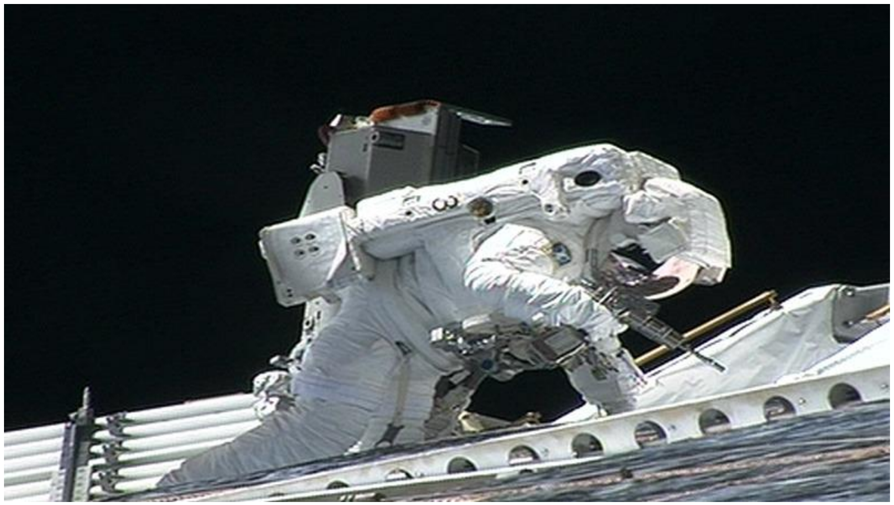






Why wearable humanoid technologies?

- Augmentation and protection in disaster and working environments



Why wearable humanoid technologies?

- Rehabilitation and personalized therapy

New humanoid-driven reform of the health system?

Why wearable humanoid technologies?

- Compensation of physical limitations
  “re-walk”

- “Goodby Wheelchairs”

Some Statistics

- 65 Mio people worldwide in wheelchairs
- 1,1 million people experience a stroke in Europe and 0,5 million in US
- Stroke has been identified by the World Health Organization in 2008 as one of the five main chronic diseases and its incidence is amplified by ageing
- In 40 years, nearly 35% of the European population will be older than 60

Higher numbers of surgical operations of the musculoskeletal system

Rehab robots, smart prostheses and exoskeletons will grow from $43.3 million to reach $1.8 billion by 2020

Why wearable humanoid technologies?

- Augmentation of human capabilities

Foldable actuator-sensor units → Multifunctional nanomaterials and new fabrication technologies for human-robot symbiosis

Transformative Impact of Wearable Humanoids

Transformative Impact of Wearable Humanoids

Karlsruhe Institute of Technology

Thanks to ...

- German Research Foundation (DFG)
  - SFB 588 www.sfb588.uni-karlsruhe.de (2001 - 2012)
  - SPP 1527 autonomous-learning.org (2010 -)
  - SFB/TR 89 www.invasic.de (2009 -)
- European Commission
  - Xperience www.xperience.org (2012-2015)
  - Walk-Man www.walk-man.eu (2013-2017)
  - KoroiBot www.koroibot.eu (2013-2016)
  - GRASP www.grasp-project.eu (2008-2012)
  - PACO-PLUS www.paco-plus.org (2006-2011)
  - New: TimeStorm, SecondHands and I-Support
- Karlsruhe Institute of Technology (KIT)
  - Professorship “Humanoid Robotic Systems”
  - Heidelberg-Karlsruhe Research Partnership (HEiKA)

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Thanks for your attention