Karlsruhe Institute of Technology

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Active Perception for Mobile Manipulation

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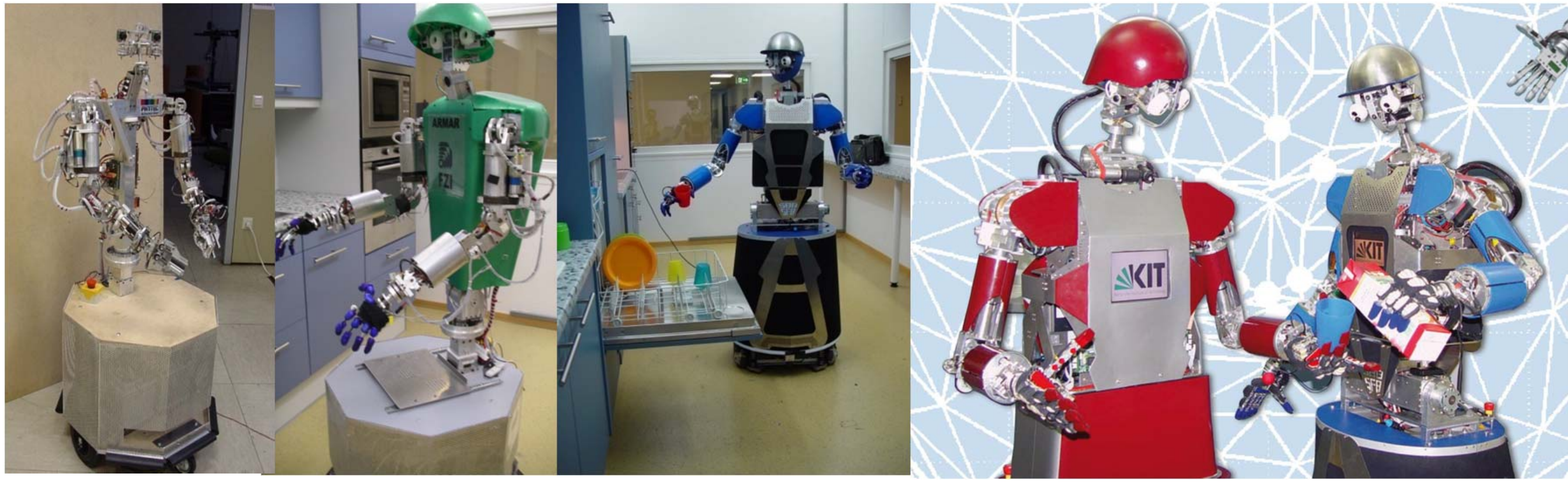

http://his.anthropomatik.kit.edu http://his.anthropomatik.kit.edu/english/65.php

Three key questions

- Grasping and manipulation in human-centered and open-ended environments
- Learning through observation of humans and imitation of human actions
- Interaction and natural communication

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Interactive tasks in the Robo-KITchen

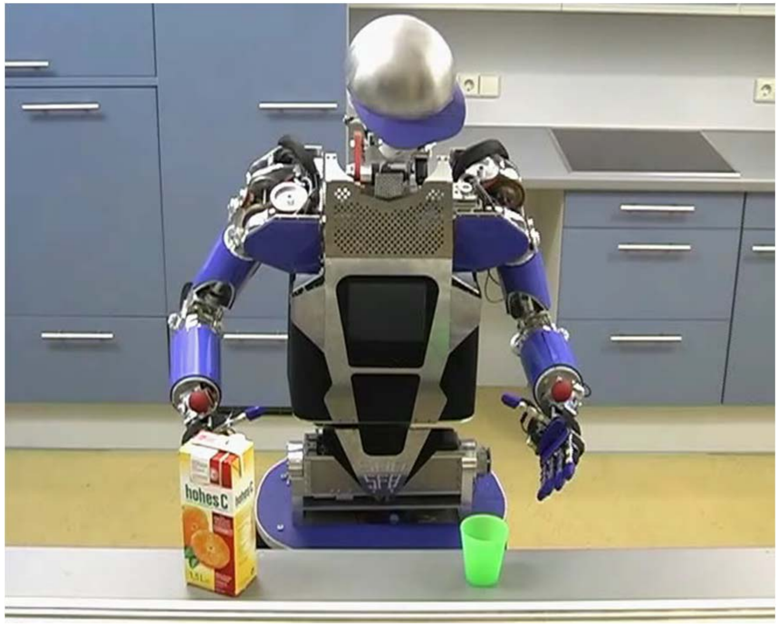
- Object recognition and localization
- Vision-based grasping
- Hybrid position/force control
- Vision-based self-localisation
- Collision-free navigation
- Combining force and vision for opening and closing door tasks
- Learning new objects, persons and words
- Audio-visual user tracking and localization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

[Humanoids 2006, IROS 2006, IROS 2007, RAS 2008, Humanoids 2008, Humanoids 2009]

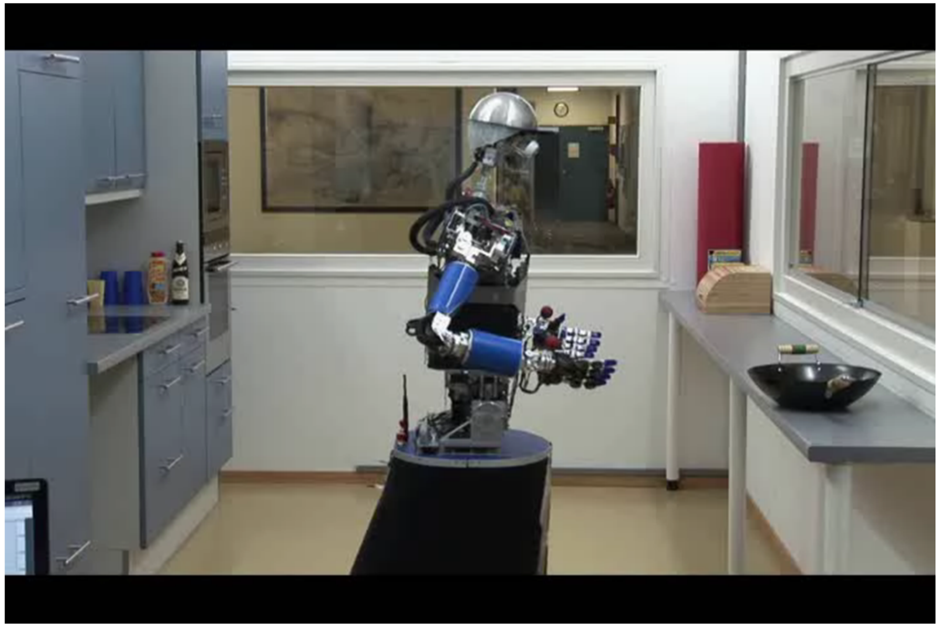
Bimanual grasping and manipulation

- Stereovision for object recognition and localization
- Visual Servoing for dual-hand grasping
- Zero-force control for teaching of grasp poses

Humanoids 2009



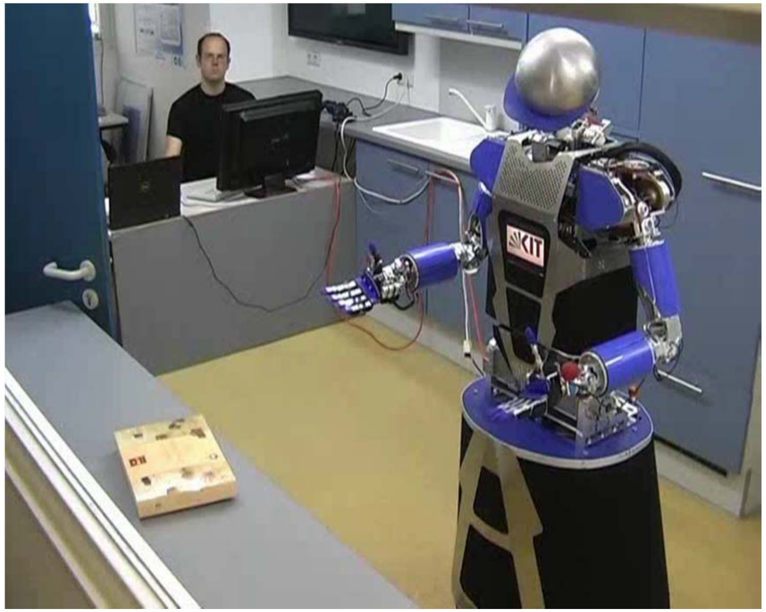
Loosely coupled dual-arm tasks



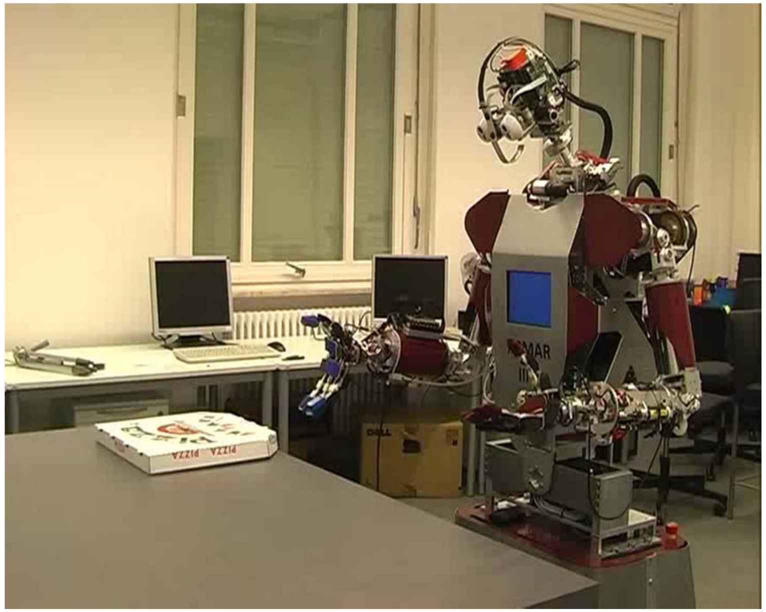
Tightly coupled dual-arm tasks

Pushing for grasping and pre-grasp manipulation

- Flat objects on the table are difficult to grasp → Pre-grasp manipulation to adjust the object before final grasping
- Learning actions on objects



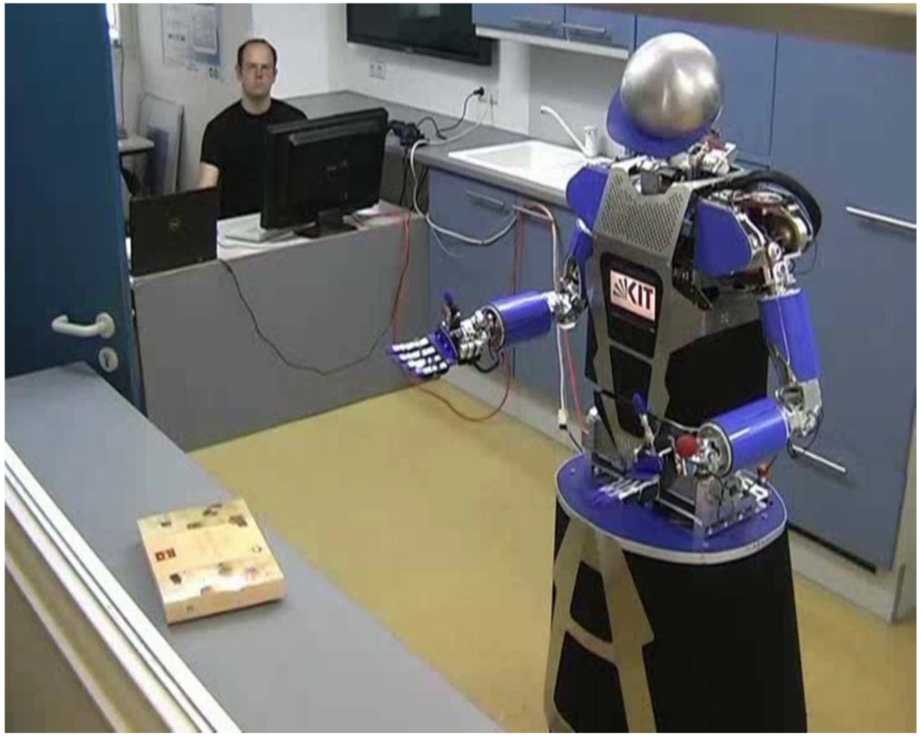
Joint work with Damir Omrcen and Ales Ude; (Humanoids 2009)



Joint work with Lillian Chang and Nancy Pollard (CMU), Humanoids 2010

Pushing for grasping

- Object independent pushing (generalization across objects).
- Learning relationship between point and angle of push and the actual movement of an object
- Direct association between the binarized object image and the response of the object with respect to the applied pushing action.
- Use the knowledge in order to find the appropriate point and angle of push in order to bring an object to a goal



Joint work with Damir Omrcen and Ales Ude; (Humanoids 2009)

- **Workshop Motion Planning on Monday:**

  Grasp and motion planning

- **Today: Mobile manipulation workshop**

  Active Perception for autonomous knowledge acquisition

Limitations and shortcuts

- Objects
  - Complete model knowledge (shape, color, texture)
  - Only visual object representation is used

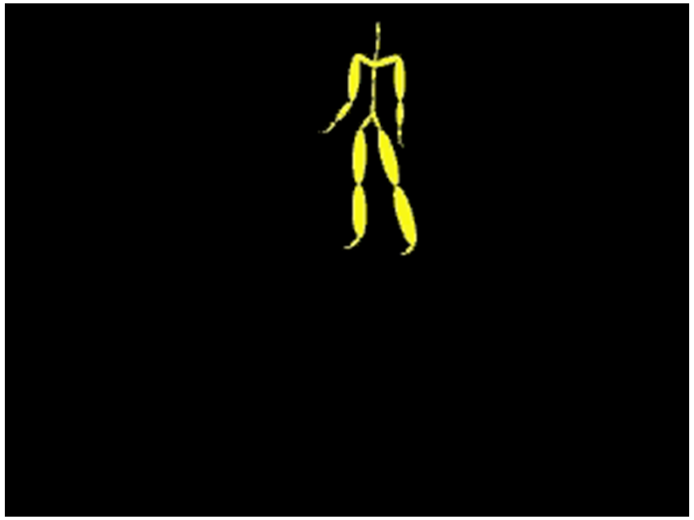
  - How to acquire multi-sensory representations of objects?
  - How to learn objects representations?
  - …

- Actions
  - Kinematic-based approaches as place holders for learned primitive actions

  - How to learn new actions?
  - How to adapt actions to new situations?
  - How to chain different actions to achieve complex tasks?
  - How to learn associations between objects and actions?
  - How to learn consequence of action?
  - …

Objects and Actions are inseparably intertwined

- Visually based object recognition fails
- Visual information is sparse and limited
- Activity involving the object decreases the uncertainty about the object's nature considerably!



CMU Graphics Lab Motion Capture Database
http://mocap.cs.cmu.edu/

Intuitions on Object-Action Complexes

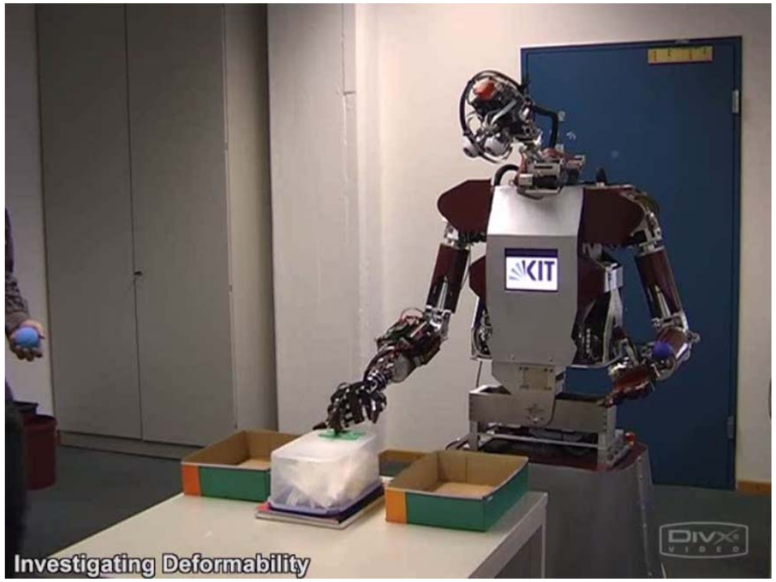
- Affordances (J.J. Gibson)
  - Objects affords actions
- Object-Action Complexes (OACs)
  - Actions define the meaning of Objects and
  - Objects suggest Actions
- OACs are associations of objects and affordances
  - Affordances can be expressed by STRIPS rules comprising:
    - Preconditions and
    - Deletions/additions

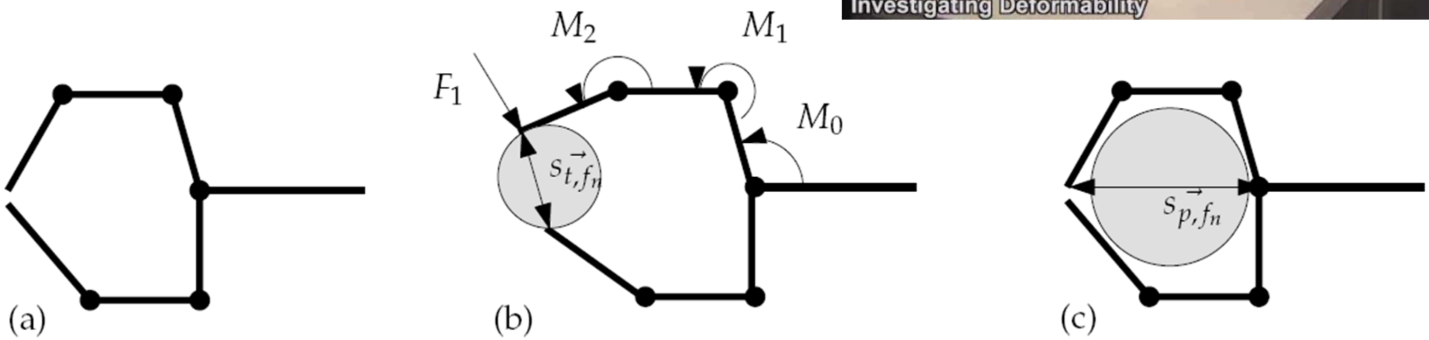
How to relax such limitations?

- Autonomous Exploration:
  - Visually-guided haptic exploration
  - Visual object search
- Coaching and Imitation
  - Learning from Observation
  - Goal-directed Imitation

Hand: available skills

- Direct/Inverse Kinematics
- Position/force control [Humanoids 2009]
- Detection of contact and "objectness"
- Assessment of deformability and object size





Failed grasp "no object"

Precision grasps: Distance between fingertips

Power grasps: Distance between fingertips and palm

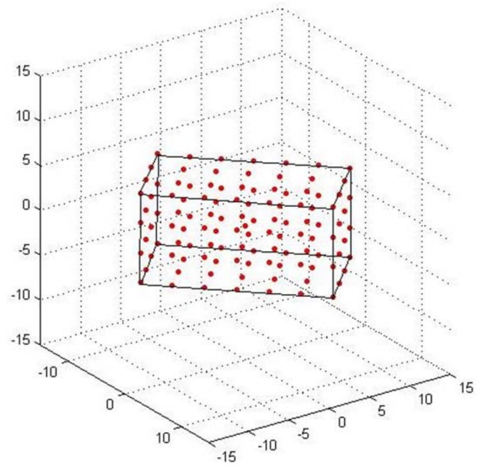
Tactile exploration using potential fields

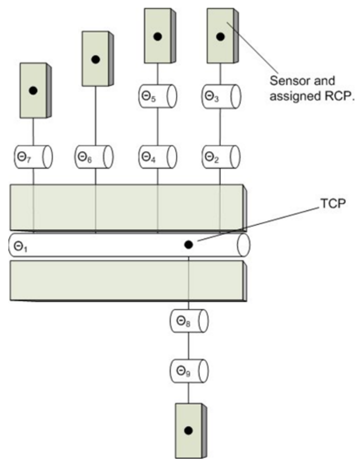
- Potential field in operational space
  - Unknown regions → attractive $\Phi_a < 0$
  - Known regions → repellent $\Phi_r > 0$
- Dynamic adaptation of potential field configuration based on tactile response
- Superposition of individual potential sources

$$\Phi(x) = \sum_i \Phi_{r,i}(x) + \sum_j \Phi_{a,j}(x)$$

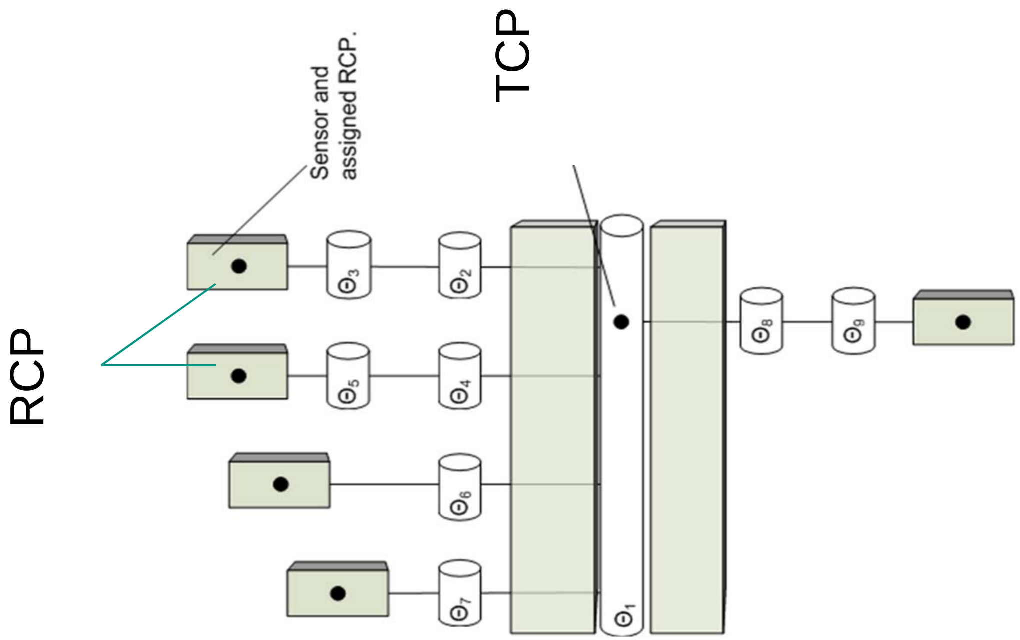
- Generation of trajectories for the fingertips by gradient methods

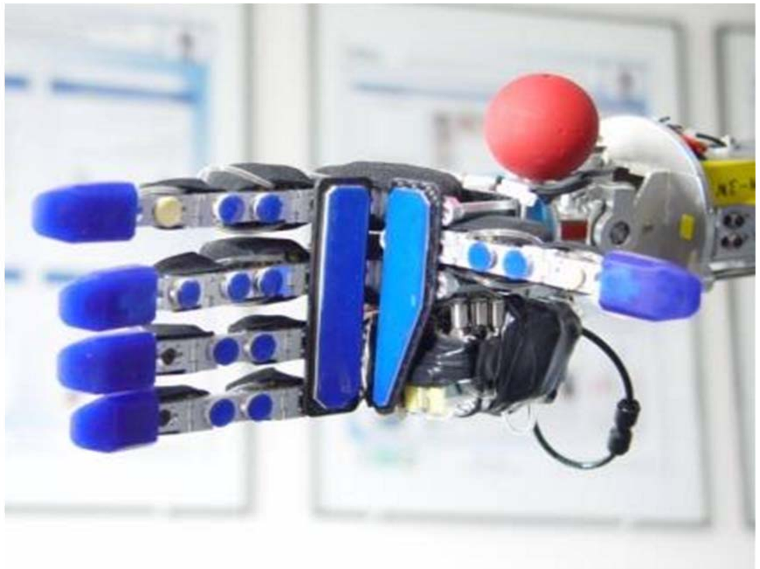
$$F = -\nabla \phi(x)$$





Hand in details

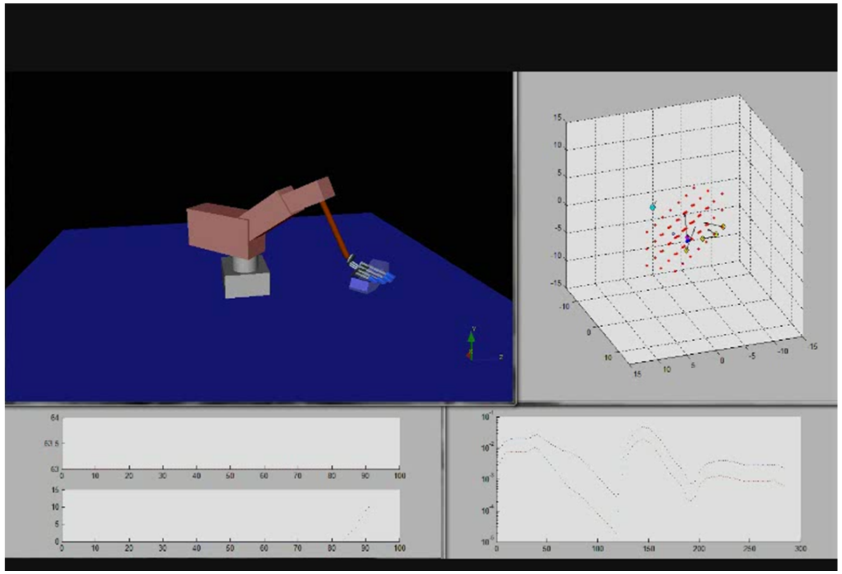


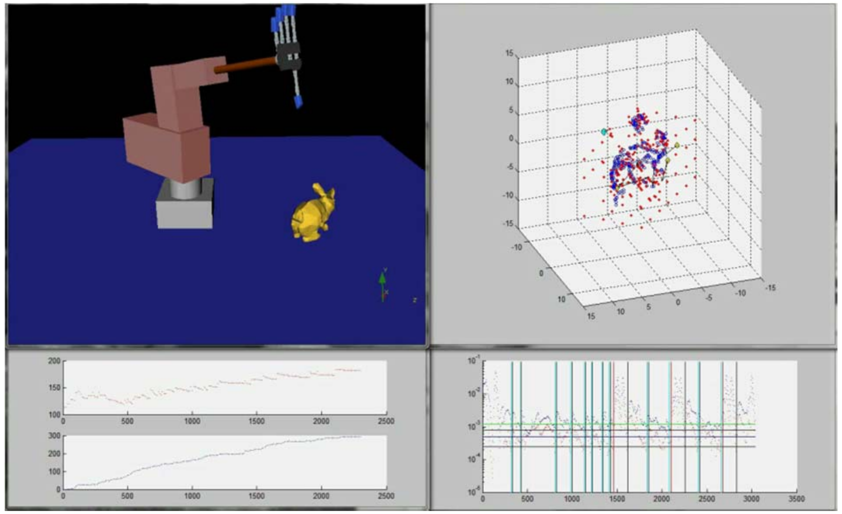


Tactile object exploration

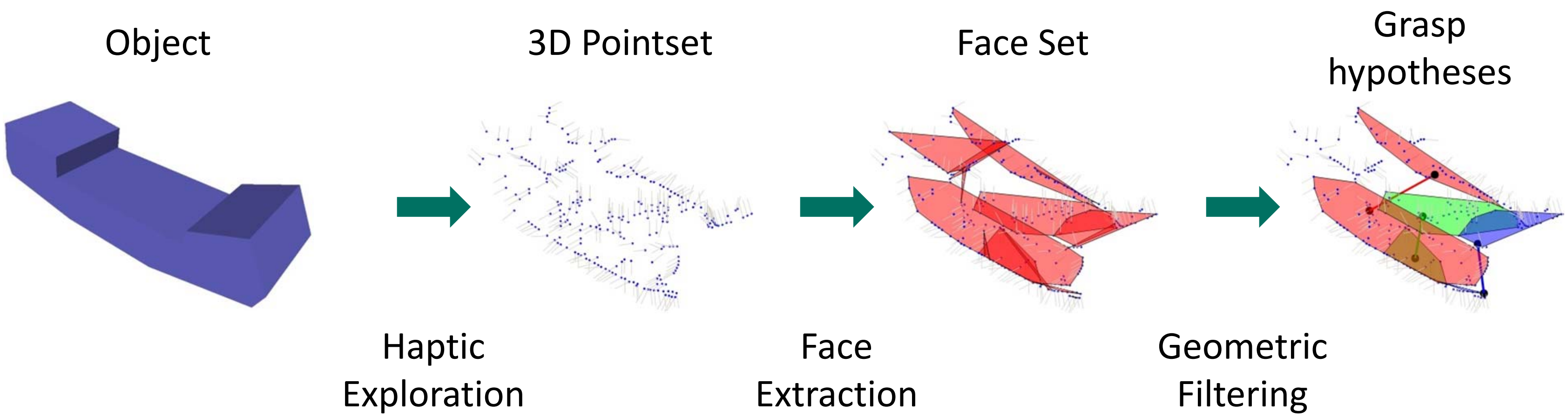
- Potential field guides the robot hand along the object surface
- Oriented 3D point cloud from contact data
- Compute face pairings from 3D point
- Calculate grasping hypotheses using a geometric feature filter pipeline
  - Parallelism
  - Minimum face size
  - Face distance
  - Mutual visibility
- Evaluation of grasp qualities

→ Association between “objects” and actions (grasps) → symbolic grasps (grasp affordances)

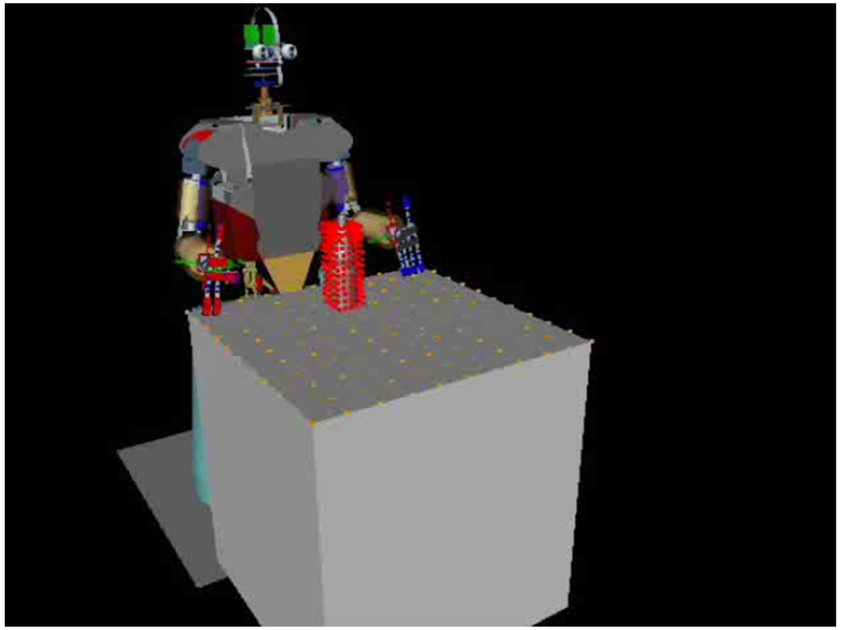


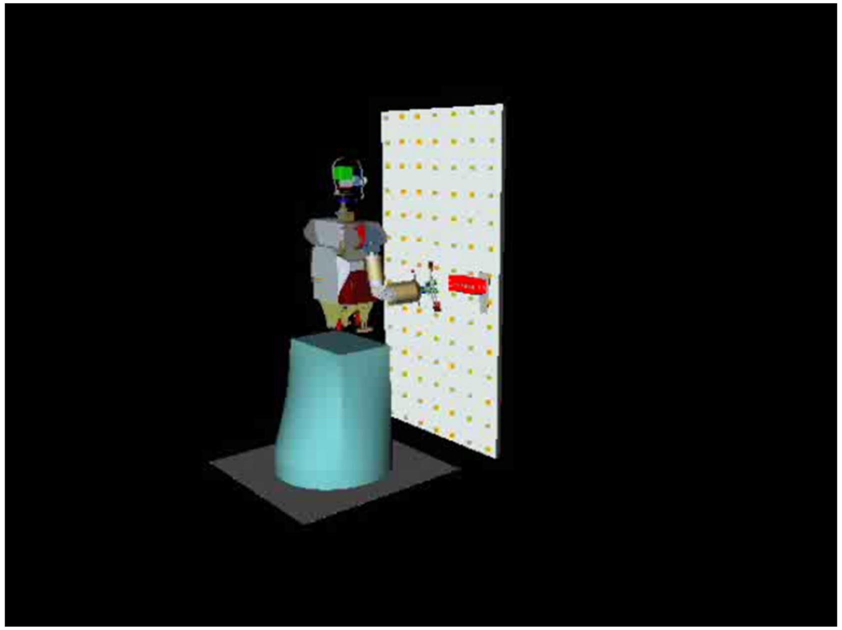


Generation of grasp hypotheses



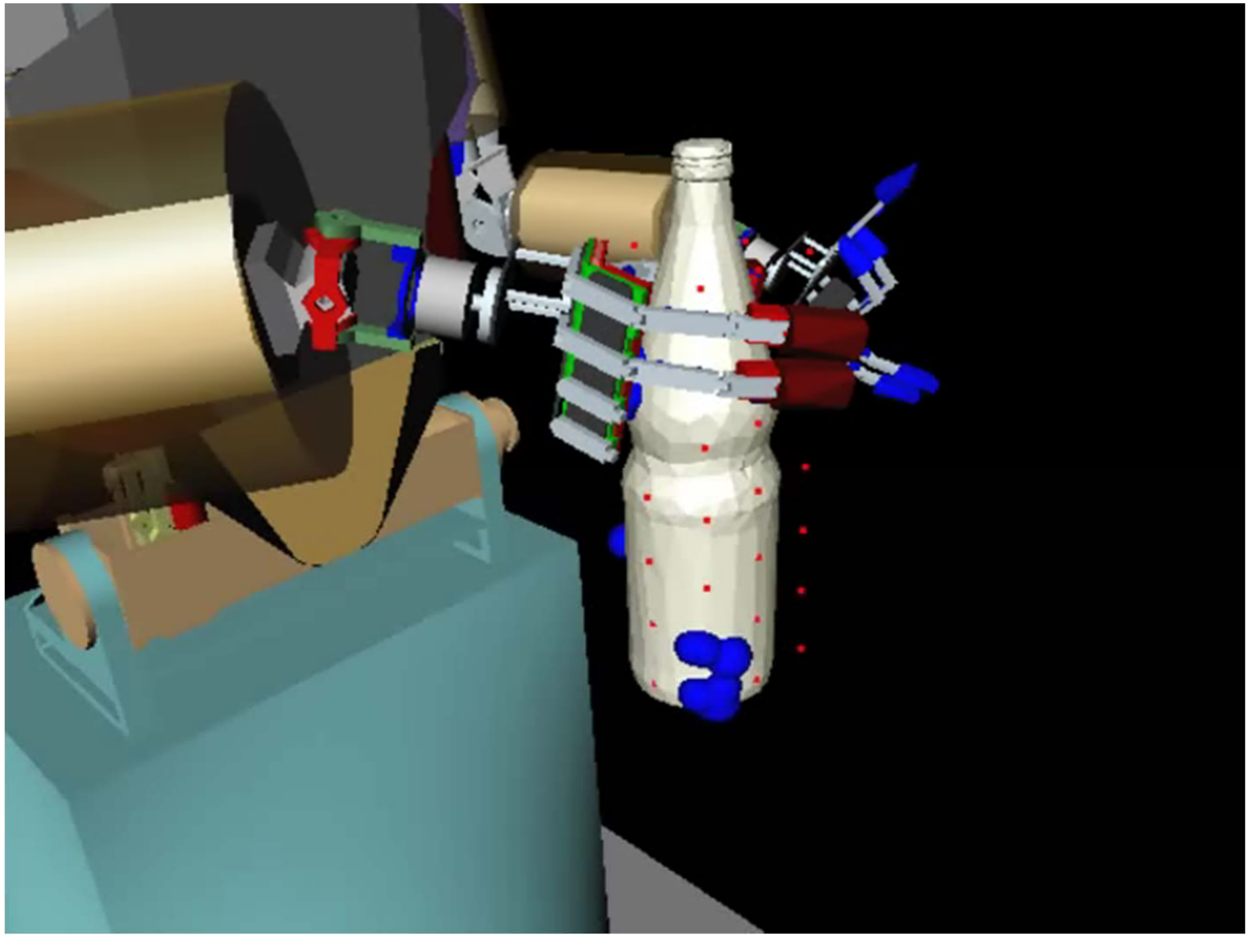
Haptic exploration on ARMAR



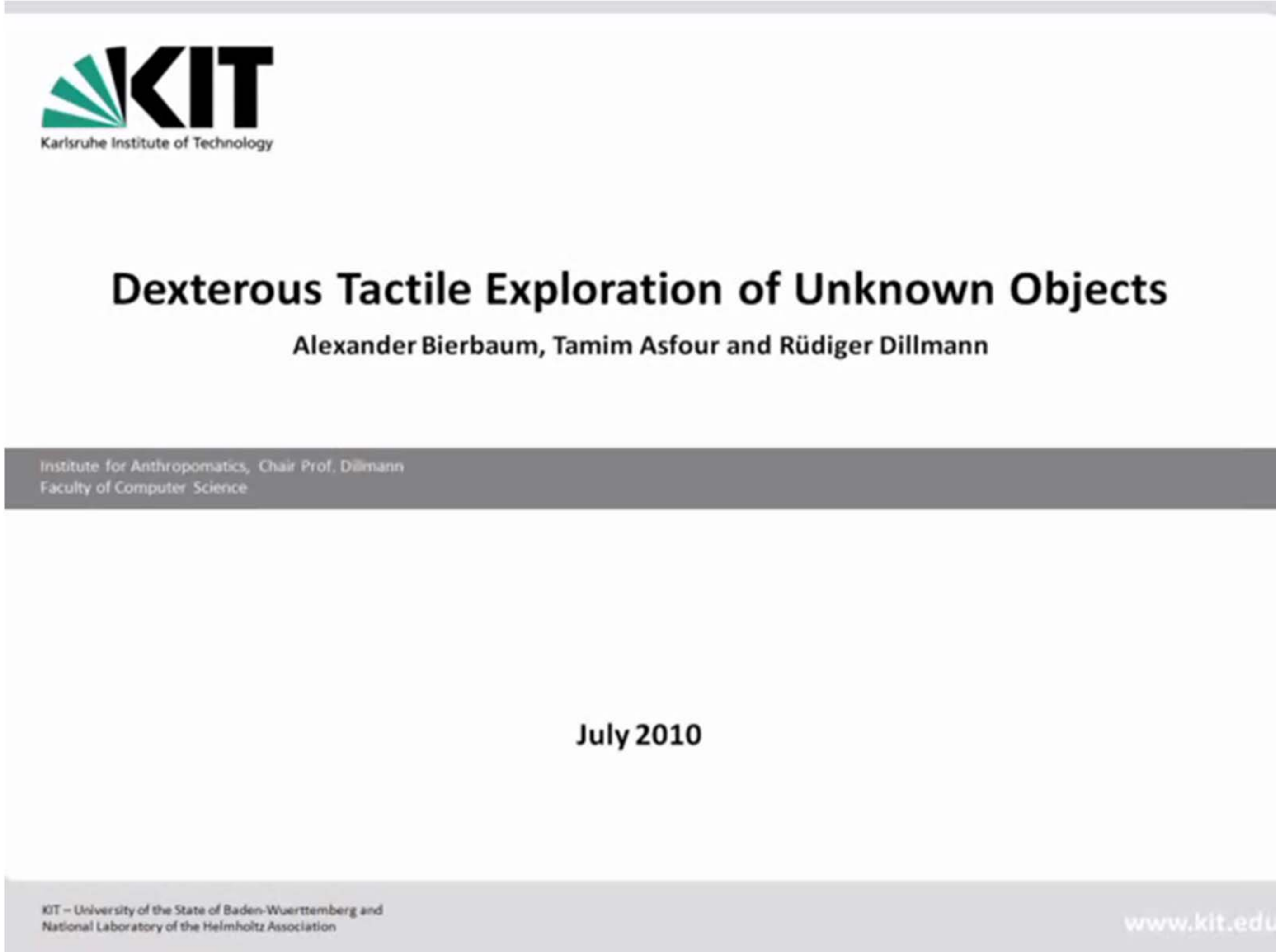


- In simulation
  - Physics extension for Open Inventor/VRML modeling of complex mechanical systems
  - Modeling of virtual sensors
  - VMC-based inverse kinematics

Haptics exploration on ARMAR

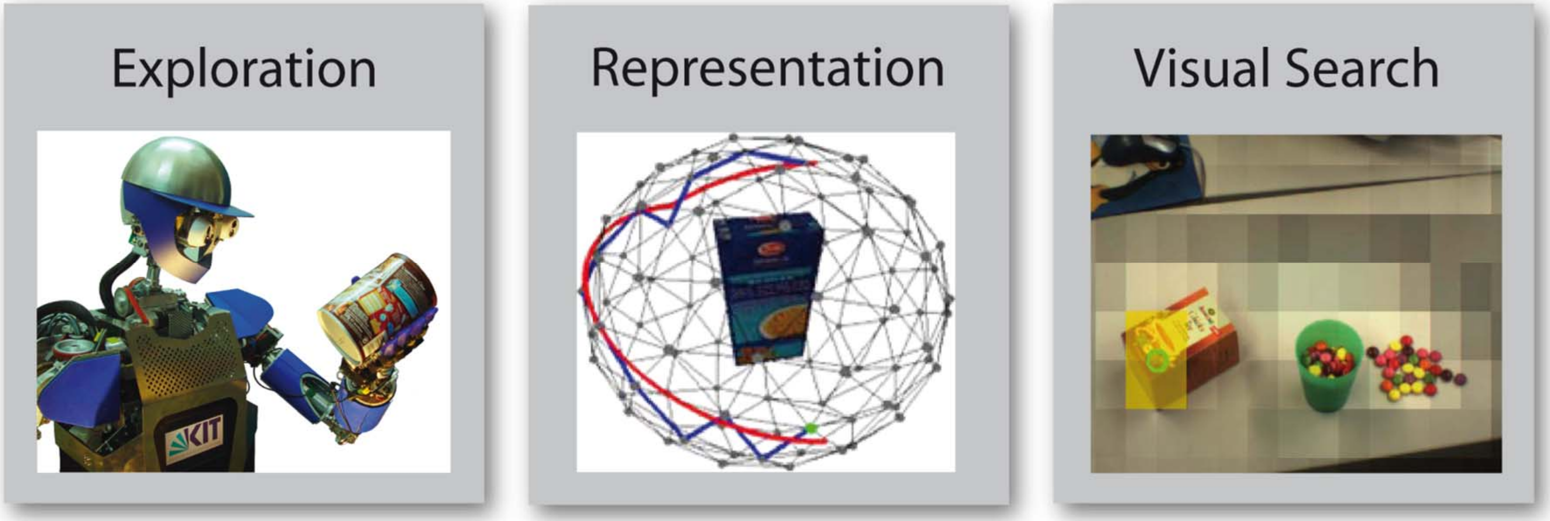


Haptic Exploration using ARMAR-III



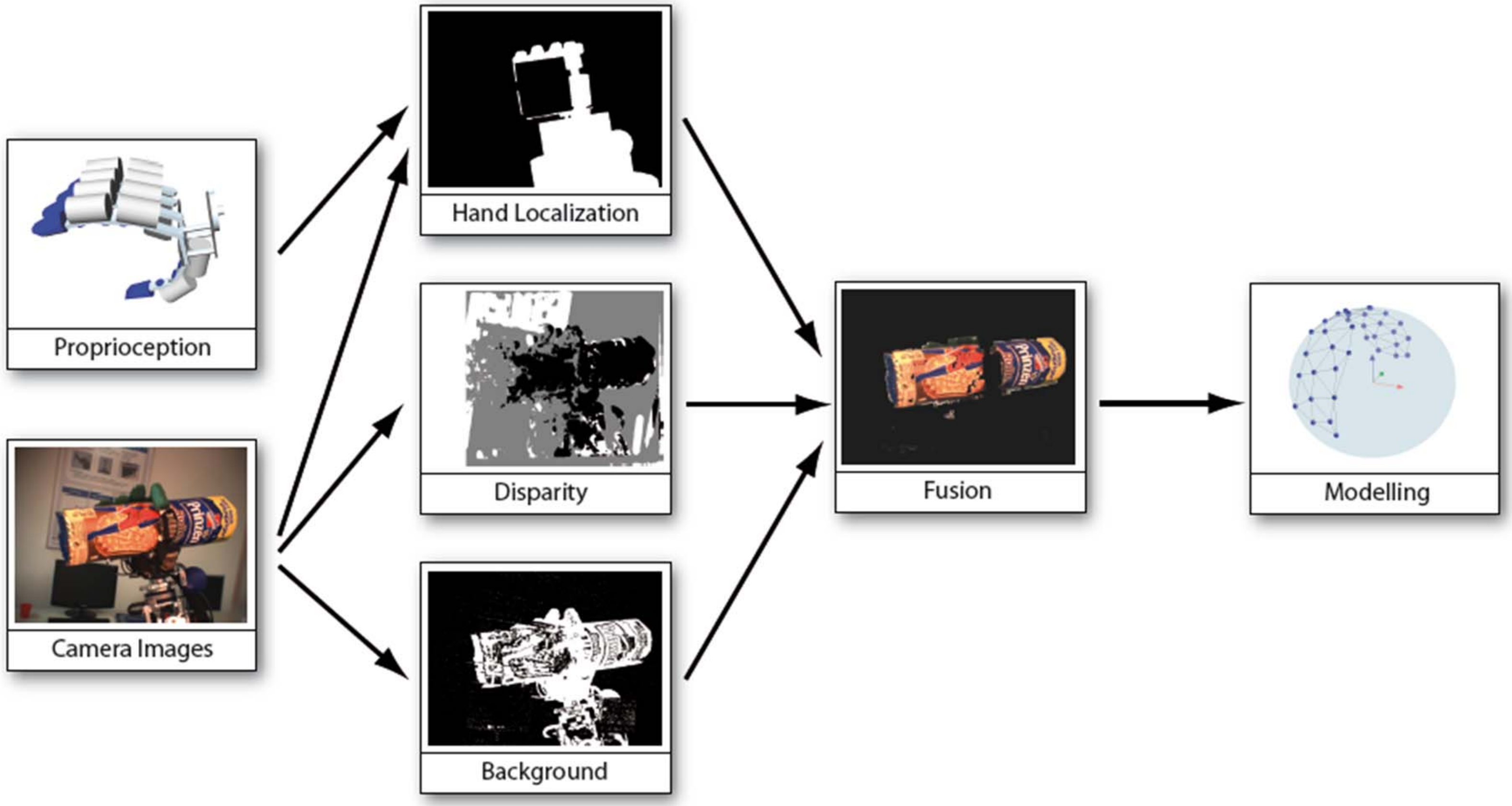
Generation of multi-view object representations

- Generation of visual representations through manipulation
- Application of generated representations in recognition tasks and visual search tasks



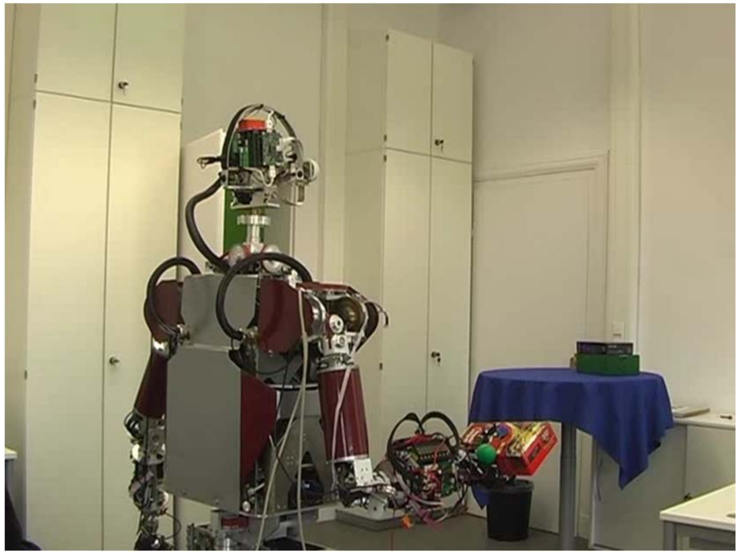
Acquisition of multiple object views

- Background-object and hand-object segmentation



Active visual search

- Generation of different views through manipulation
- Active search using perspective and foveal camera
- Integration of object hypotheses in an ego-centric representation (scene memory)

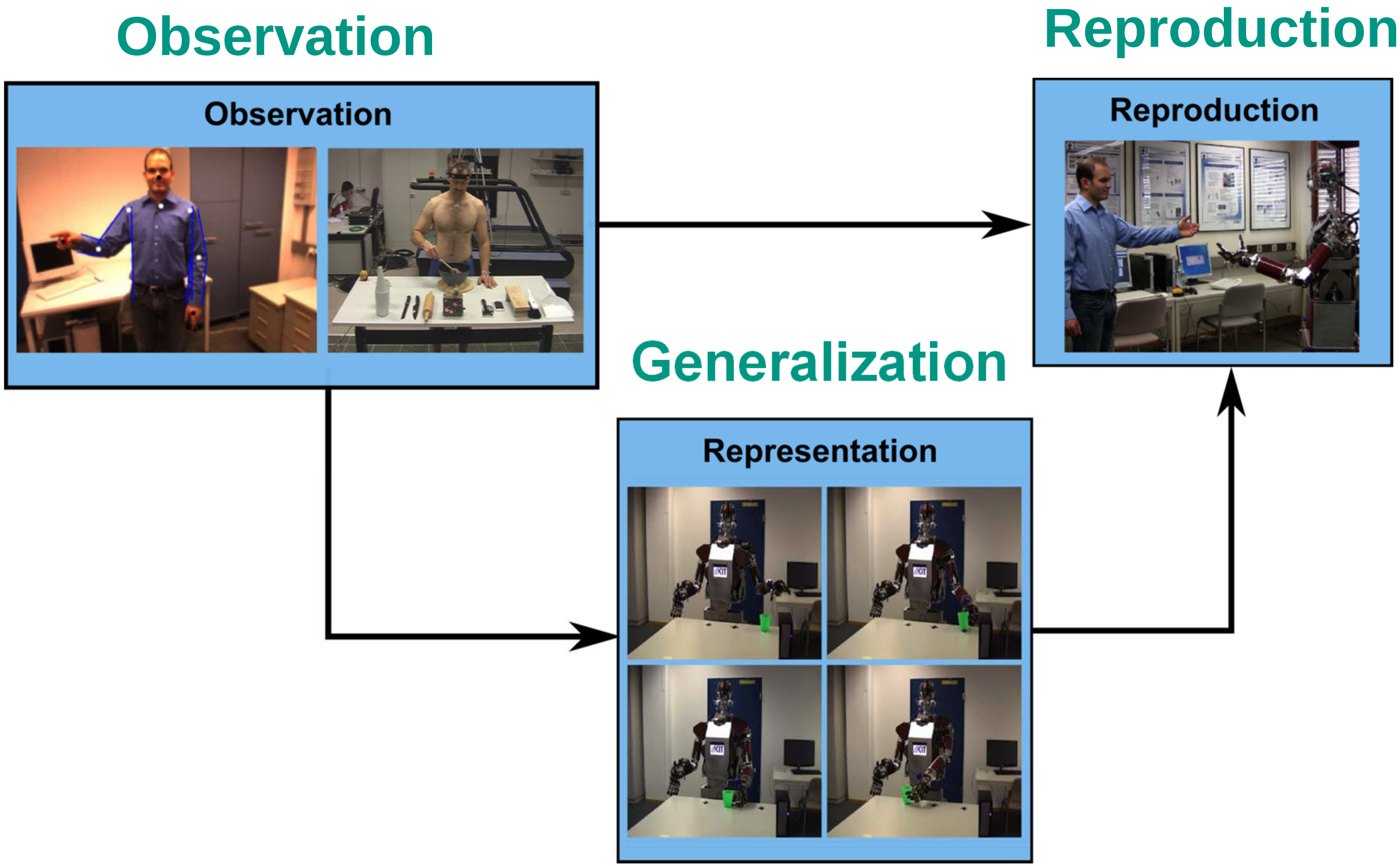


ICRA 2010
Humanoids 2009
ICRA 2009

How to relax the limitations in our scenario?

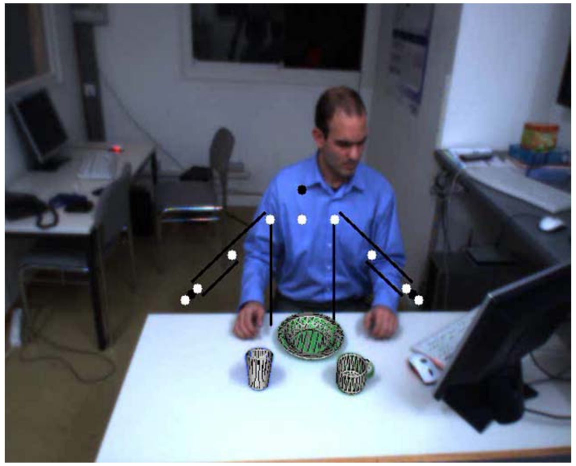
- Autonomous Exploration
  - Visually-guided haptic exploration
  - Visual object search
- Coaching and Imitation
  - Learning from Observation
  - Goal-directed Imitation

Learning from human observation



Stereo-based 3D Human Motion Capture (HMC)

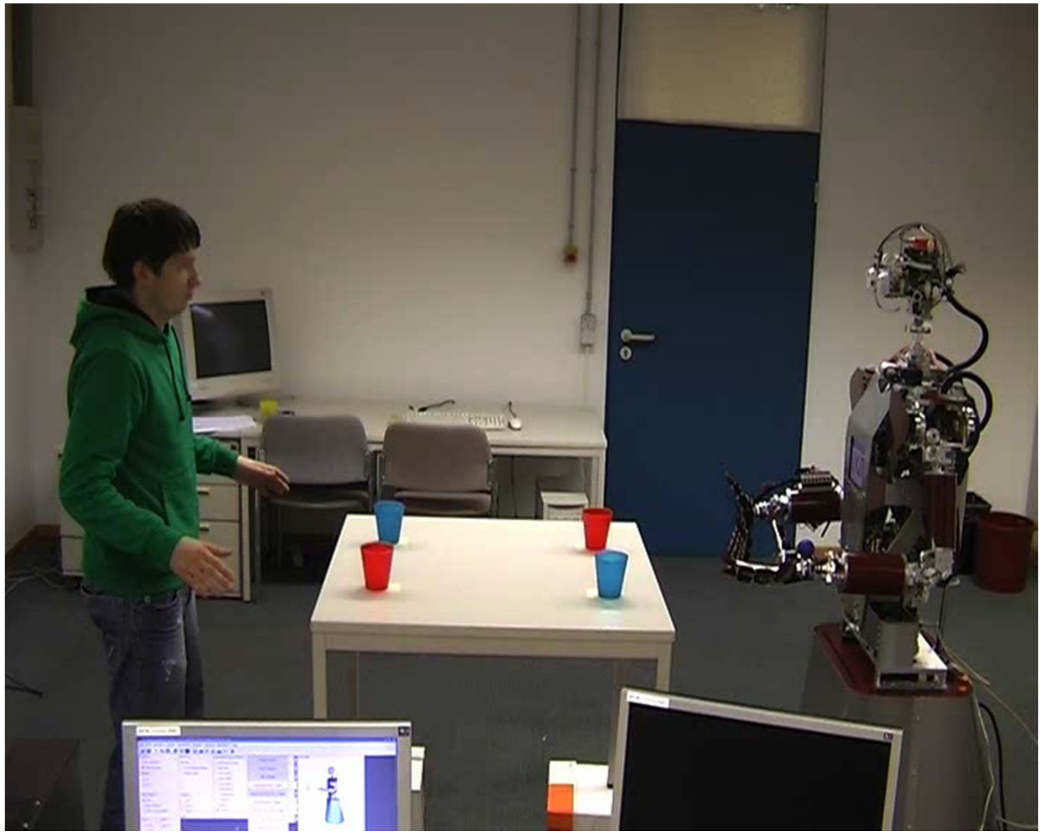
- Capture 3D human motion based on the image input from the cameras of the robot's head only
- Approach
  - Hierarchical Particle Filter framework
  - Localization of hands and head using color segmentation and stereo triangulation
  - Fusion of 3d positions and edge information
  - Half of the particles are sampled using inverse kinematics
- Features
  - Automatic Initialization
  - 30 fps real-time tracking on a 3 GHz CPU, 640x440 images
  - Smooth tracking of real 3d motion



Reproduction on ARMAR

- Tracking of human and object motion
- Visual servoing for grasping

Generalisation?



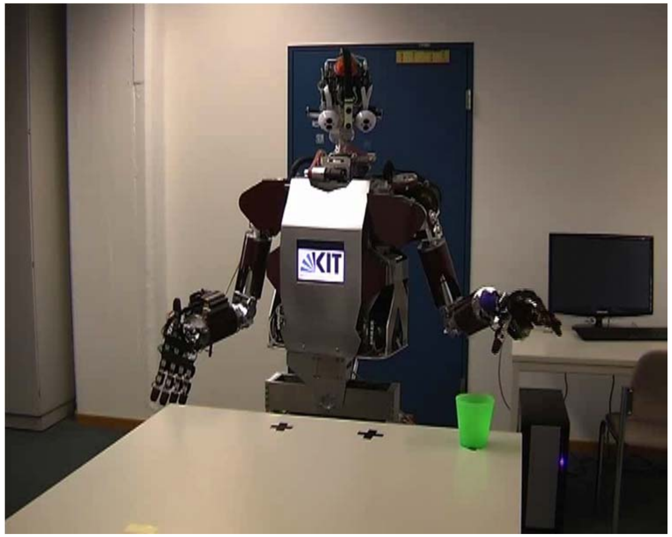
Action representation

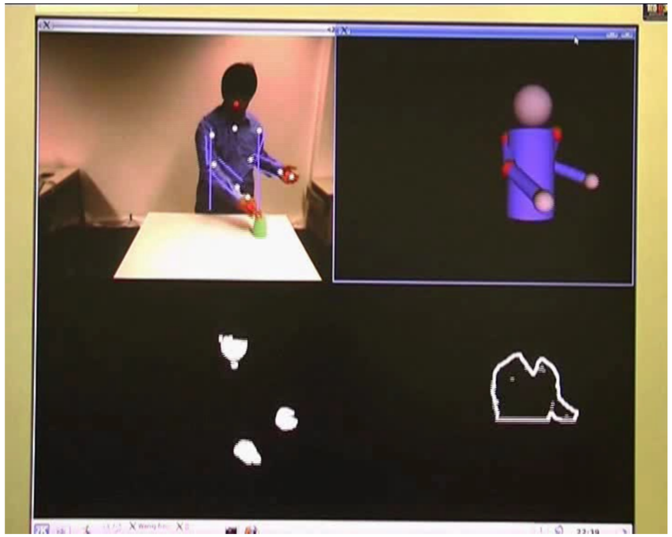
- Hidden Markov Models (HMM) Humanoids 2006, IJHR 2008
  - Extract key points (KP) in the demonstration
  - Determine key points that are common in multiple demonstrations (common key points: CKP)
  - Reproduction through interpolation between CKPs
- Dynamic movement primitives (DMP) ICRA 2009, T-RO 2010
  - Ijspeert, Nakanishi & Schaal, 2002
  - Trajectory formulation using canonical systems of differential equations
  - Parameters are estimated using locally weighted regression
- Spline-based representations Humanoids 2007
  - fifth order splines that correspond to minimum jerk trajectories to encode the trajectories
  - Time normalize the example trajectories
  - Determine common knot points so that all example trajectories are properly approximated. Similar to via-point, key-points calculation.

Learning from Observation

- Library of motor primitives
  - Markerless human motion tracking
  - Object tracking

- Action representation
  - Dynamic movement primitives for generating discrete movements
  - Adaptation of dynamic systems to allow sequencing of movement primitives
  - Associating semantic information with DMPs
  - → sequencing of movement primitives
  - → Planning

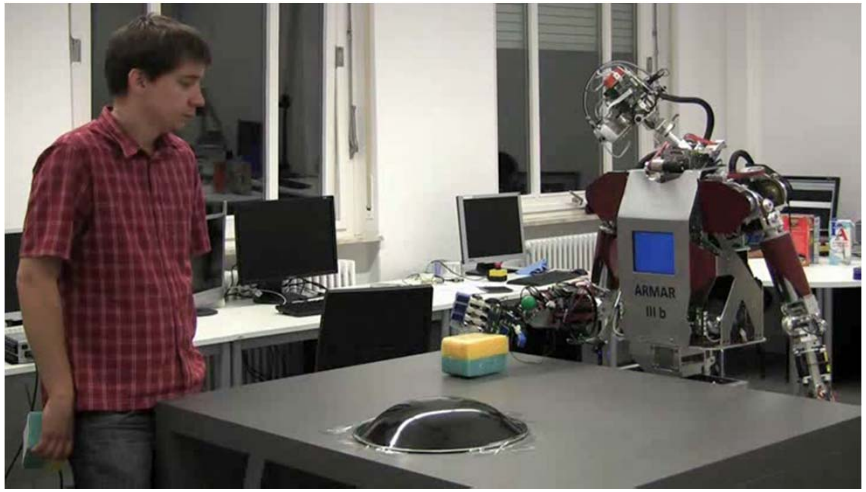




Learning from Observation

- Periodic movements (Wiping)
  - Extract the frequency and learn the waveform.
  - Incremental regression for waveform learning

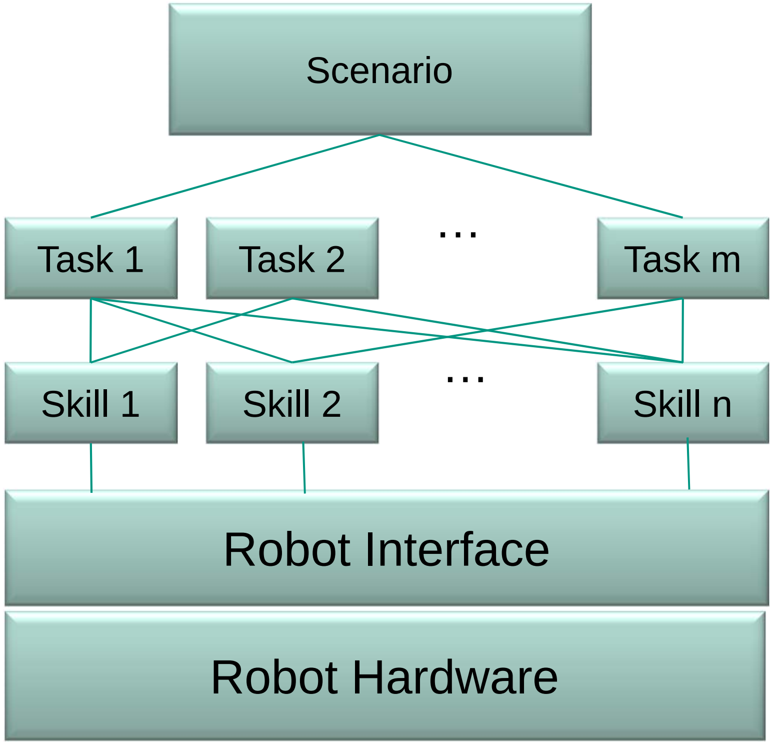
- Adaptation of the learned movement to maintain contact with different surfaces, based on force-feedback.



Joint work with Andrej Gams and Ales Ude, Humanoids 2010

API of the ARMARs

- Robot interface (API) allows access to the robot's sensors and actors via C++ variables and method calls
- Skills: implemented atomic capabilities of the robot
  - SearchForObject
  - Grasp
  - Place
  - HandOver
  - Open/Close door
  - …
- Tasks: combination of several skills for a specific purpose
  - Bring object from …
  - Put object on
  - Stack objects
  - …



Connecting High-level Task Planning to Execution

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PKS planner (STRIPS-like planner)

Joint work with Ron Patrick and Mark Steedman, University of Edinburgh

Thanks

- Humanoids@KIT
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  - Martin Do
  - Markus Przybylski
  - Tamim Asfour
  - Pedram Azad (not in the picture)
  - Paul Holz (not in the picture)
  - Ioana Gheta (not in the picture)
  - Christian Böge (not in the picture)
  - Sebastian Schulz (not in the picture)
  - Isabelle Wappler

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Thank you ...

... for your attention

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    - GRASP www.grasp-project.eu
    - PACO-PLUS www.paco-plus.org

Deutsche Forschungsgemeinschaft
DFG

CogSys
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