Karlsruhe Institute of Technology

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High Performance Humanoid Technologies

On the Duality of Grasping and Balancing

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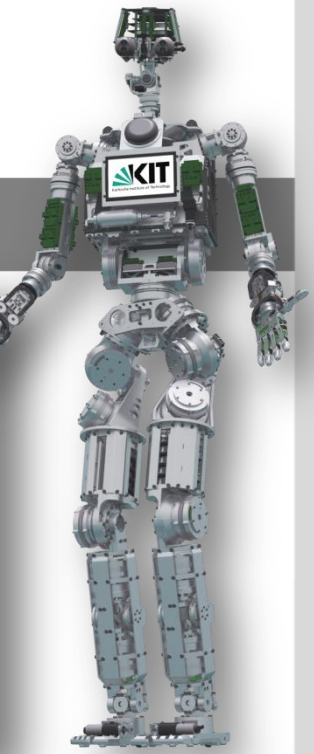
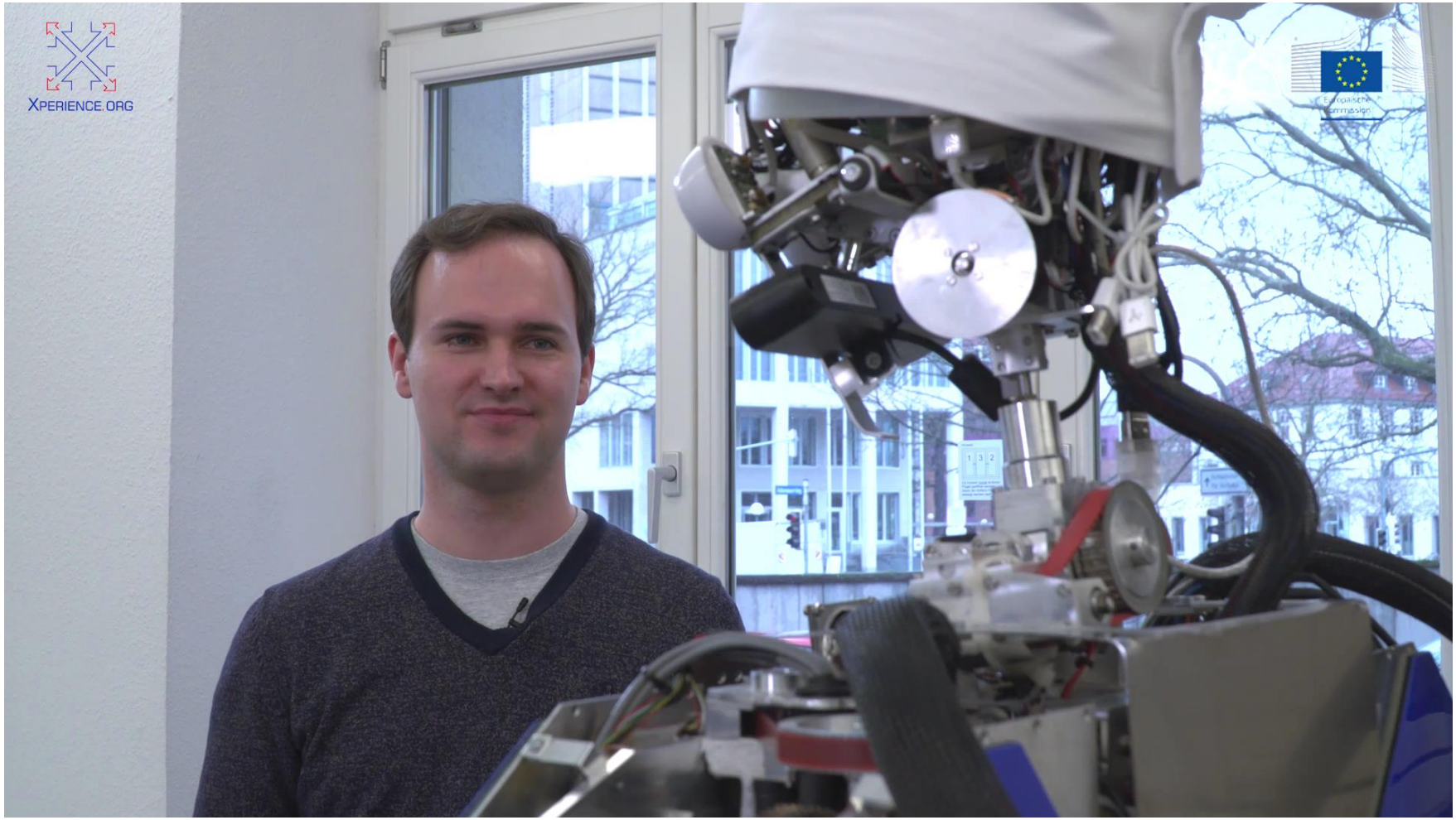


http://www.humanoids.kit.edu

http://h2t.anthropomatik.kit.edu

Integrating language, planning and execution with OACs



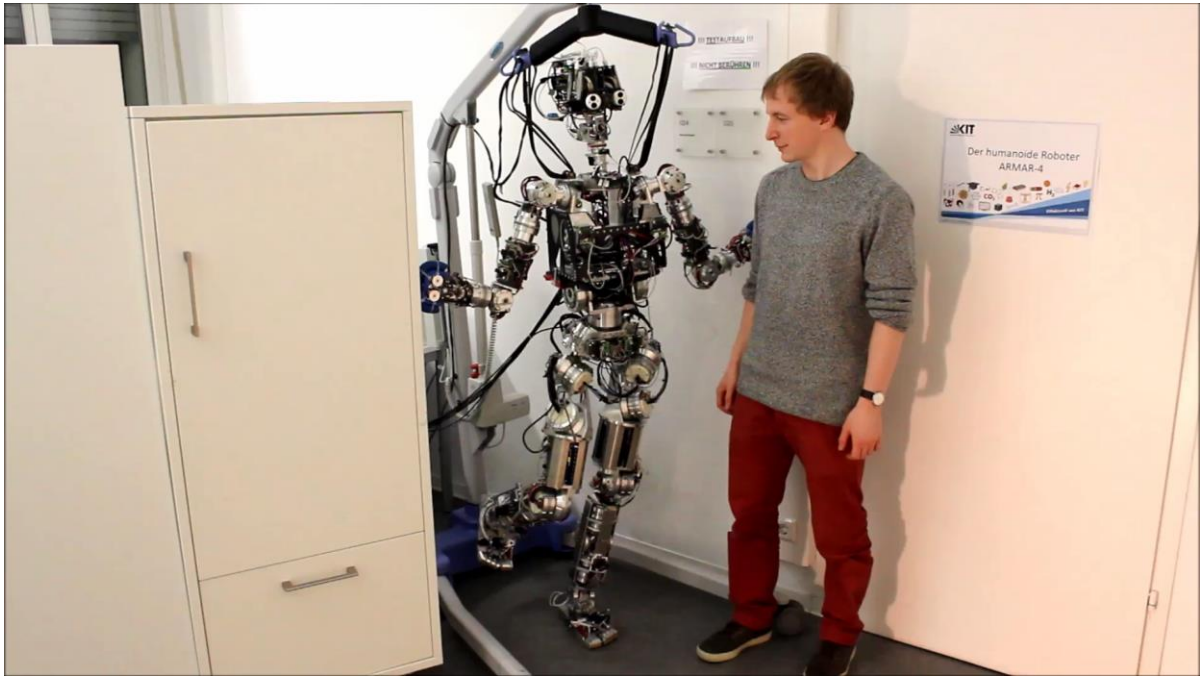
KIT whole-body human motion database

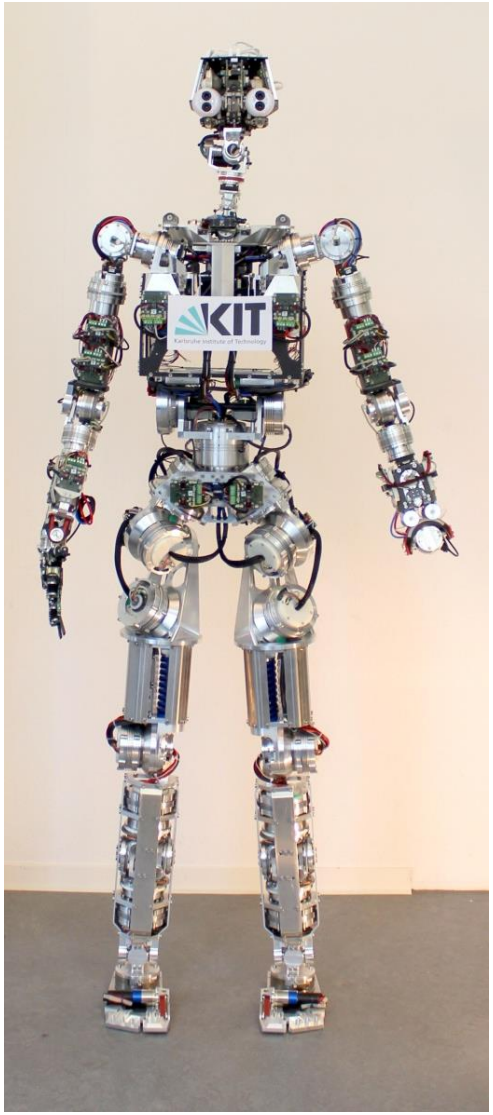
https://motion-database.humanoids.kit.edu/

Mandery et al. "Unifying Representations and Large-Scale Whole-Body Motion Databases for Studying Human Motion", IEEE Transactions on Robotics, 2016

ARMAR-IV: whole body motion and push recovery

- 63 DOF
- Torque-controlled!





Multi-contact active compliance balancing controller

Duality

Duality - Boolean Algebra

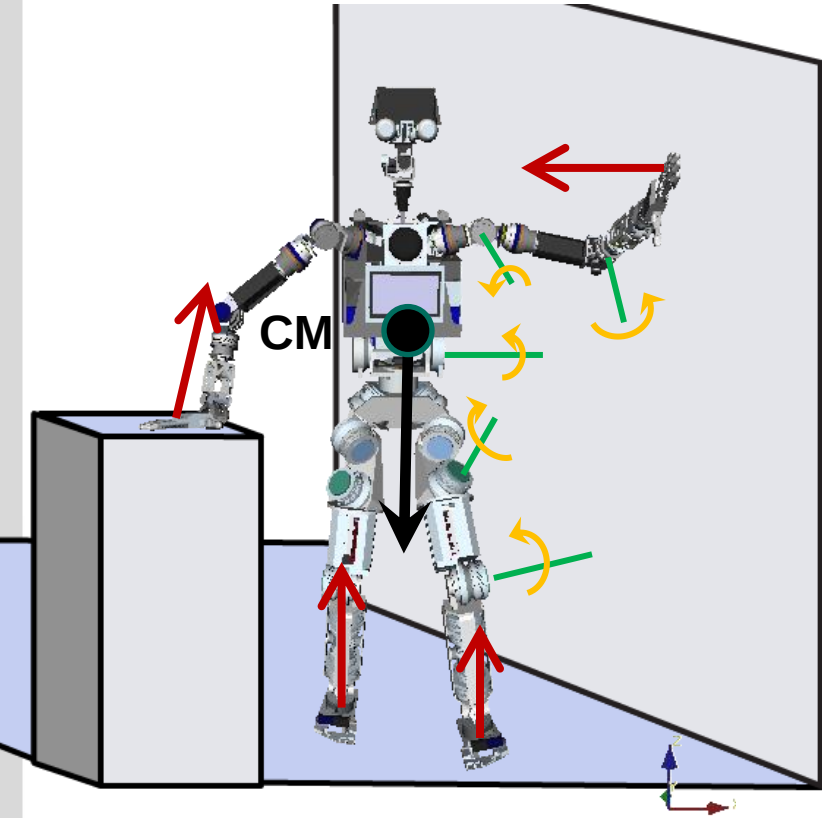
$$\begin{array}{ll} \wedge \leftrightarrow \vee & \mathbf{0} \leftrightarrow \mathbf{1} \\ \boldsymbol{a} \leftrightarrow \boldsymbol{a} & \overline{\boldsymbol{a}} \leftrightarrow \overline{\boldsymbol{a}} \end{array}$$

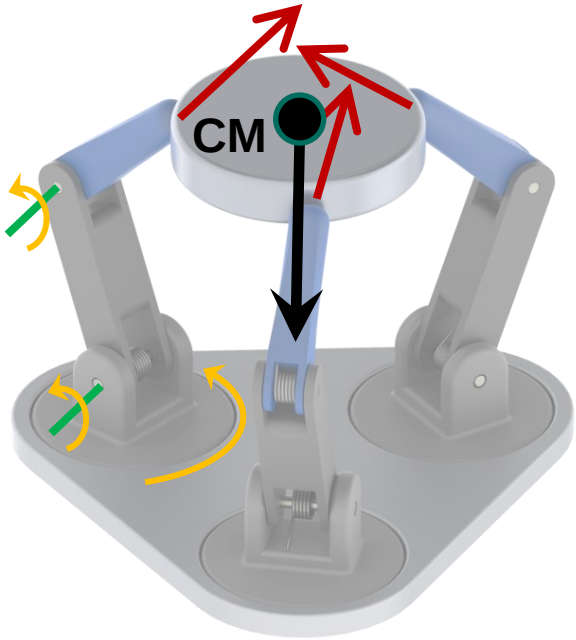
$$\begin{aligned} a \wedge a &\overset{H3}{=} (a \wedge a) \vee 0 \\ &\overset{H4}{=} (a \wedge a) \vee (a \wedge \overline{a}) \\ &\overset{H2}{=} a \wedge (a \vee \overline{a}) \\ &\overset{H4}{=} a \wedge 1 \\ &\overset{H3}{=} a \qquad \text{q.e.d.} \end{aligned}$$

$$\begin{aligned} a \vee a &\overset{H3}{=} (a \vee a) \wedge 1 \\ &\overset{H4}{=} (a \vee a) \wedge (a \vee \overline{a}) \\ &\overset{H2}{=} a \vee (a \wedge \overline{a}) \\ &\overset{H4}{=} a \vee 0 \\ &\overset{H3}{=} a \qquad \text{q.e.d.} \end{aligned}$$

The duality of grasping and balancing

Equilibrium is reached by balancing similar sets of forces



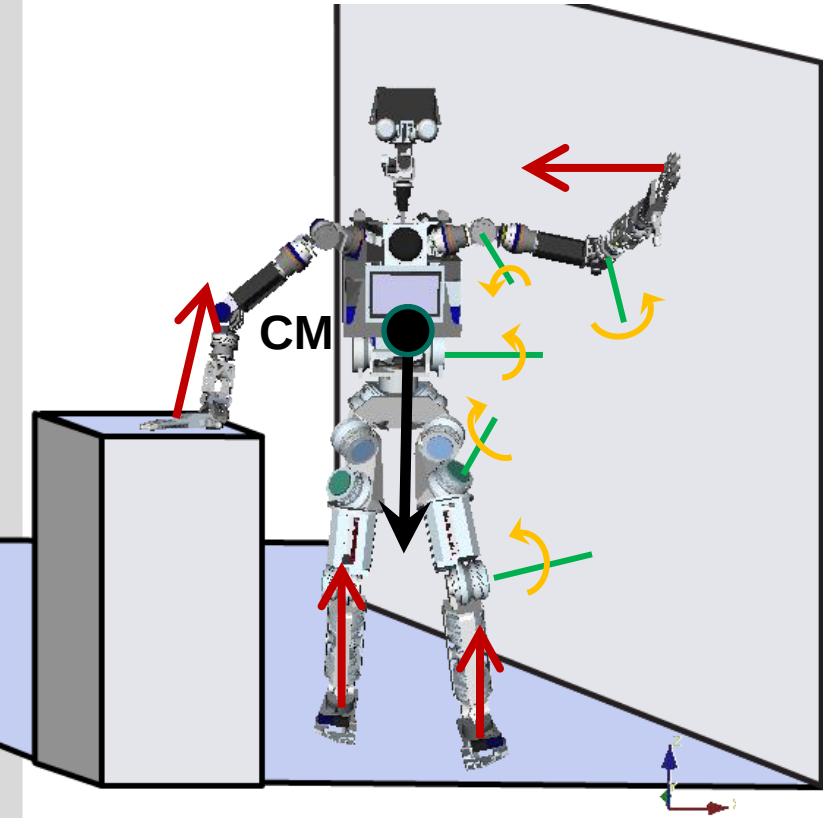


Ground reaction forces ⟷ Fingertip forces

Weight of the body (CM) ⟷ Weight of the object (CM)

Torques on the joints ⟷ Torques on the joints

The duality of grasping and balancing



Concepts of grasping can be applied to loco-manipulation

$$\mathbf{G}^T\mathbf{T} = \mathbf{J}_H\dot{\Theta}$$
$$\mathbf{J}_H^T\boldsymbol{\lambda}_f = \boldsymbol{\tau}$$
$$-\mathbf{G}\boldsymbol{\lambda}_f = \mathbf{W}$$
$$\boldsymbol{\lambda}_f \in \mathscr{F}$$

Balance ⟷ Stable grasp

Step planning ⟷ Grasp synthesis

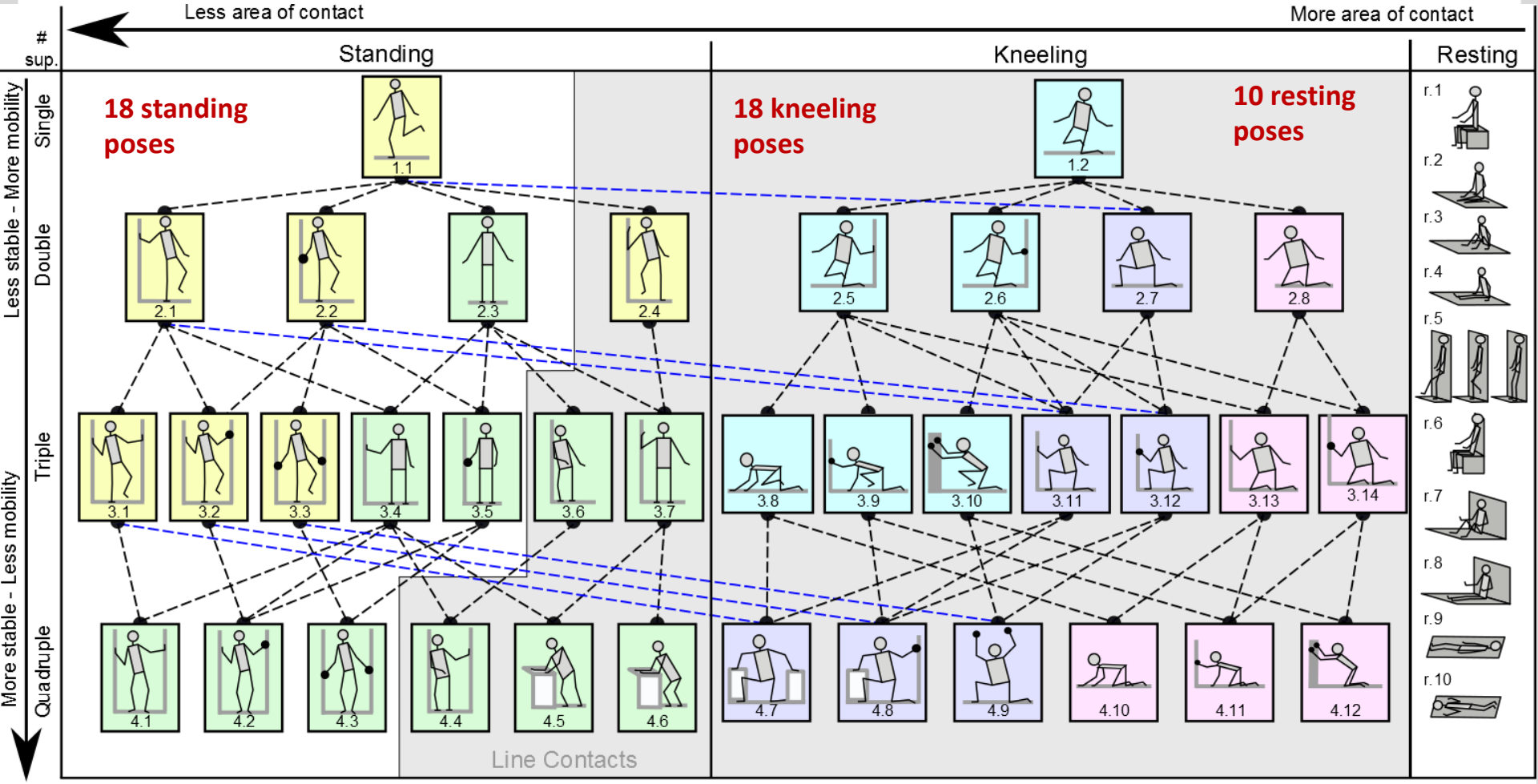
On the Duality of grasping and balancing

- Selection of support pose ⟷ Grasp selection
- Selection of contact points ⟷ Grasp synthesis
- Classification of support poses possibilities ⟷ **Grasping taxonomies**

M. R. Cutkosky, 1989 | N. Kamakura, 1989 | T. Feix et al, 2009 | Bollock et al. 2013

- Applications of grasping taxonomies
  - Benchmark to test robot hand abilities
  - Simplify grasp synthesis
  - Inspire hand design
  - Optimization of synergies: Formulation of dexterity/functionality as number of achievable grasps for maximization
  - Guide autonomous grasp selection

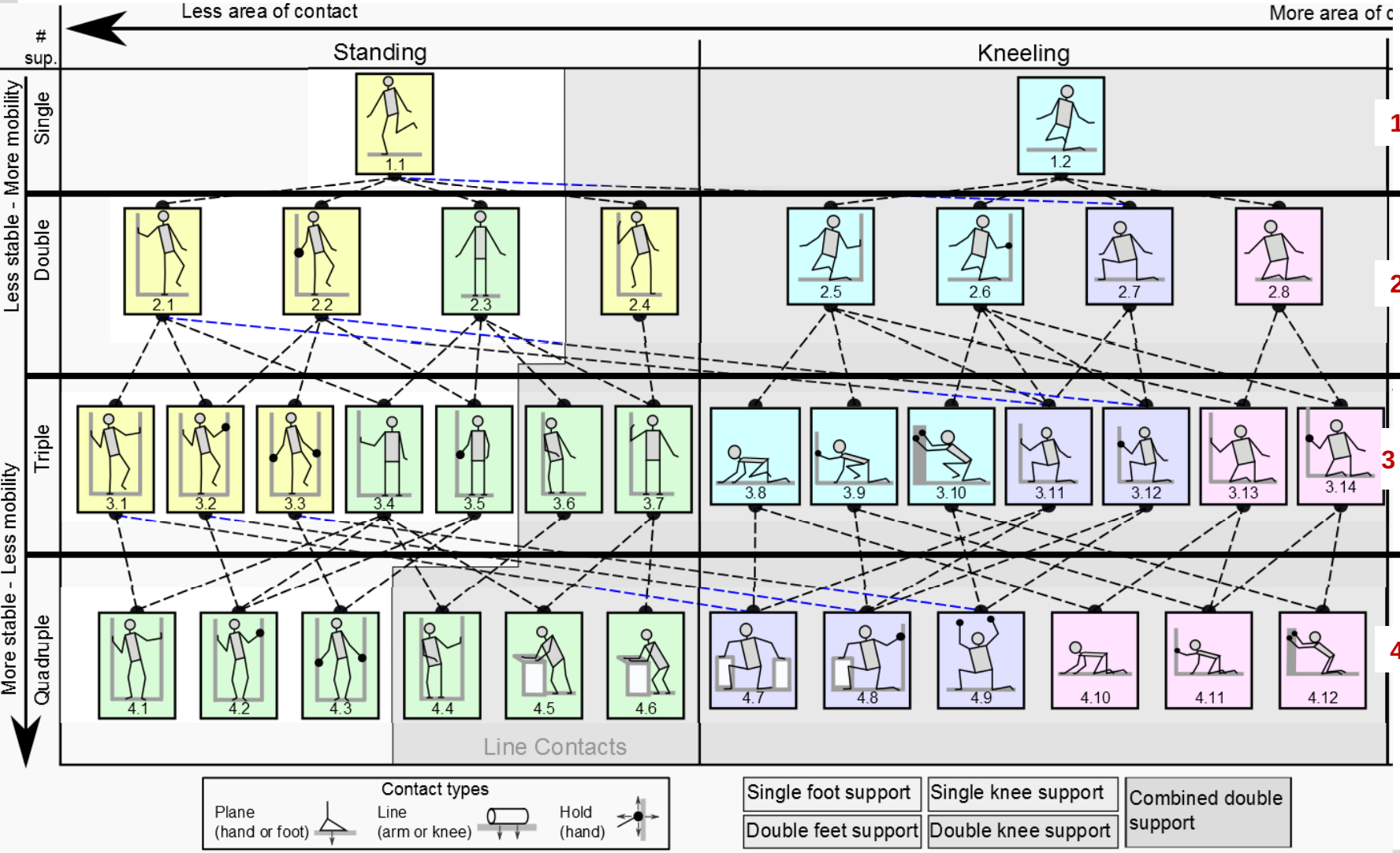
Taxonomy of whole-body poses



Total: 46 classes

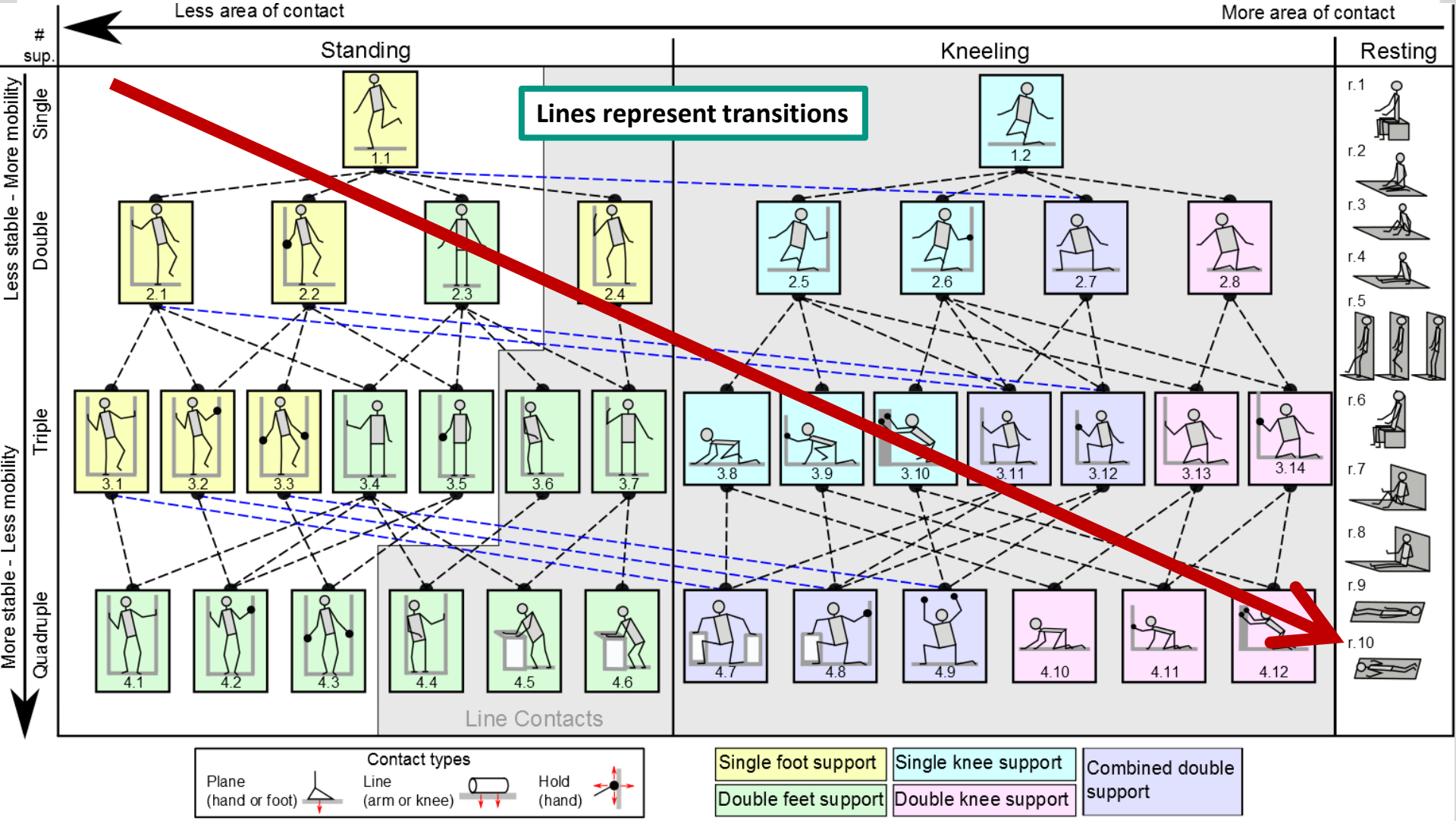
Borras and Asfour, IROS 2015

Taxonomy of whole-body poses



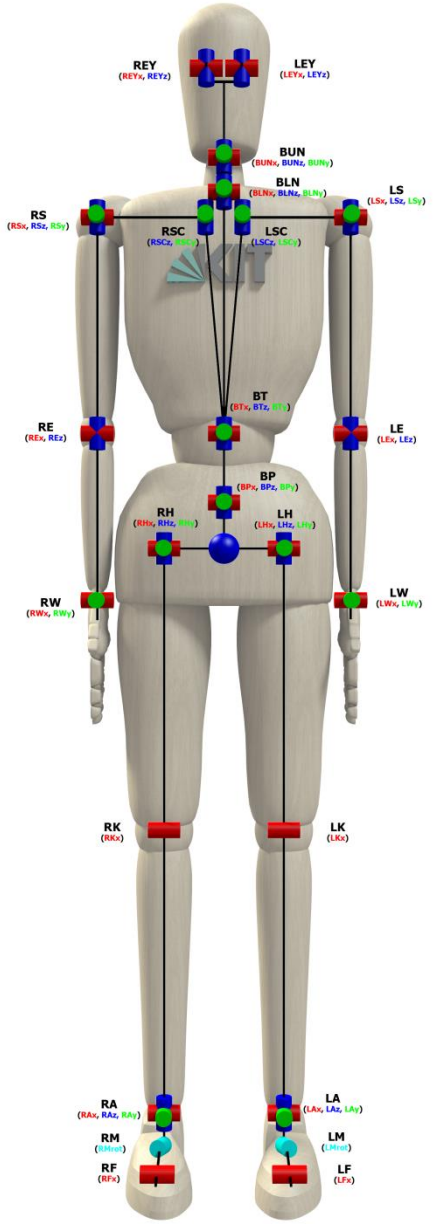
Borras and Asfour, IROS 2015

Taxonomy of whole-body poses



Validation of the taxonomy

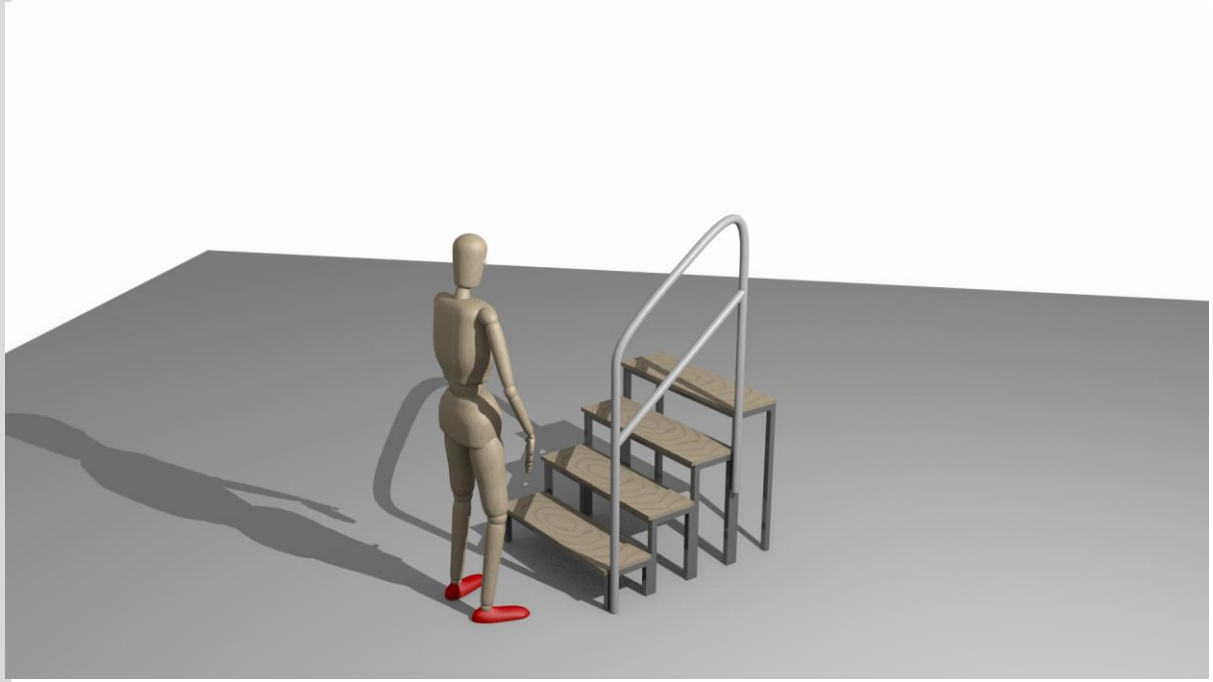
- Analyses of different human loco-manipulation tasks with supports
- Reference model of the human body (Master Motor Map: MMM) with 104 DOF
- Motion capture data mapped to reference model of the human body (MMM)
- Automatic segmentation to detect support poses and transitions
- Automatic generation of a taxonomy of the poses and their transitions in der motion data



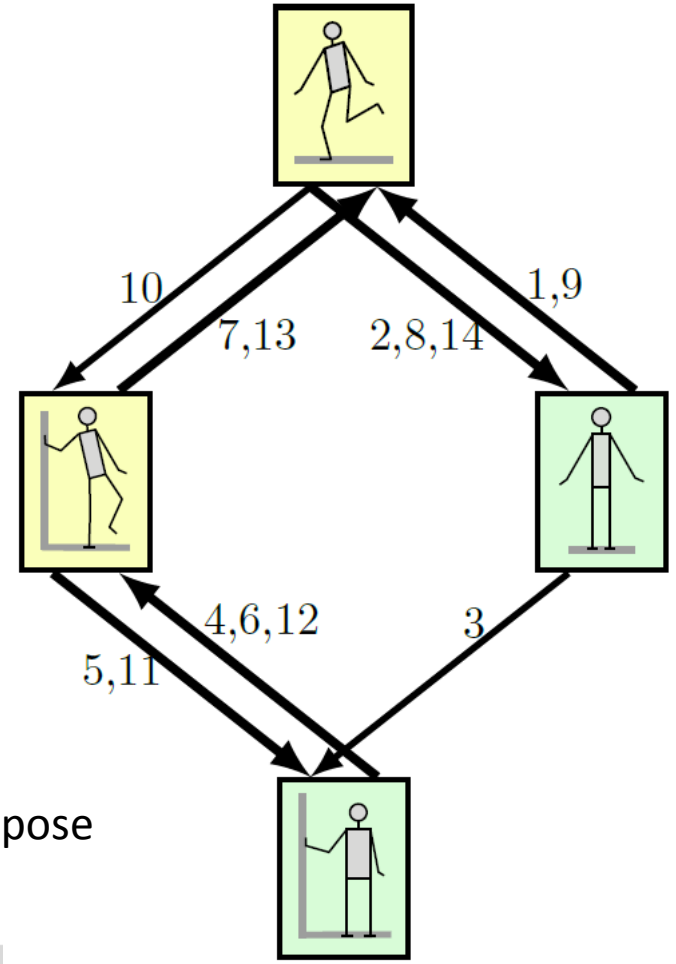
Analysis of pose transitions

Going upstairs with a handle

Detection of support contacts highlighted in red

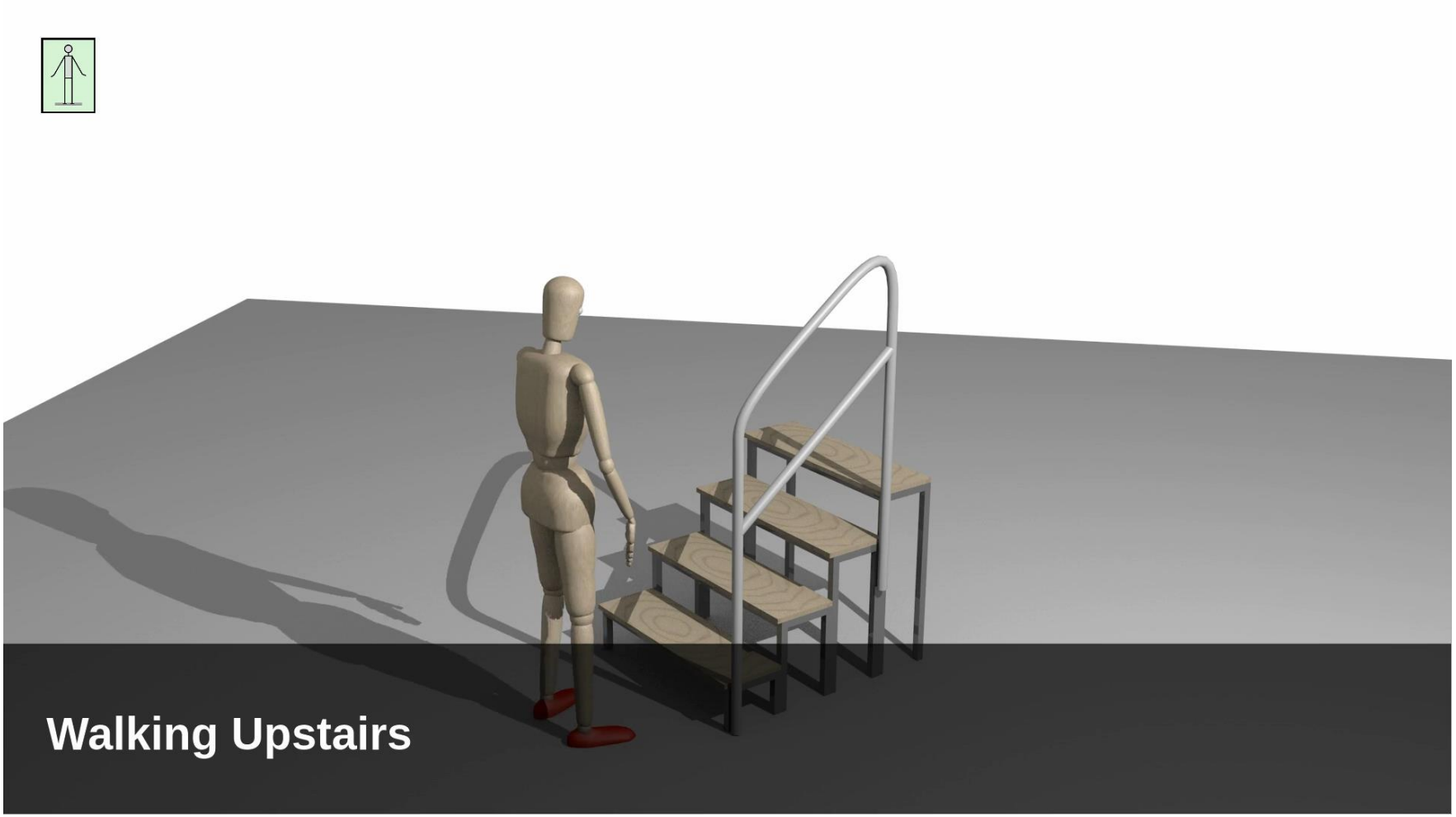


Generated graph of transitions:

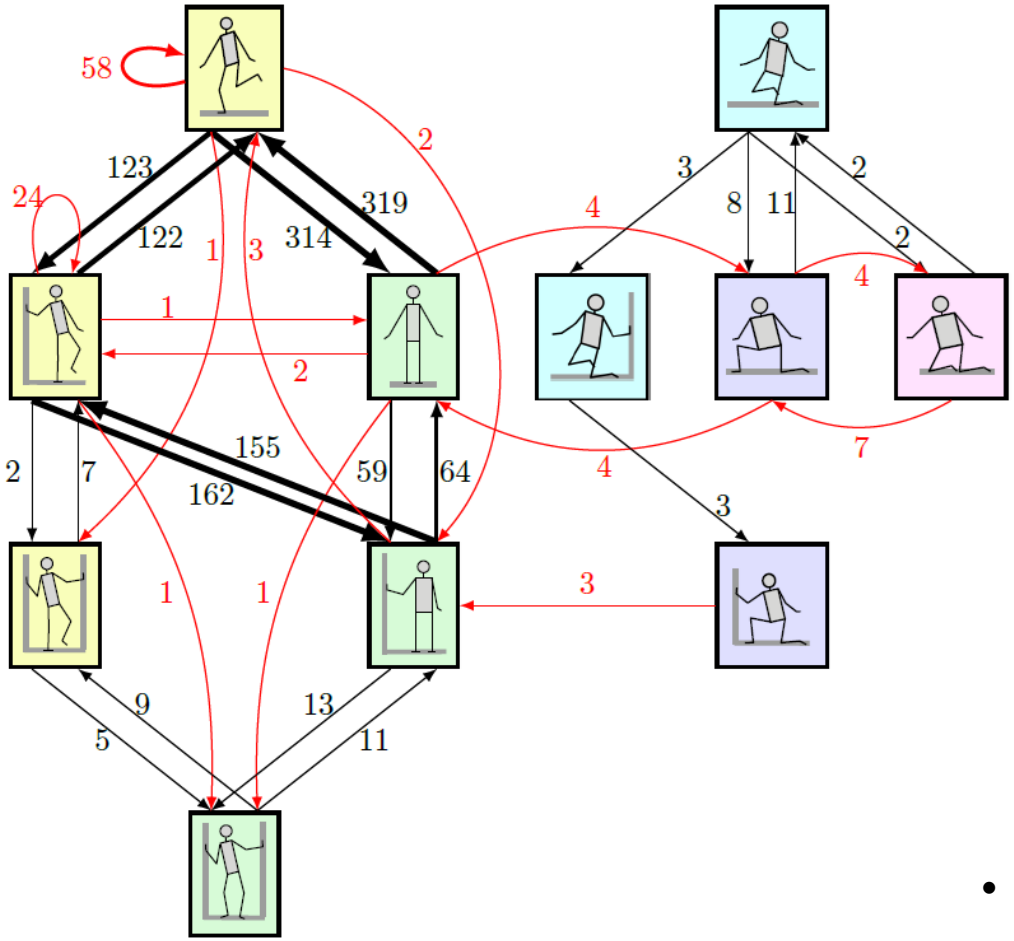


Subject swings left leg with a *right foot – right hand* support pose

Analysis of whole-body loco-manipulation tasks



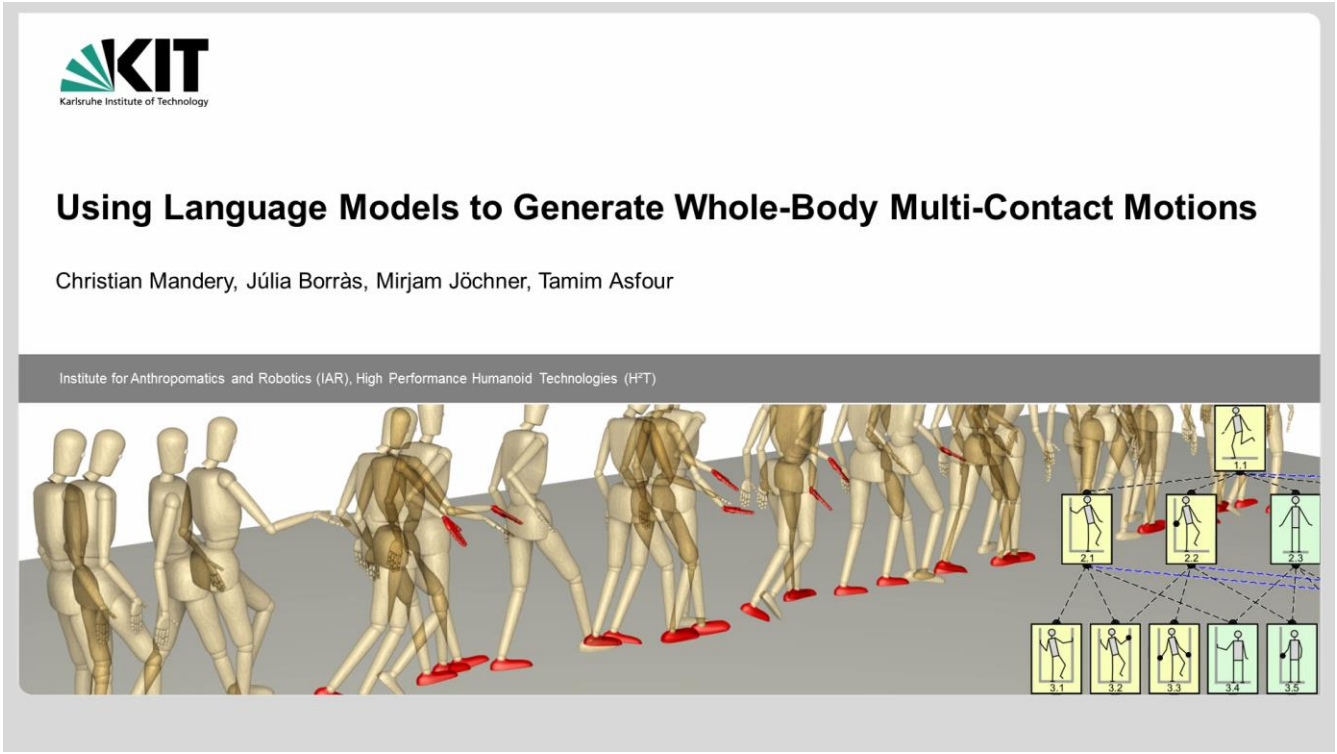
Data-driven validation of the taxonomy



- Total of **121** motions processed
  - **Locomotion**
    - Upstairs/downstairs with handle
    - Walk with handle
    - Walk avoiding obstacles using hand supports
  - **Loco-manipulation**
    - Lean to reach/place/wipe
    - Bimanual pick and place of big objects
  - **Balancing**
    - push recovery
    - recovery due to lost balance
  - **Kneeling motions**
- 4,5% of poses missed (all double foot supports (the looping edges))

Motion as sequences of whole-body poses (words)

- Whole-body motion planning based on the taxonomy and motion primitives between support poses
- **n-gram language model**: Statistical approach to learning conditional transition probabilities between whole-body shape poses



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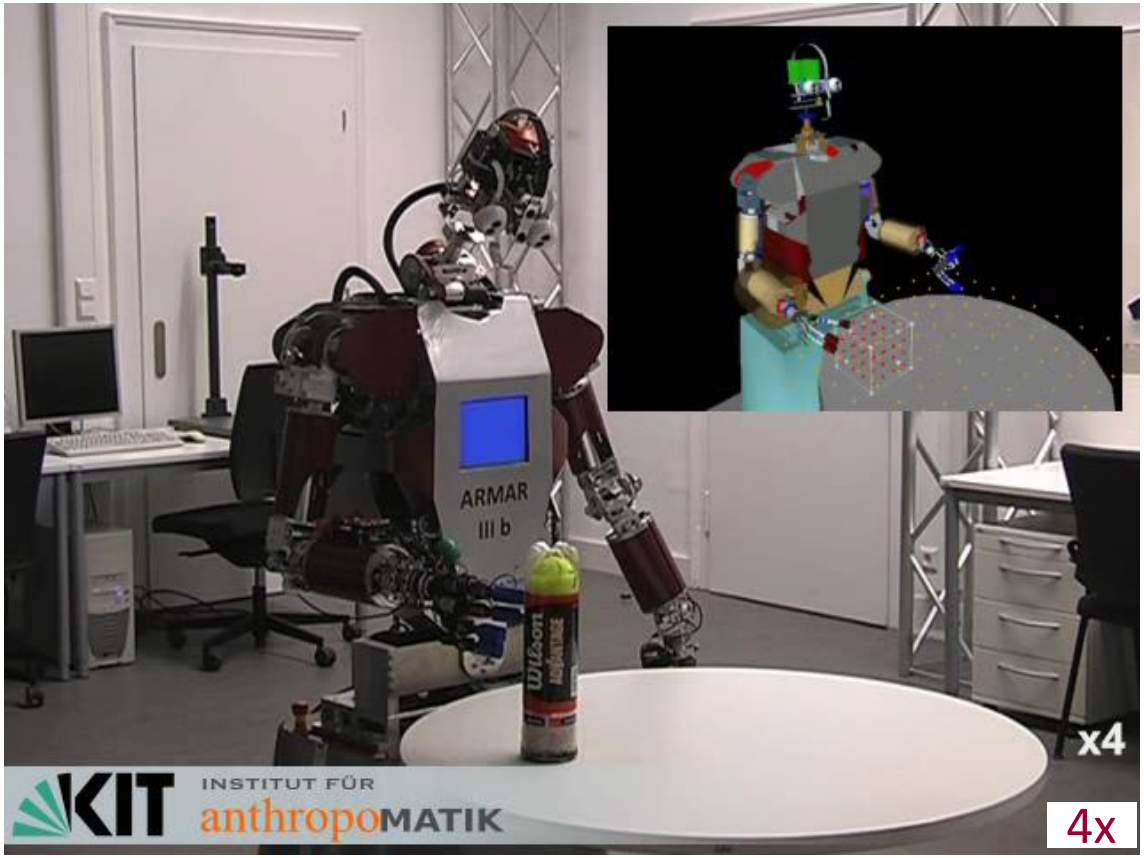
Extraction of grasping affordances

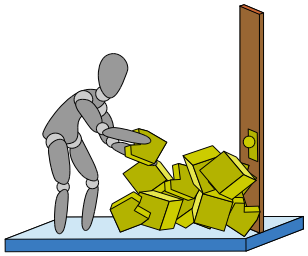
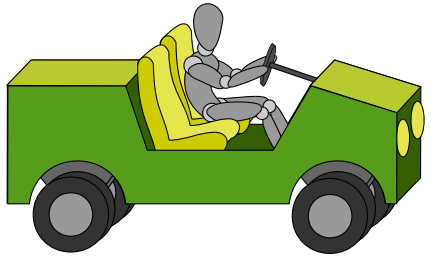
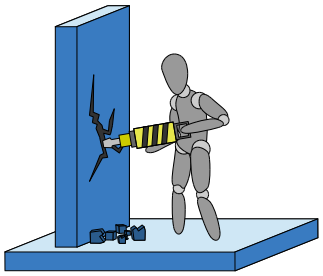
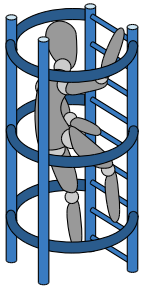
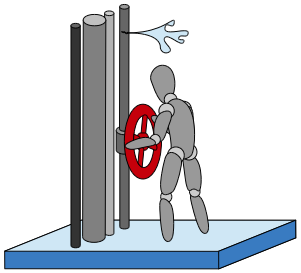
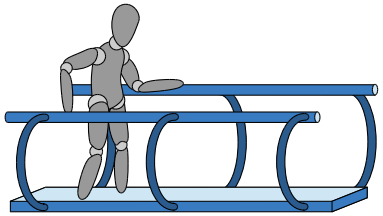
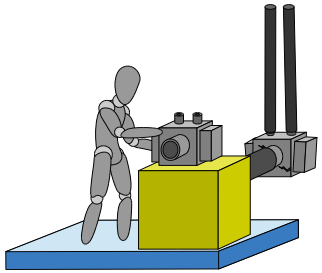


Association between “objects” and grasping actions → “grasp affordances”

Whole body loco-manipulation tasks

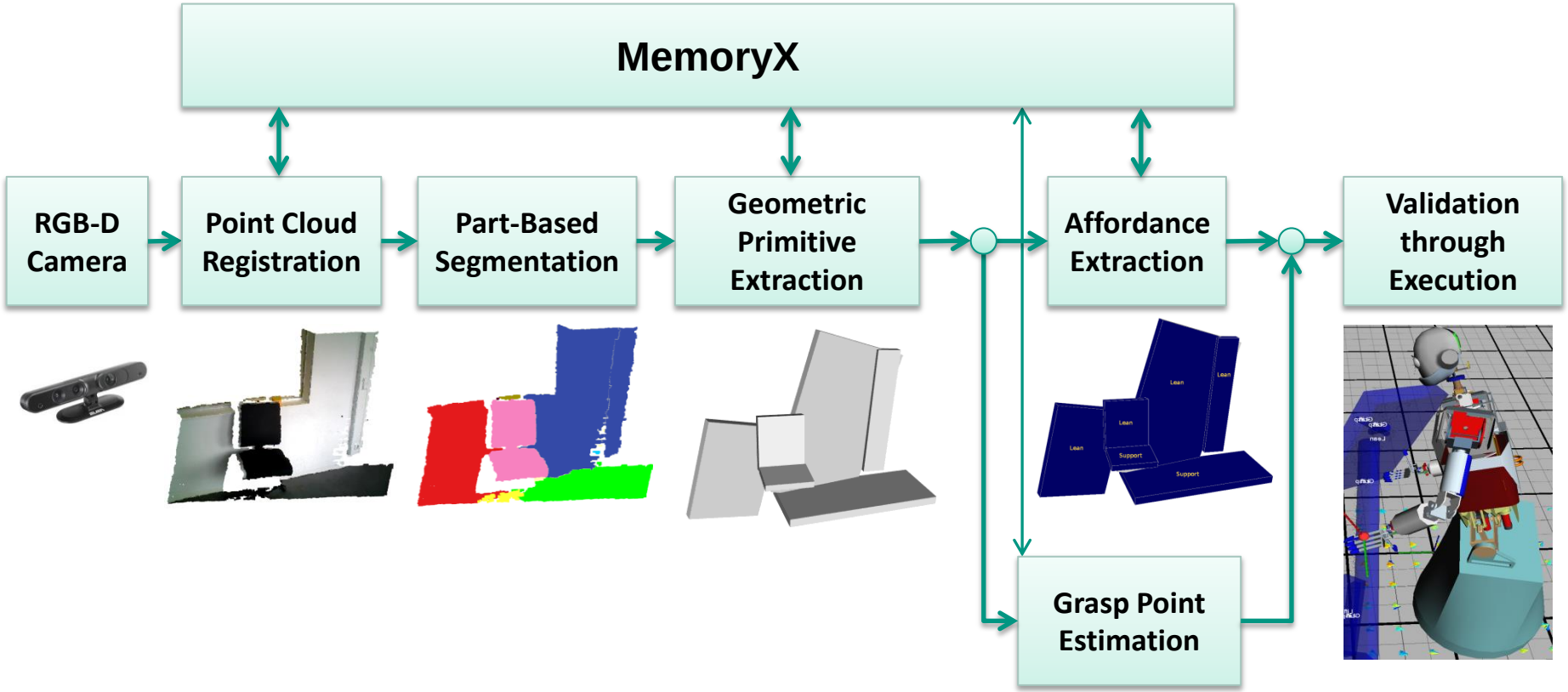
- These are whole body grasps !



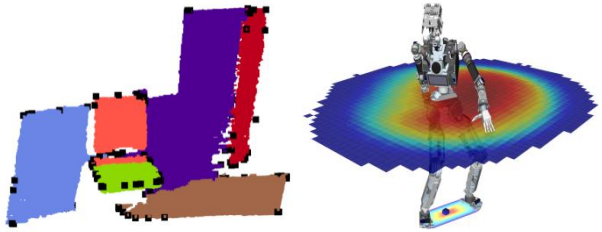








http://www.walk-man.eu

Affordance Extraction Pipeline

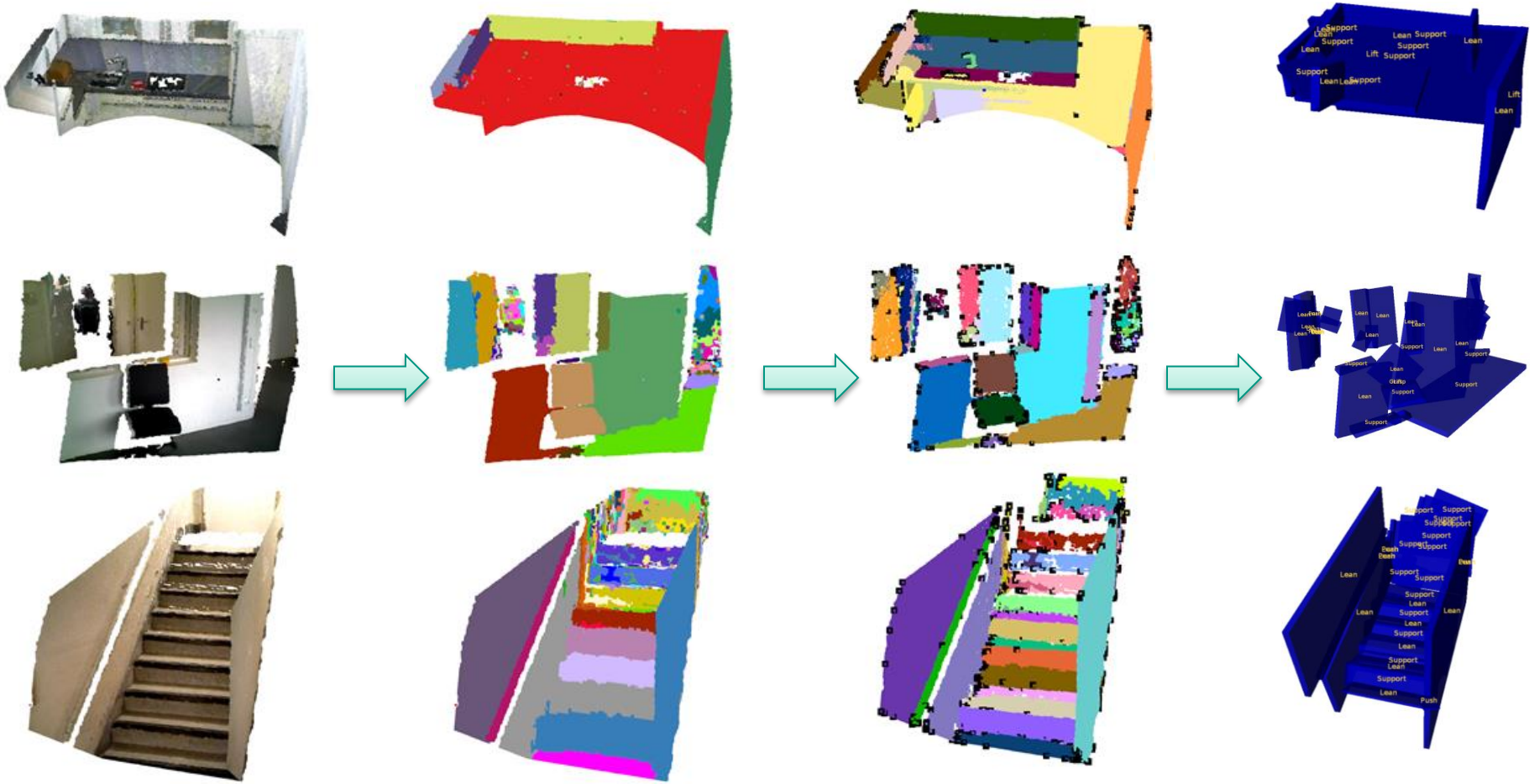


3D point clouds → environmental primitives → affordance



From 3D Point Clouds to Affordances

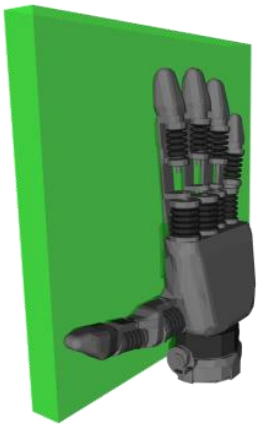
Registered Point Clouds | Segmented Point Cloud | Primitive & Grasp Points | Affordances



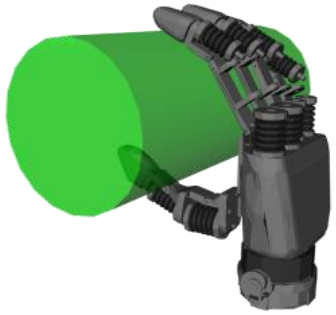
Formalization of whole body affordances

- Most whole-body actions rely on fundamental grasp affordances (Leaning, holding, pushing, stepping, …)

- **Hierarchical formalism** for affordances
  - Based on **elementary power grasp affordances**



Platform grasp



Prismatic grasp

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Hierarchical formalization of affordances

- Affordances are represented as certainty functions Θ

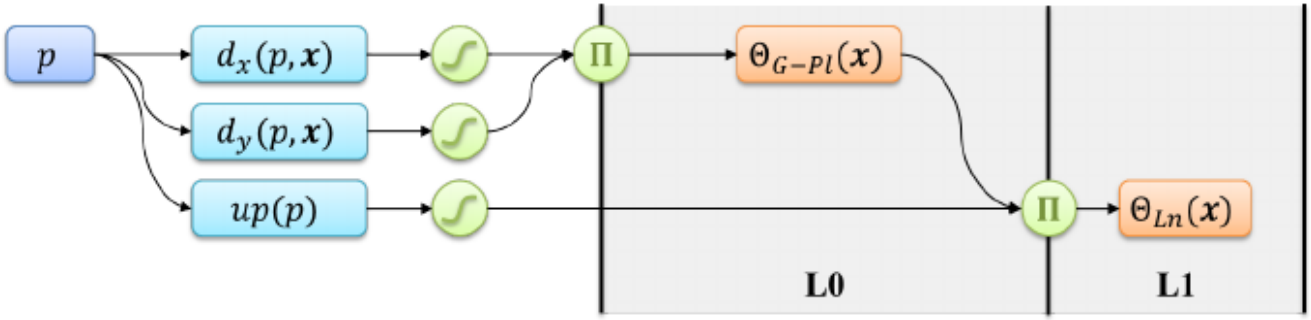
$$\Theta_a : \Pi \times \mathcal{S} \rightarrow [0, 1]$$

- Map a combination of a primitive π and an end-effector pose $\boldsymbol{x}$ to a certainty value

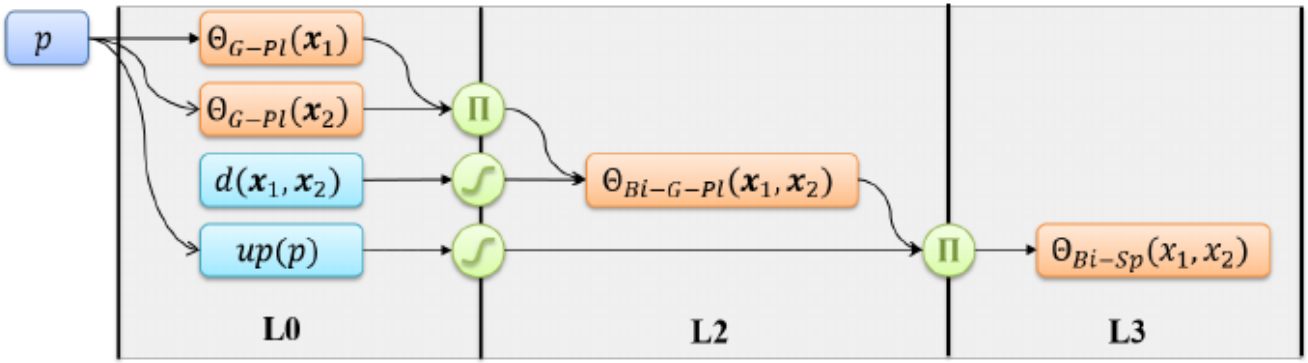
- Affordance certainty functions are composed of:
  - Properties of the primitive π w.r.t. the end-effector pose $\boldsymbol{x}$
    - Via sigmoid-threshold functions
  - Lower level affordance certainty functions
    - Via multiplication

Hierarchical formalization of affordances

- Unimanual **lean affordance**
  - Based on a platform grasp affordance

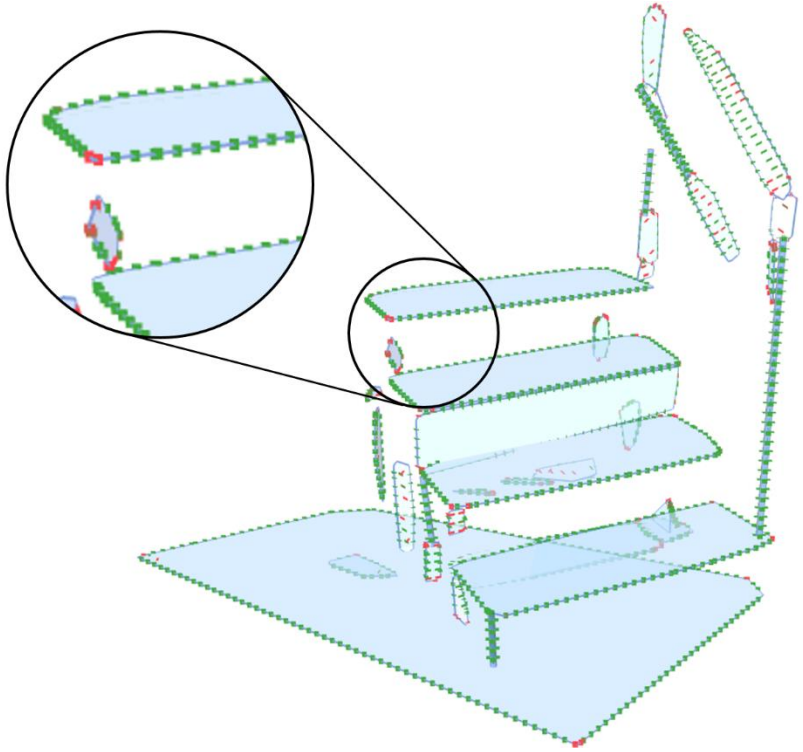


- Bimanual **support affordance**
  - Based on two platform grasp affordances

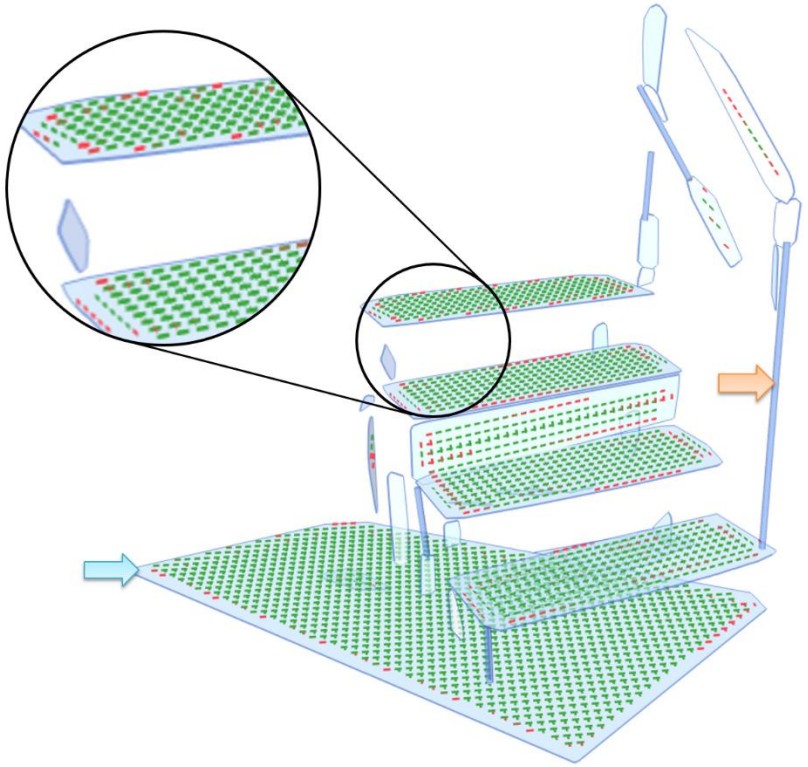


Hierarchical formalization of affordances

- Visualization of affordance certainty functions



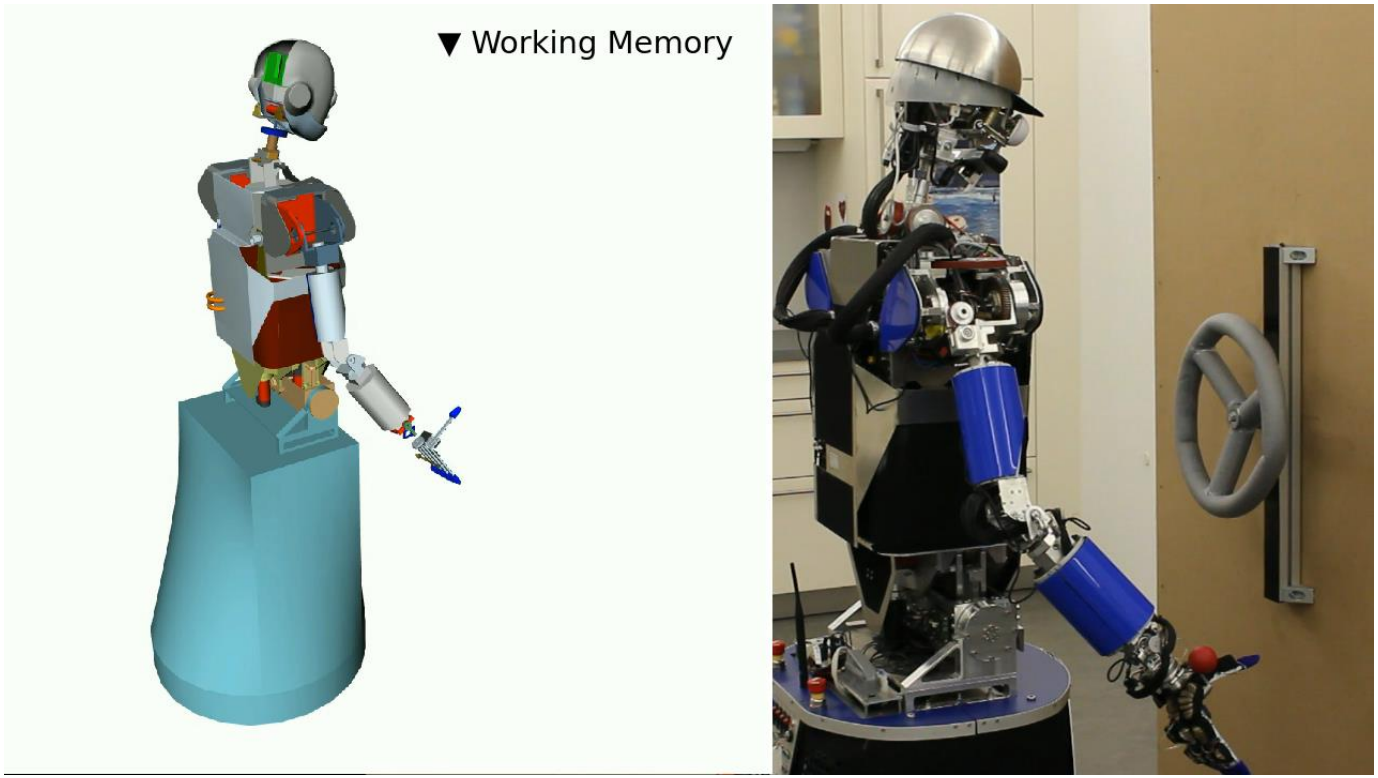
Prismatic grasp



Platform grasp

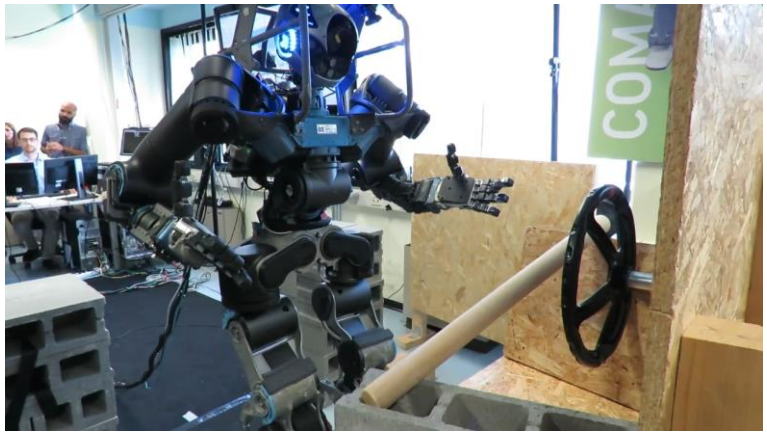
Experimental evaluation (ARMAR-III)

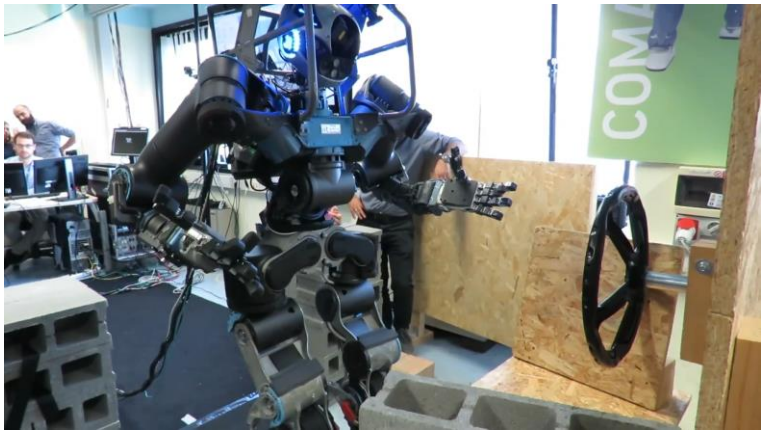
- Detection of a **bimanual valve turning** affordance
- Execution of the corresponding OAC
- ASUS Xtion **RGB-D** sensor

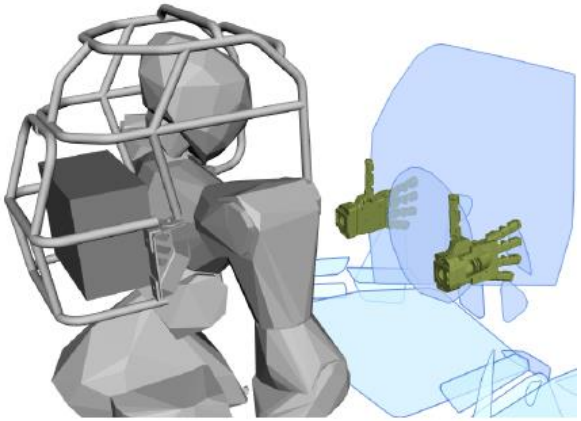


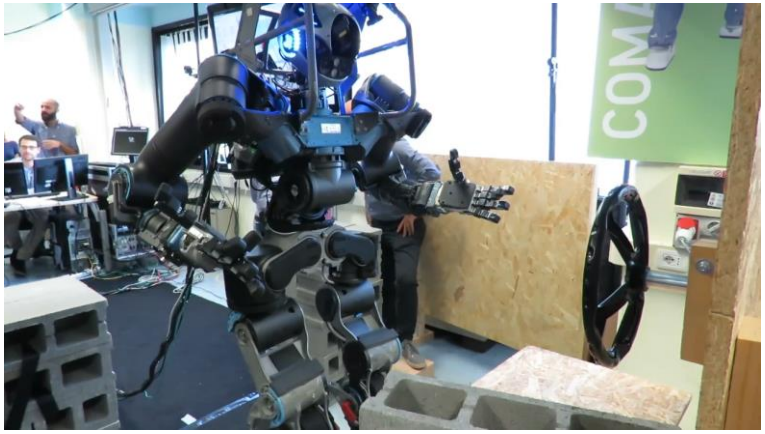
Experimental evaluation (WALK-MAN)

- Semi-public demo at project review
- MultiSense SL **stereo camera**









Conclusion

- Duality allows to transfer concepts across domains
- Grasping and whole-body actions (e.g. Balancing)
  - Taxonomy for whole-body actions for the generation of whole-body grasps
  - Description of whole-body affordances based on two fundamental grasping affordances
  - More coming soon !

Thanks to …

Karlsruhe Institute of Technology

Humanoids@KIT

H2T

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 Union
  - SecondHands www.secondhands.eu (2015-2019)
  - TimeStorm www.timestrom.eu (2015-2018)
  - I-Support www.i-support.eu (2015-2017)
  - Walk-Man www.walk-man.eu (2013-2017)
  - KoroiBot www.koroibot.eu (2013-2016)
  - Xperience www.xperience.org (2012-2015)
  - GRASP www.grasp-project.eu (2008-2012)
  - PACO-PLUS www.paco-plus.org (2006-2011)

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

Thanks for your attention