Karlsruhe Institute of Technology

Humanoids 2016
IEEE-RAS International Conference on Humanoid Robots

High Performance Humanoid Technologies

Bootstrapping Object Exploration and Dexterous Manipulation

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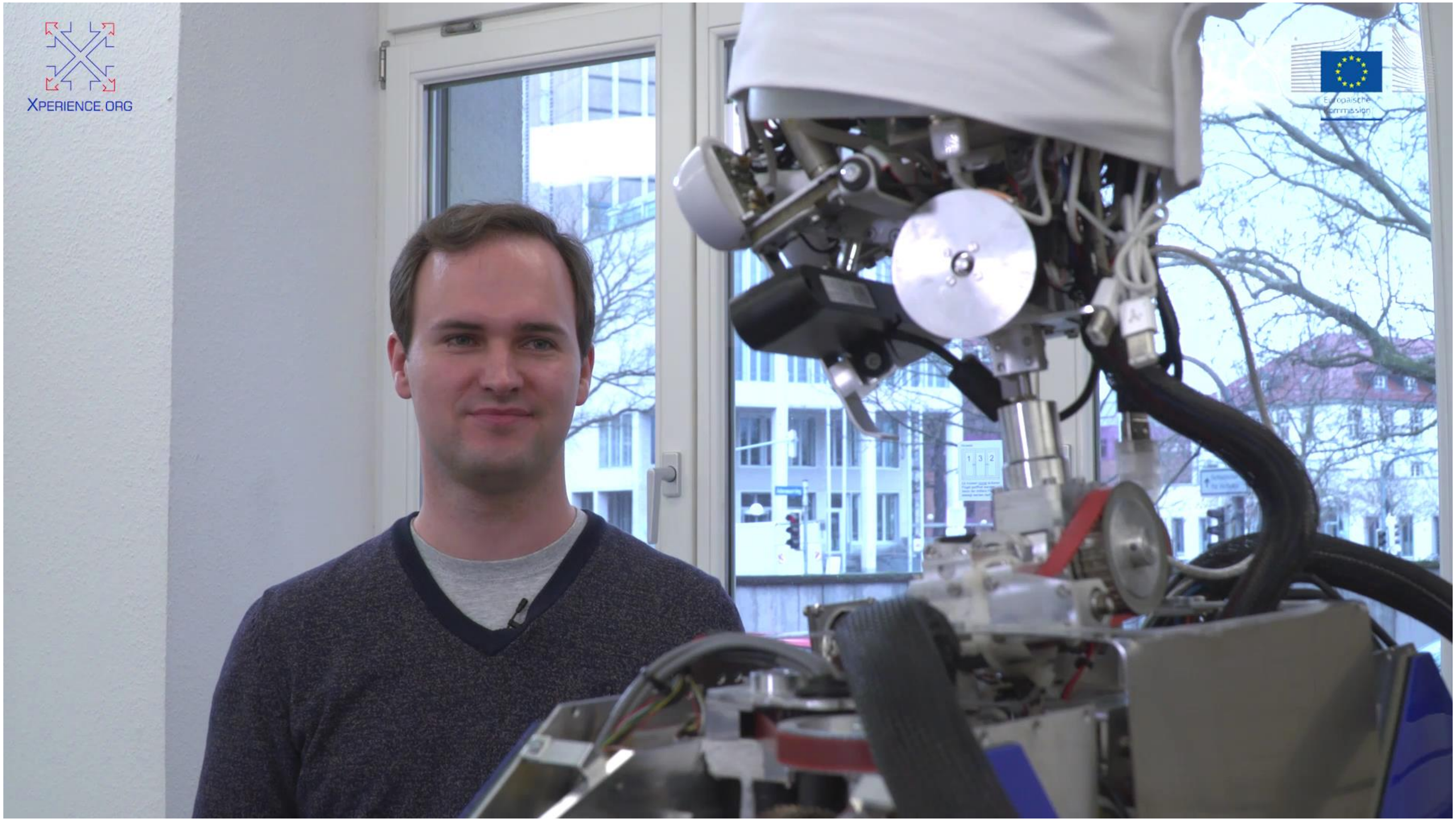
Institute for Anthropomatics and Robotics, High Performance Humanoid Technologies

ARMAR-III in the RoboKITchen

45 minutes, more than 2000 times since February 3, 2008

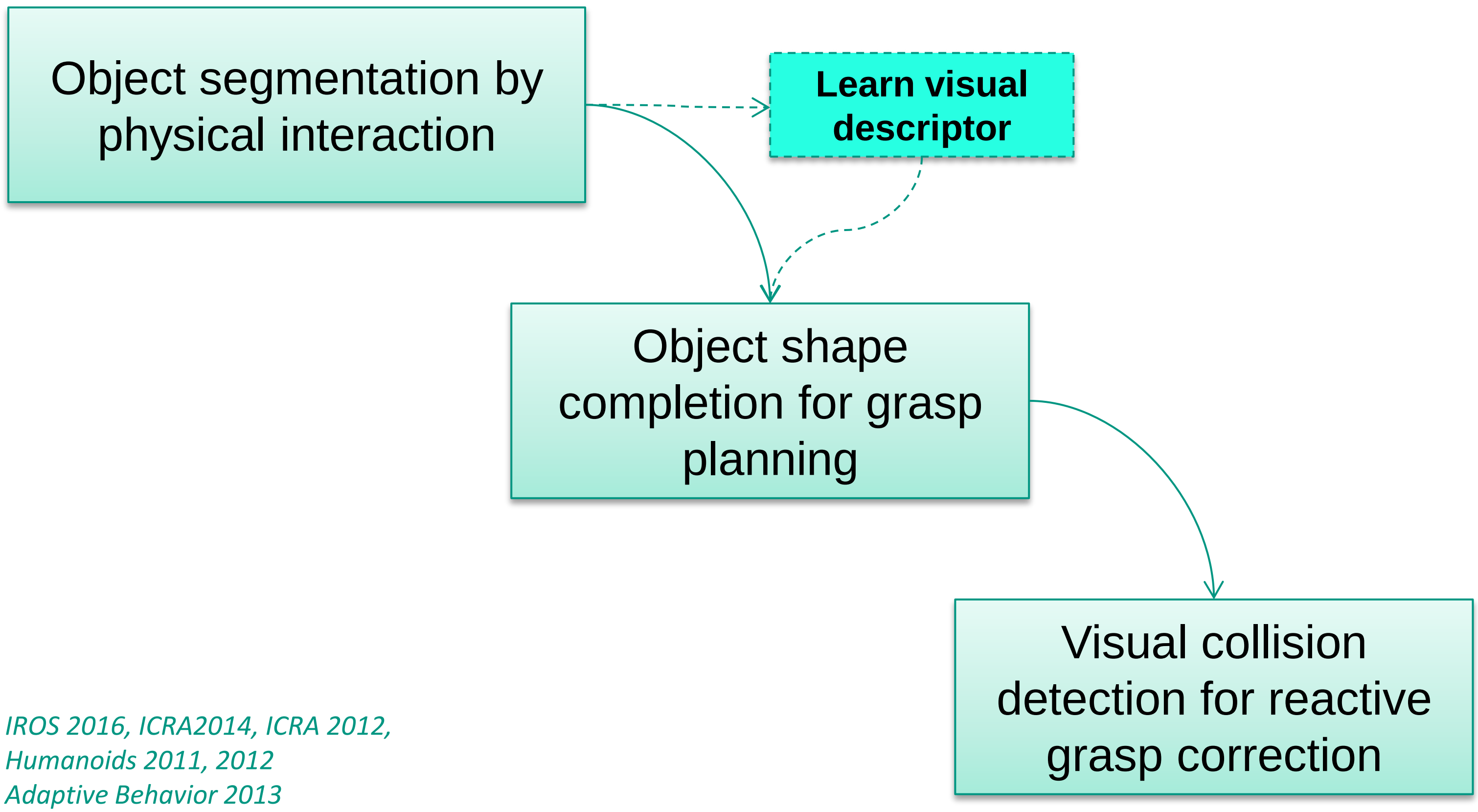
Integrating language, planning and execution with OACs



In this talk

- Integrating action, vision and haptics for grasping
  - Discovery, segmentation and grasping of unknown objects
  - 3D object shape completion
  - Visual collision detection
- Haptic exploration
  - Local implicit surface estimation
  - New sensor of direct measurement of surface orientation

Vision and physical interaction for grasping



IROS 2016, ICRA2014, ICRA 2012,
Humanoids 2011, 2012
Adaptive Behavior 2013

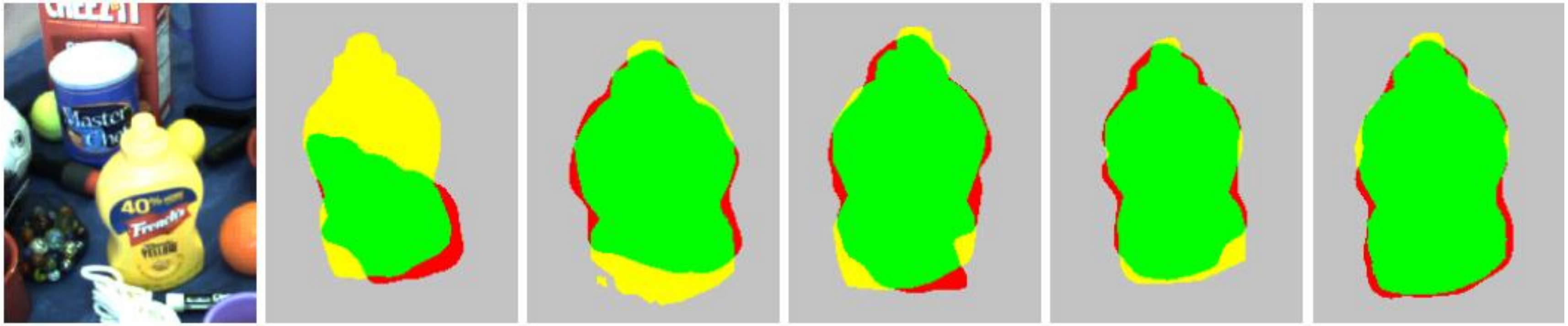
Discover, segment, learn and grasp unknown objects

ICRA2014, ICRA 2012, Humanoids 2011, 2012 Adaptive Behavior 2013

Evaluation of segementation

- Segmentation evaluated on 49 objects from the Yale-CMU-Berkley object and model set (*Calli et al. (2015)*)

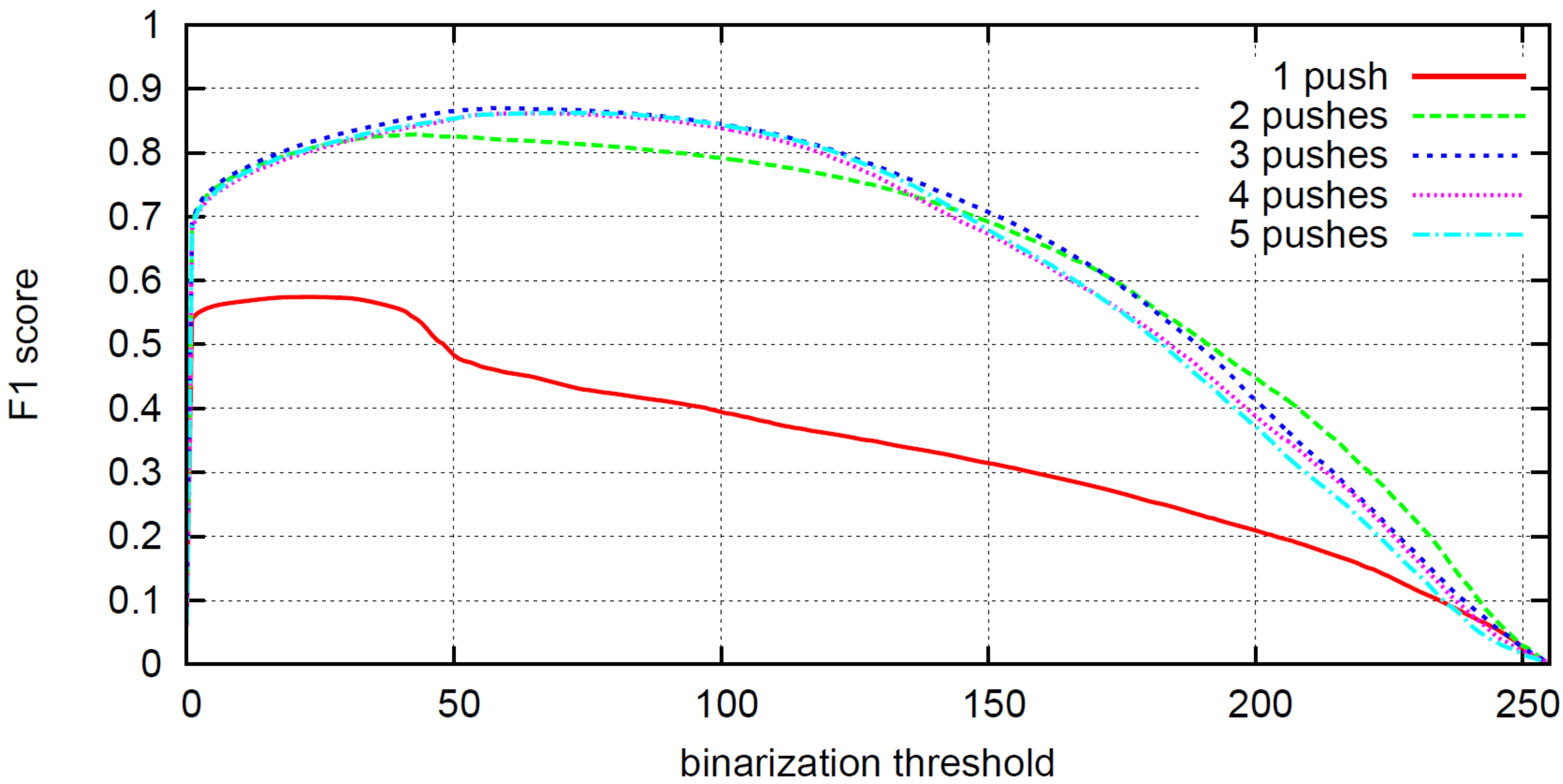
- Compare segmentation to ground truth:
  - Projection of hypothesis points into image
  - Extention with with Gaussian filter, binarization



- Quality measures:
  - Precision p = TP / (TP + FP)
  - Recall r = TP / (TP + FN)

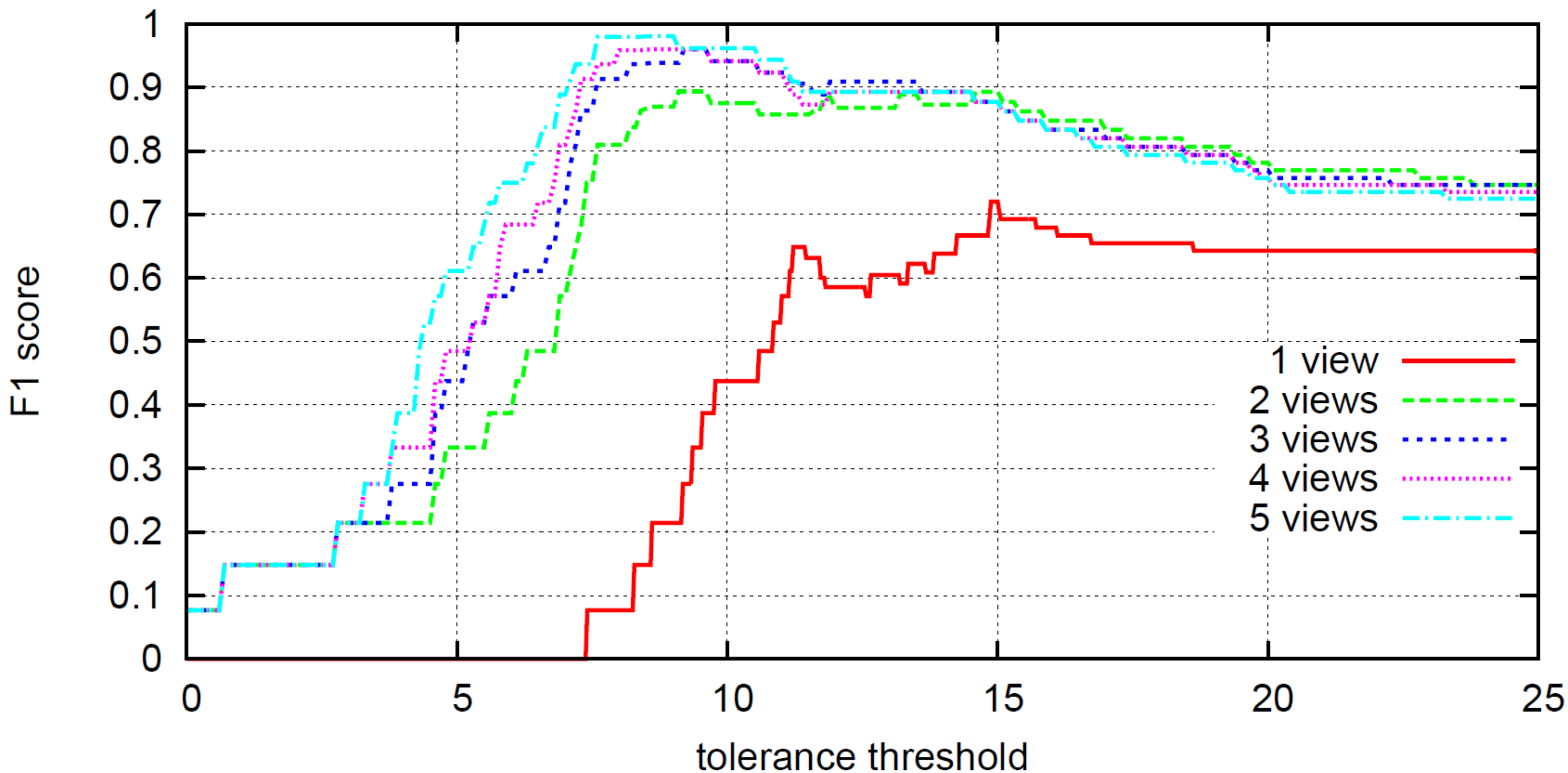
Quality of the segmentation

- F1 score: $F1 = 2\,\frac{p\,r}{p+r}$

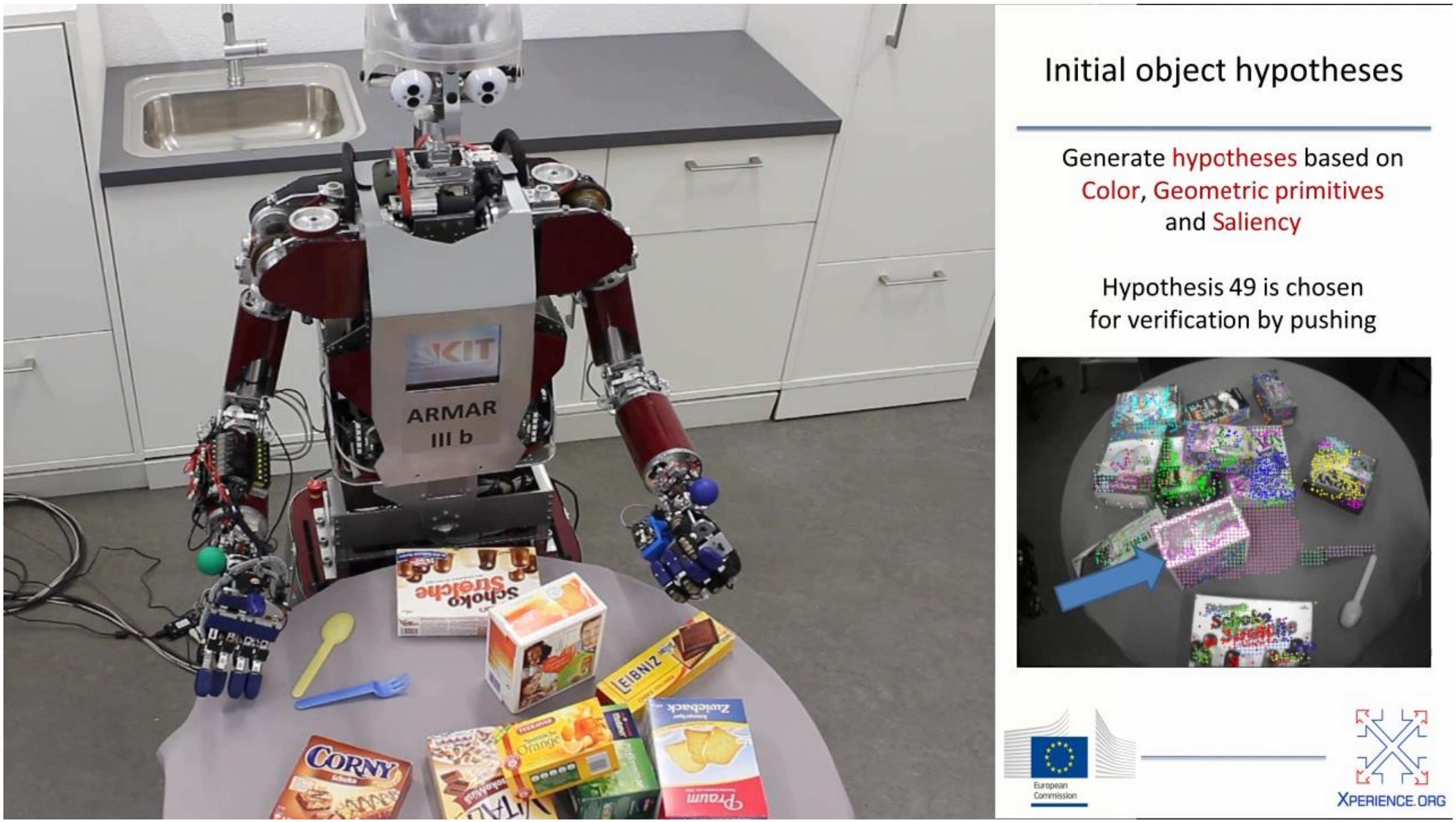


Object learning results

- Object recognizer trained with the segmentations
  - Based on point clouds and color
- Recognition using all descriptors obtained after *n* pushes

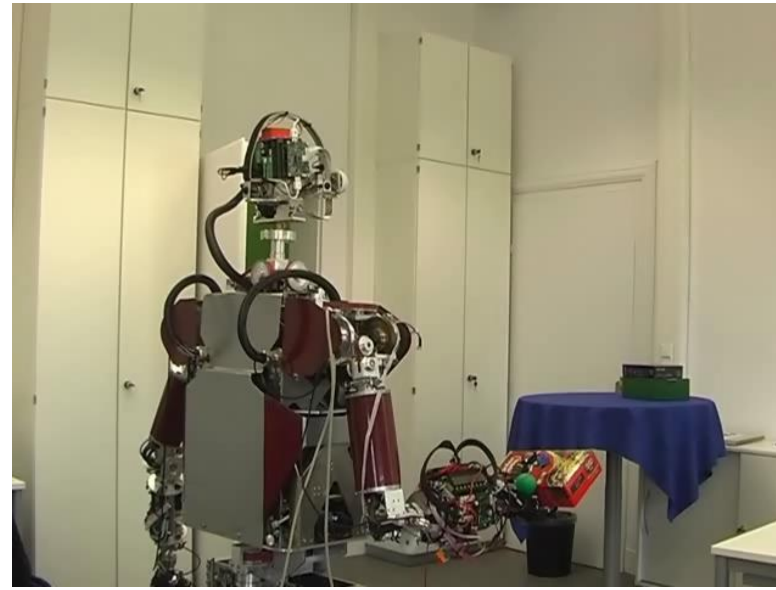


Combining action, vision and haptics for grasping



Learning object representations by manipulation

- Generation of visual representations
  - Perspective and foveal camera
  - Multi-view appearance-based representation
- Scene memory
  - Integration of object hypotheses in an ego-centric representation "transsaccadics memory"
  - Active visual search

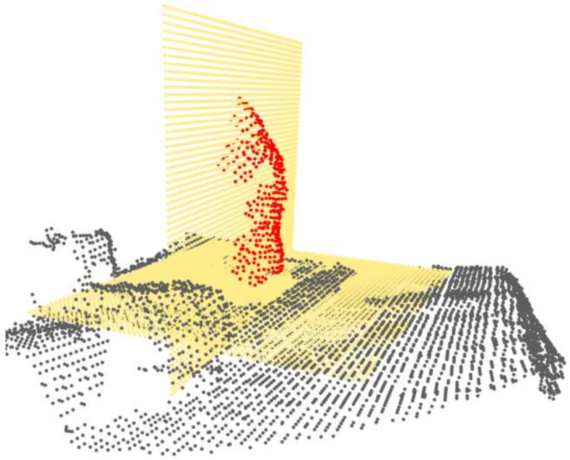


ICRA 2013, 2010, 2019
Humanoids 2009

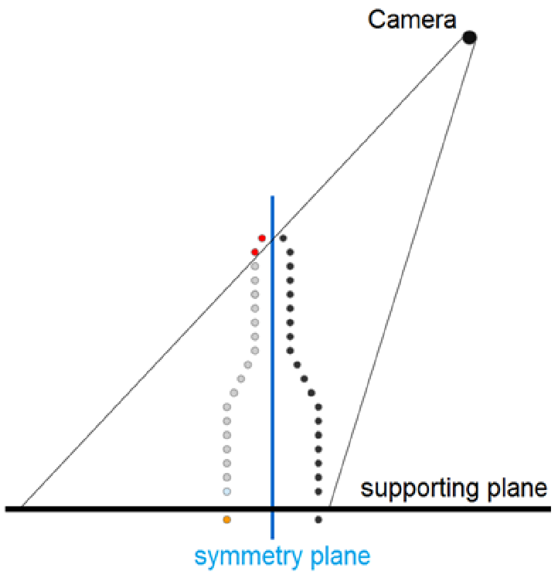
Noodles Search Orientation 1

Heuristic 3D shape completion from vision

- **Approach:** Symmetry assumption and information from scene context
  - Estimate possible support surfaces based on neighboring points around the segmented object
  - Search for best symmetry plane perpendicular to these support surfaces



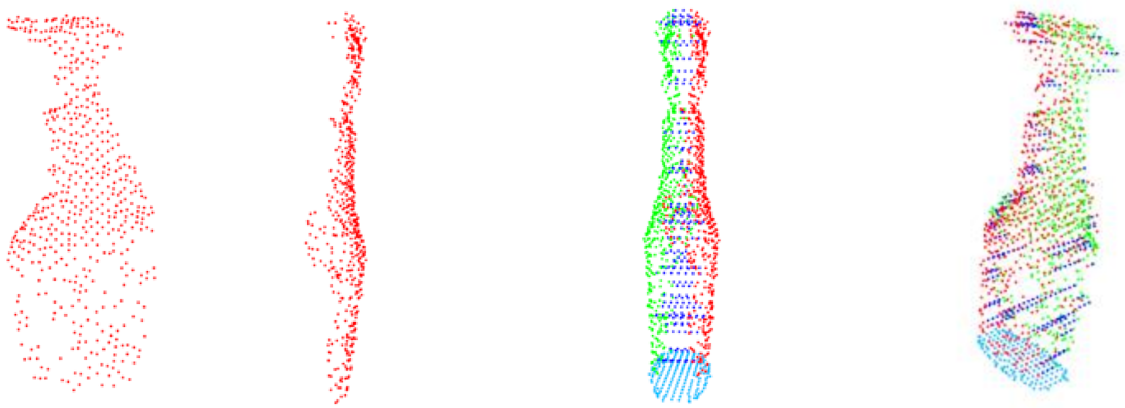
- Select symmetry plane candidates
  - Mirror object points on them
  - Rate them based on visibility criteria



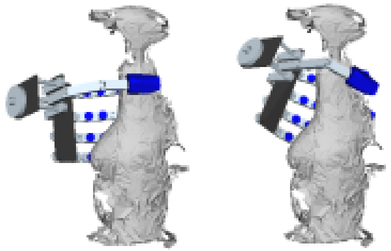
- Mirrored points may
  - Coincide with the original points
  - Lie behind the original points
  - Lie in front of the object
  - Lie besides the object

Heuristic 3D shape completion from vision

- Resulting 3D point clouds
  - Mirroring at the symmetry plane (green)
  - Intersection of estimated support plane and bottom part of the object (light blue)
  - Edges: lines from the front to the back side in the depth direction (dark blue)

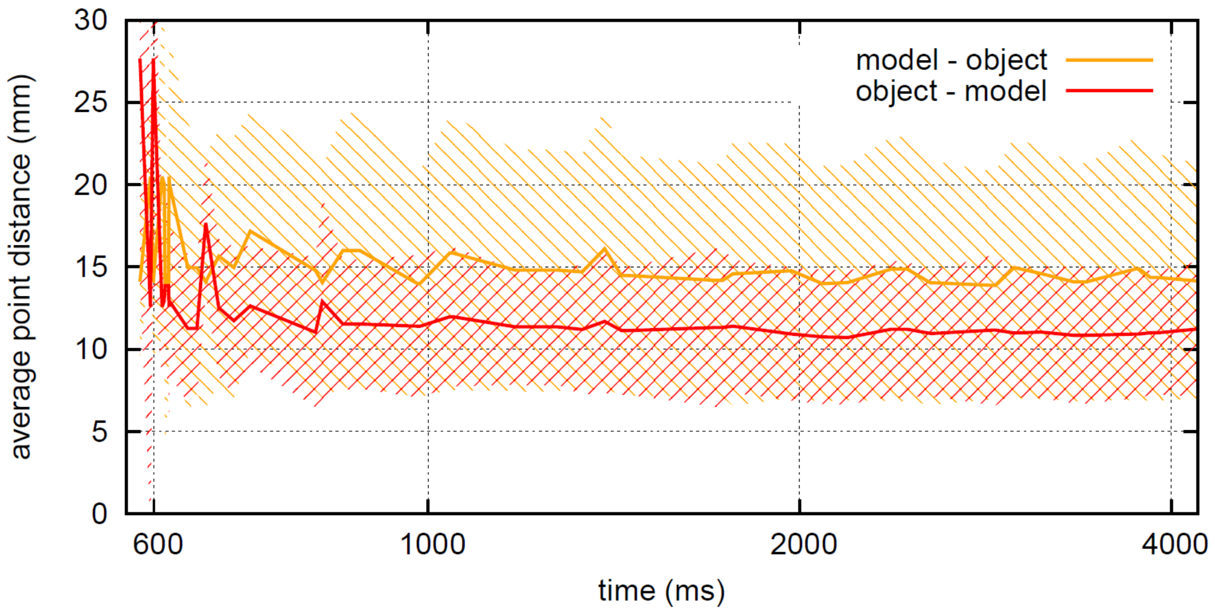


- Completed shape allows grasp planning, but inaccuracies must be expected and handled



Shape completion results

- Complete shapes obtained from segmentation
- Mean distance between completed shape and ground truth model, depending on calculation time



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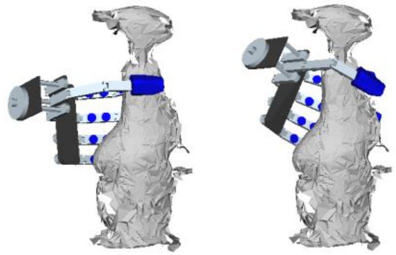


Visual collision detection for reactive grasp correction

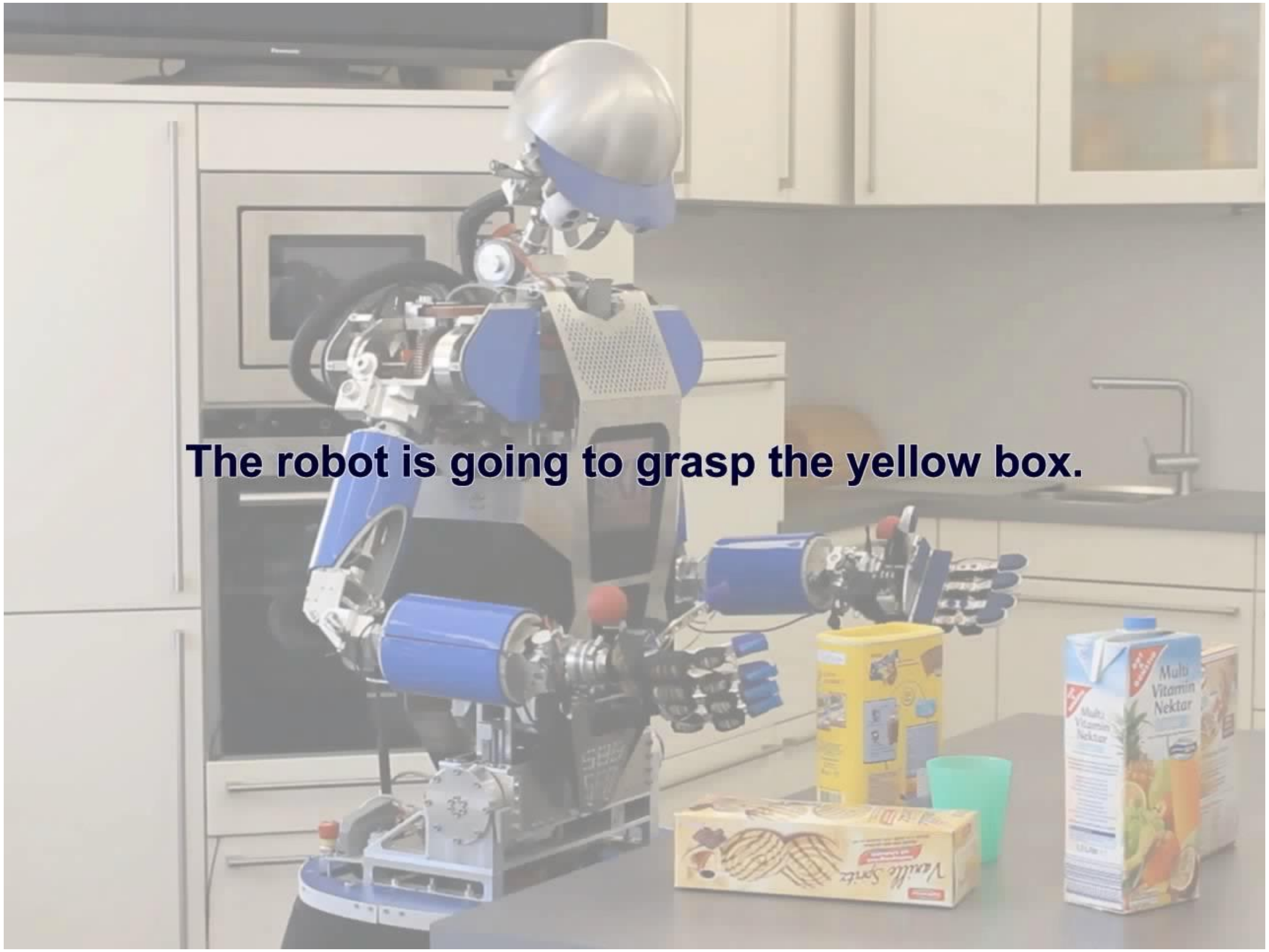
- **Detect premature collisions** of hand and object
  - With force/torque sensors, haptic sensors, finger joint angles…
  - Sensors not sensitive enough for light objects

- **Idea**: Detect hand-object collision **visually**
  - Detect object motion caused by the collision
  - Complement haptic/force sensory information for light objects

Visual collision detection

- **Hand tracking** using a **particle filter**
  - Use spherical marker and fingertips for exact hand localization
  - Fingertips are important for localization of the collision
- **Optical flow for object movement detection**
  - Problem: When the robot moves, everything moves in the image
  - Cluster optical flow by motion direction
- When a **new motion cluster** appears in front of the hand that doesn’t fit to the rest of the movement in the scene, the object probably started to move
- **No object knowledge needed except approximate size**

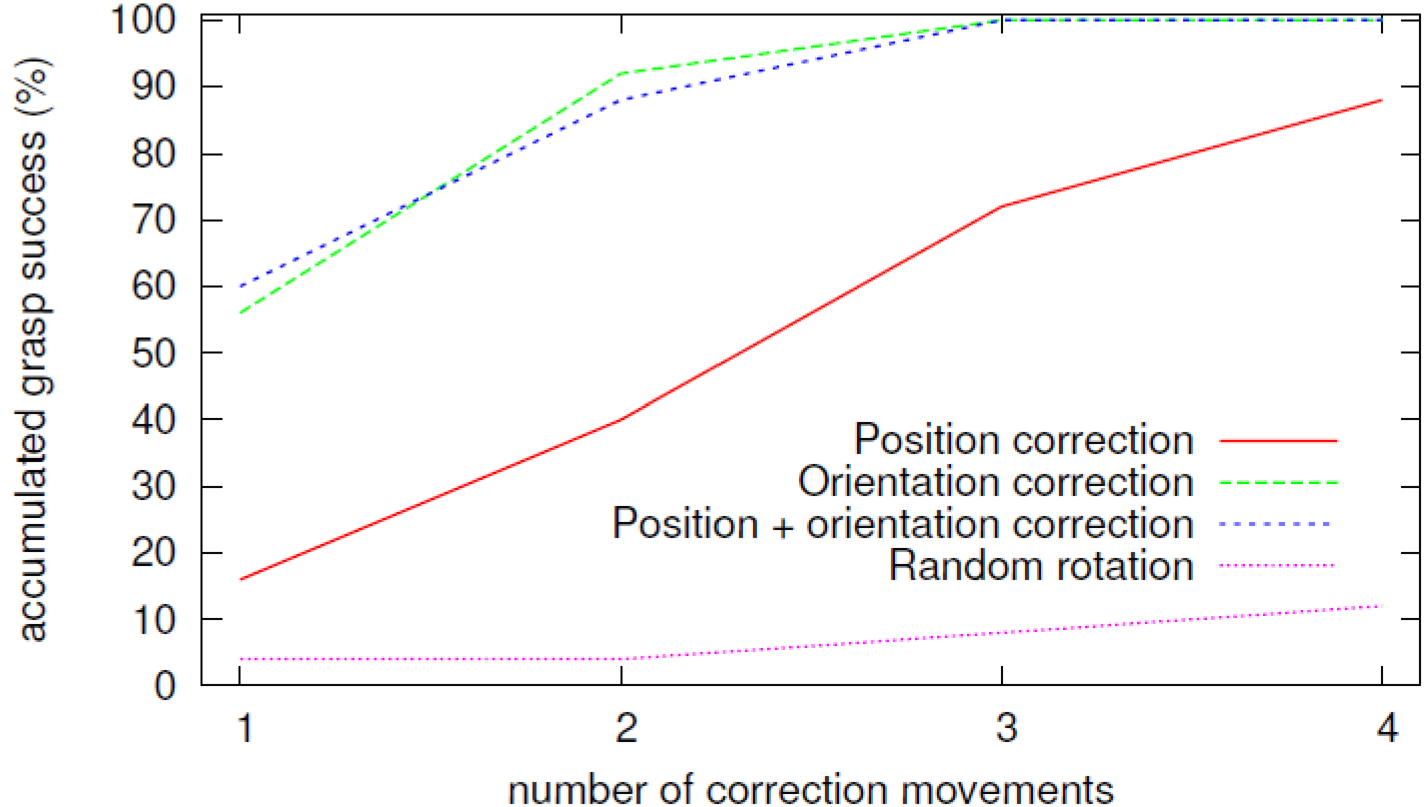
Visual collision detection for reactive grasping



Humanoids 2014

Grasp success depending on strategy

- Correction of predefined grasps that are slightly incorrect
- Success rate after up to *n* corrective movements:



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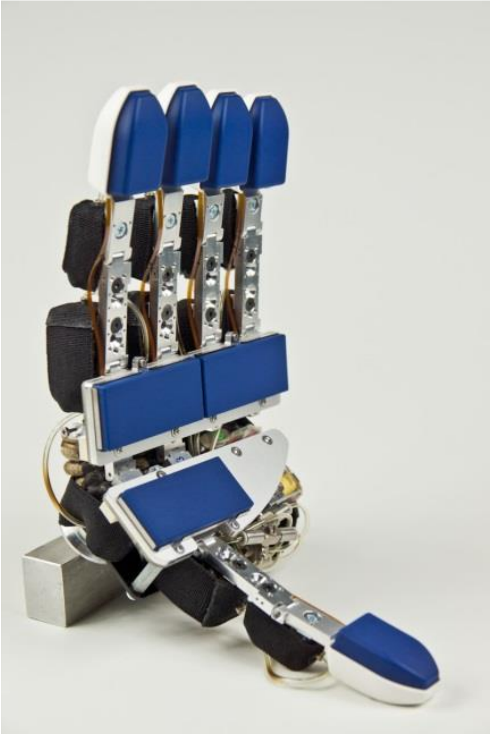
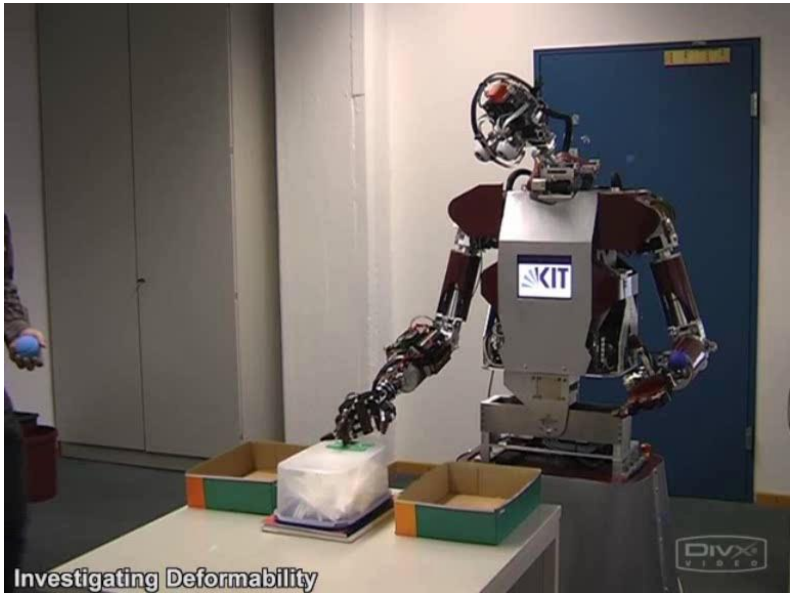
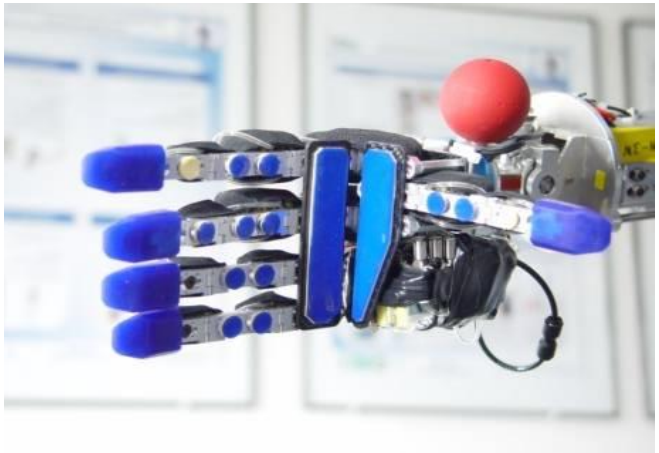
ARMAR hands

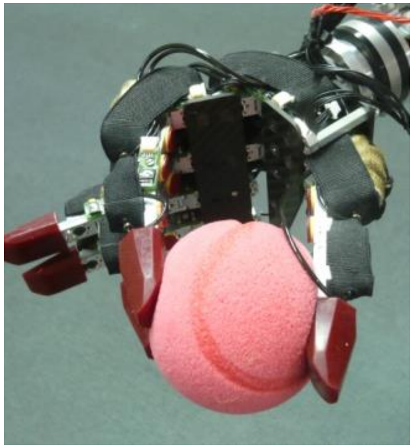
- 8-11 DoF; pneumatic actuators
- Position, pressure and tactile sensors





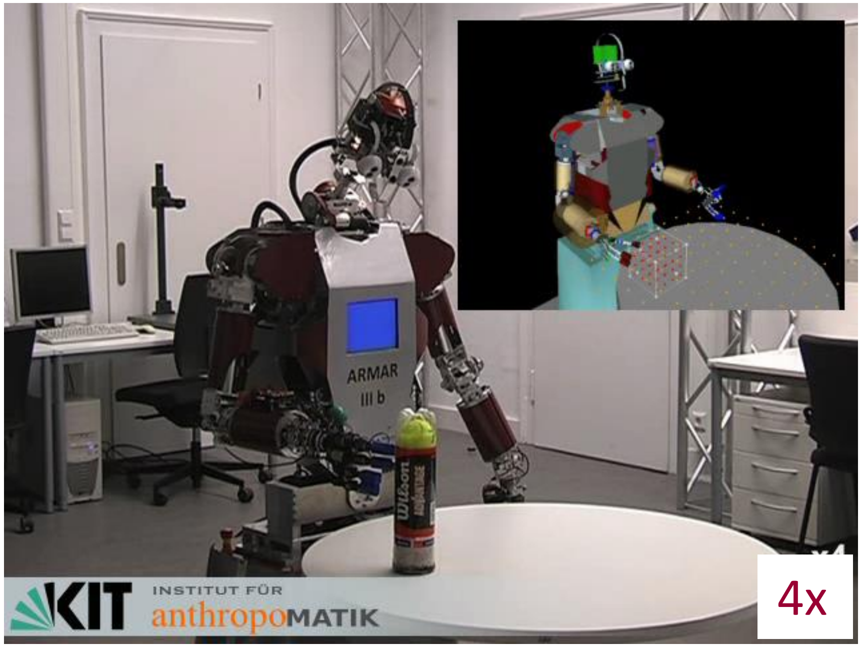
Humanoids 2009





Tactile object exploration for grasping

- Potential field approach to guide the robot hand along the object surface
- Oriented 3D point cloud from contact data
- Extract faces from 3D point cloud in a geometric feature filter pipeline
    - Parallelism
    - Minimum face size
    - Face distance
    - Mutual visibility



ISRR 2011, Humanoids 2009, 2008

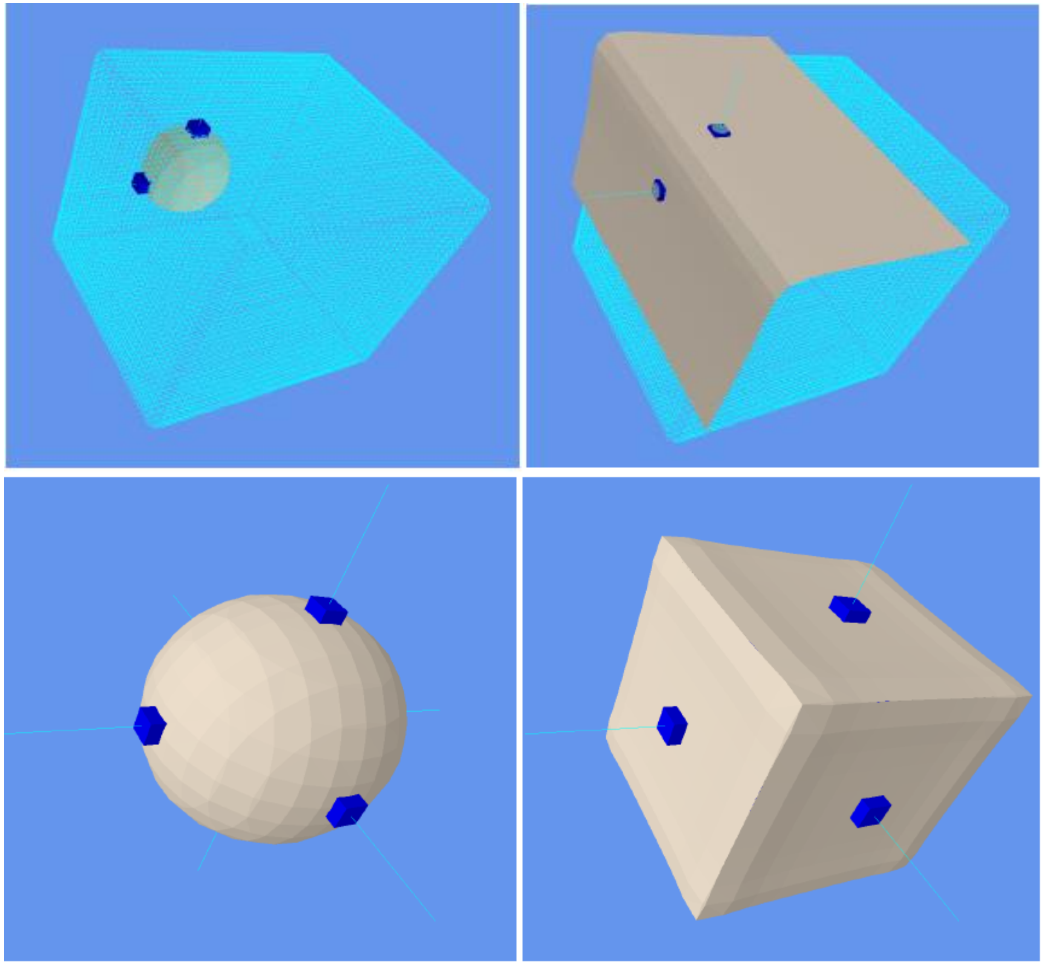
Association between “objects” and grasping actions → “grasp affordances”

Local implicit surface estimation

- Haptic exploration → sparse contact point data
- Accurate surface estimation is needed for **grasp planning** or **object classification**
- **How to estimate 3D object models based on sparse contact data?**
- Surface representations
  - Parametric models, e.g. superquadrics; object decomposition, …
  - Implicit surface models, e.g. Gaussian Process Implicit Surfaces (GPIS) which can approximate arbitrary shapes given sufficient input data; but details such as corners and edges are usually smoothed out
  - **New Approach based on local implicit shape estimation**

Humanoids 2016 – Interactive Session ThPoS.5
Ottenhaus et al. *Local Implicit Surface Estimation for Haptic Exploration*

Local implicit surface estimation

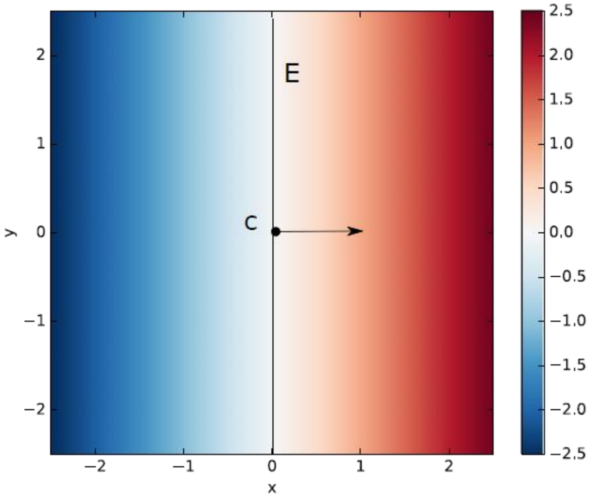


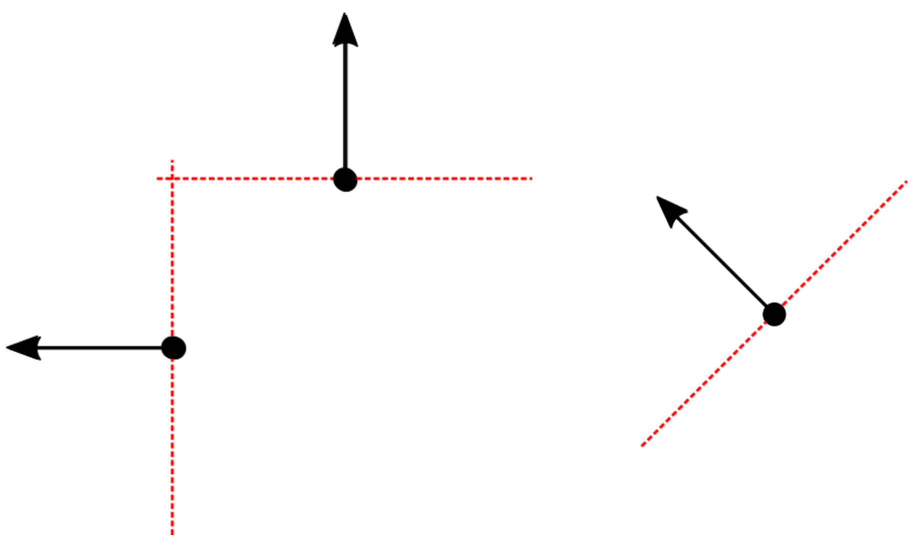
Gaussian Process | Our method

Idea and approach

- Contact points define planes
- Represent contact planes by implicit functions $s_i(x)$
- Superposition of all implicit function $s_i(x)$ to implicit surface potential function $f(x)$
- Weighted superposition of contact planes → planes are not "deformed"

Signed distance funktion $s(x)$





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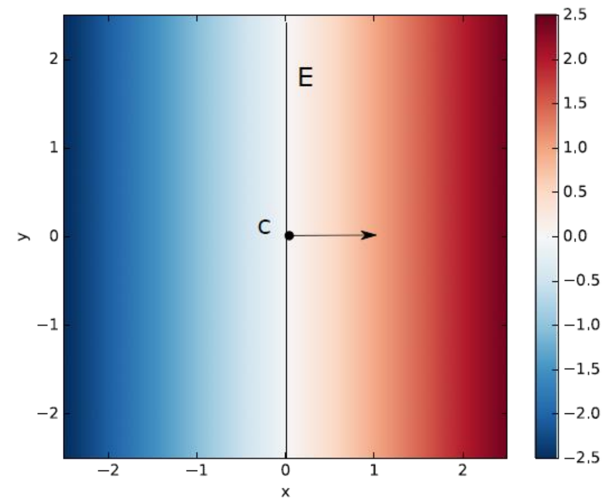

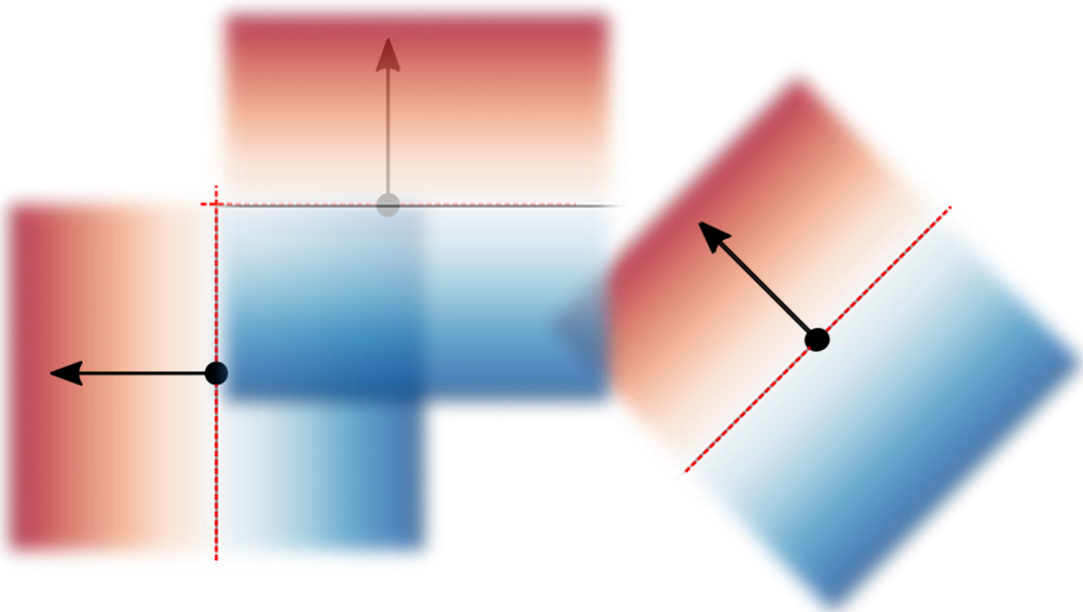

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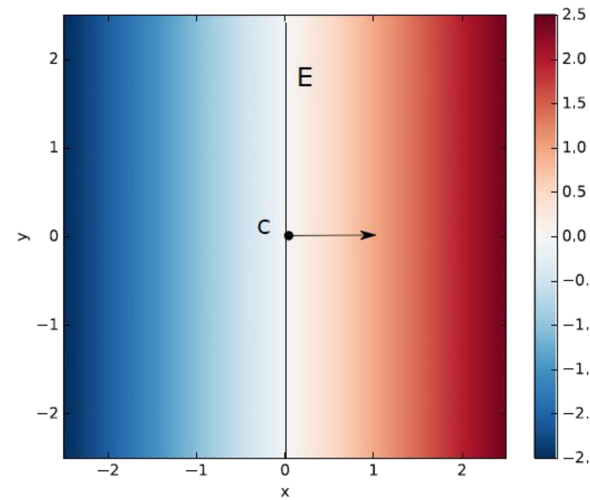
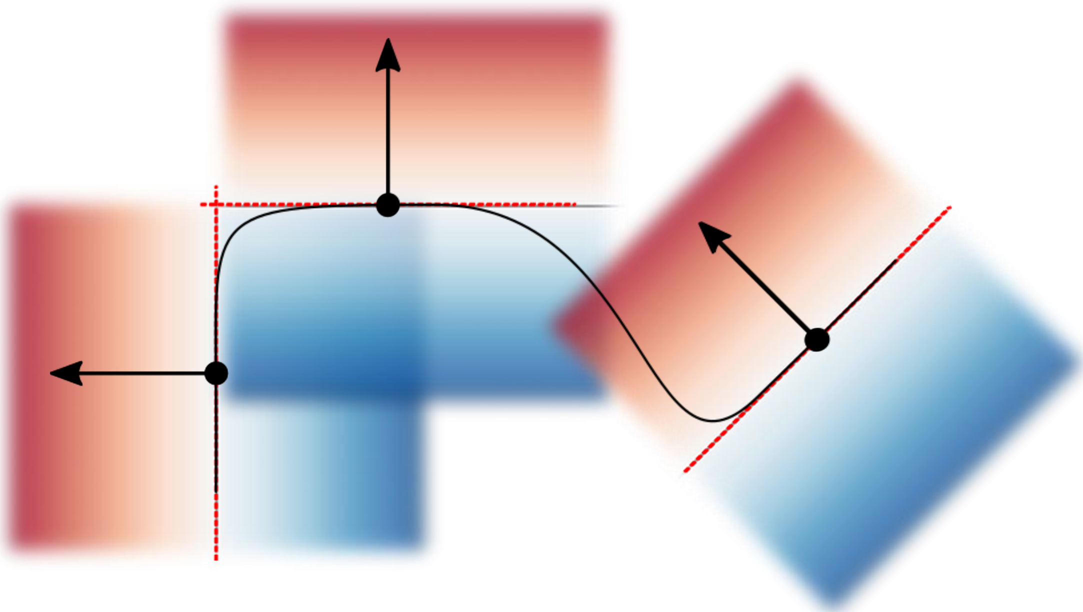




Superposition of contact implicit functions

- All implicit functions are superimposed using kernel functions

$$u_i = u_i(x)$$

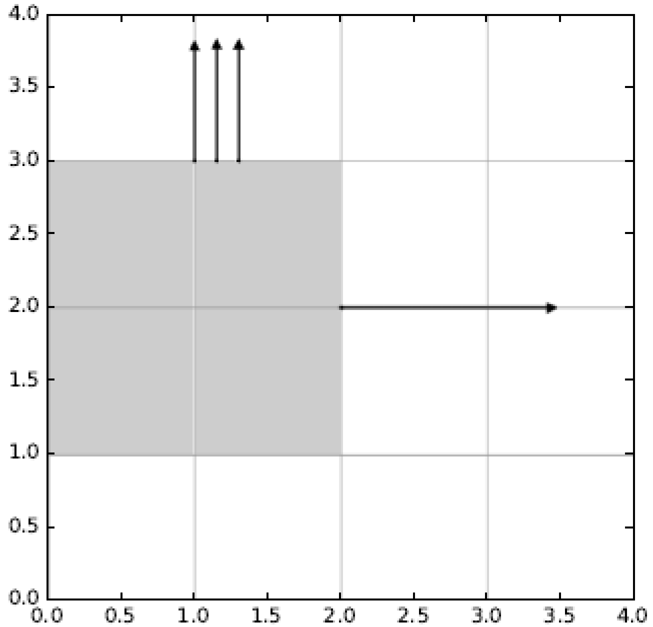
  - Kernel decrease with increasing distance to the contact point
  - Guarantee local influence of the contacts

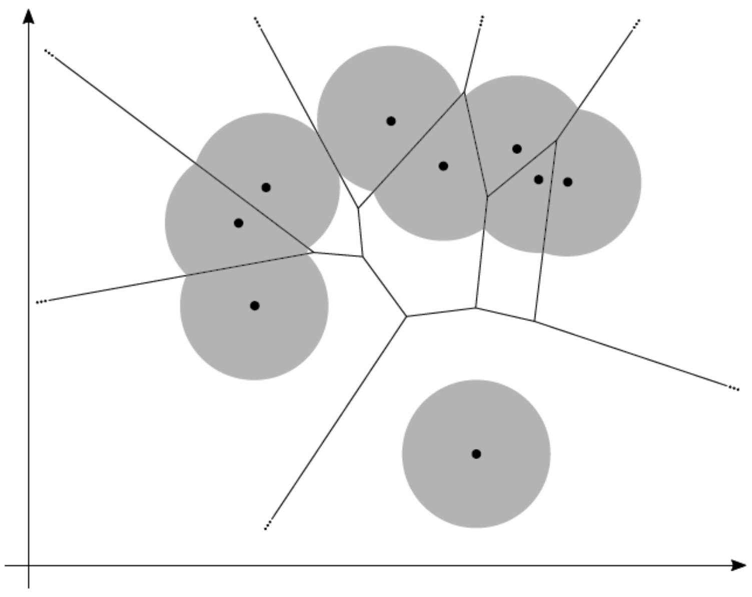
$$f(\mathbf{x}) = \sum_{i=1}^{N} u_i \cdot s_i(\mathbf{x})$$

Weighting of contact implicit functions

- Balance irregular distribution of the contact points

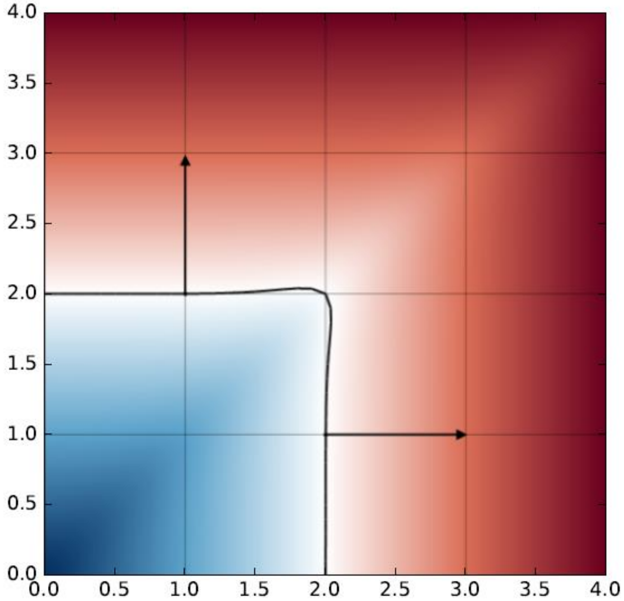
$$f(\mathbf{x}) = \sum_{i=1}^{N} u_i \cdot w_i \cdot s_i(\mathbf{x})$$



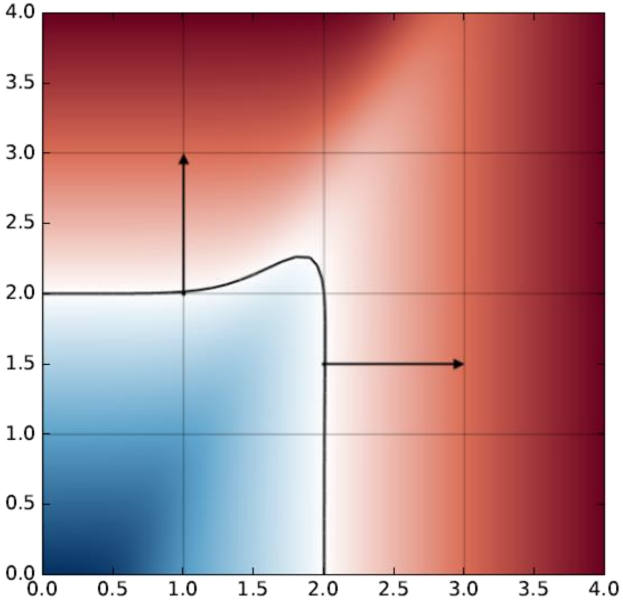


Weighting of contact implicit functions

$$f(\mathbf{x}) = \sum_{i=1}^{N} u_i \cdot w_i \cdot s_i(\mathbf{x}) \cdot ?$$



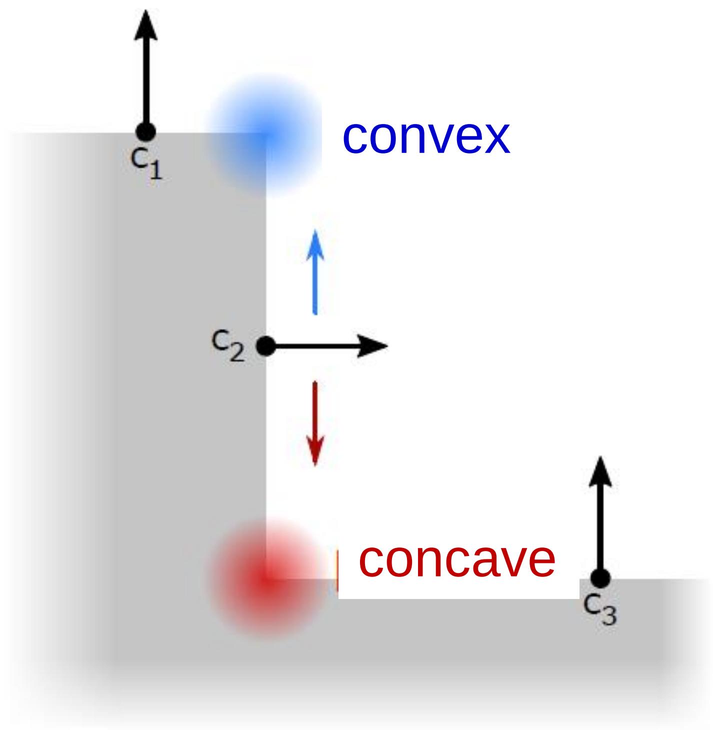
Contacts at the same distance from an edge



One contact is closer to an edge

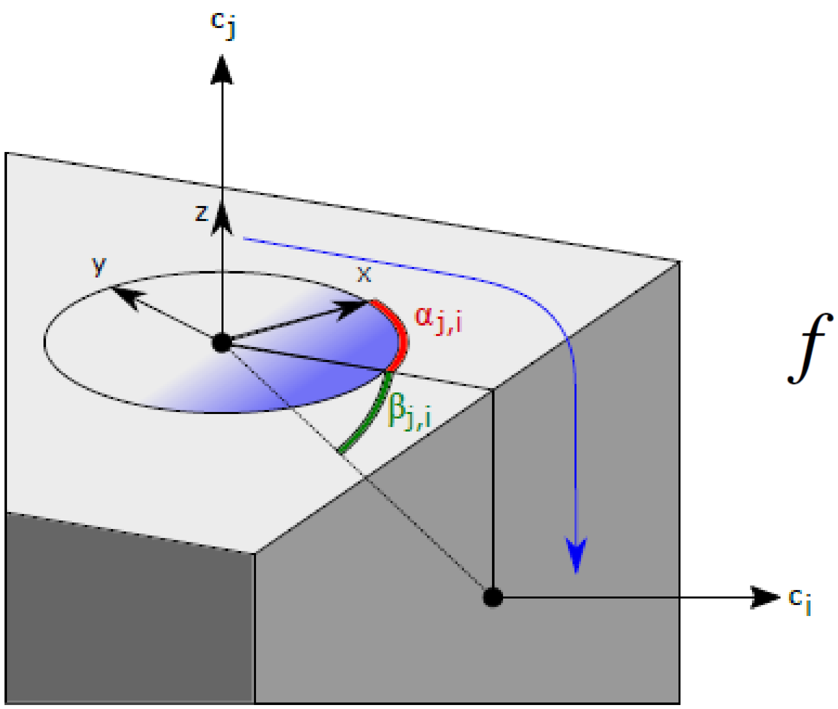
Convexity/concavity features (CCF)

- Describe local convexity/concavity
- Depends on direction of contact point normals
- Contact can be convex in one direction and concave in another.



Convexity/concavity features (CCF): Definition

- Angle α describes the direction to the neighborhood contact
- Angel β describes convexity/concavity



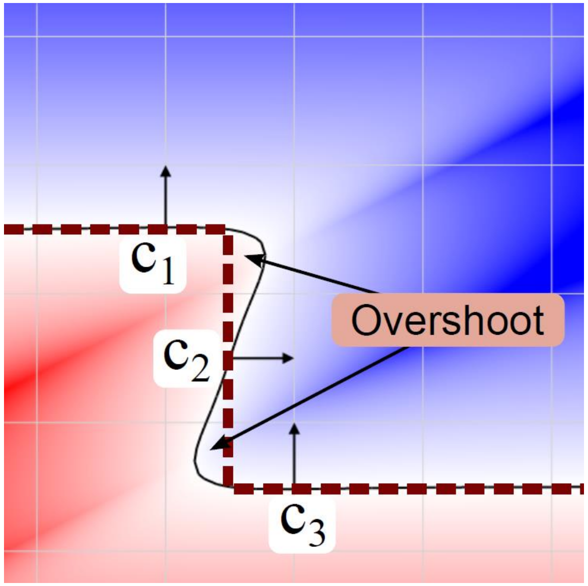
$$f(\mathbf{x}) = \sum_{i=1}^{N} u_i \cdot w_i \cdot v_i \cdot s_i(\mathbf{x})$$

Convexity/concavity features model

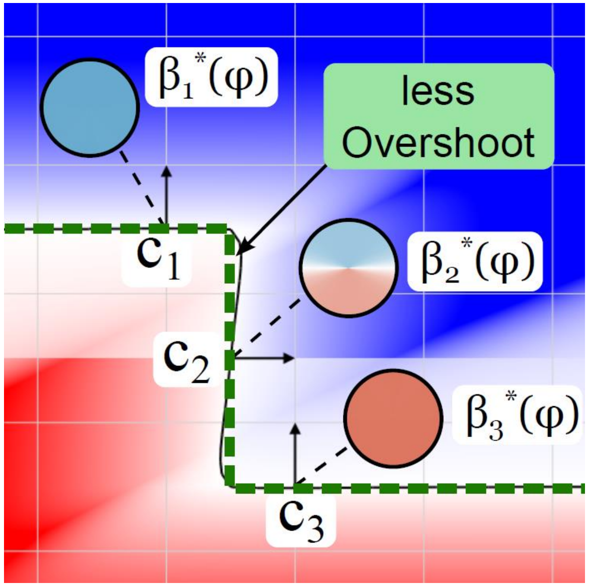
- Measure for local convexity/concavity

$$\beta_i{}^*(\varphi_i(\boldsymbol{x})) = \frac{\sum_{j \neq i} k_{i,j,\phi}(\varphi_{i,j}(\boldsymbol{x}))\sin(\alpha_{i,j})}{\sum_{j \neq i} k_{i,j,\phi}(\varphi_{i,j}(\boldsymbol{x}))}$$

Without CCF

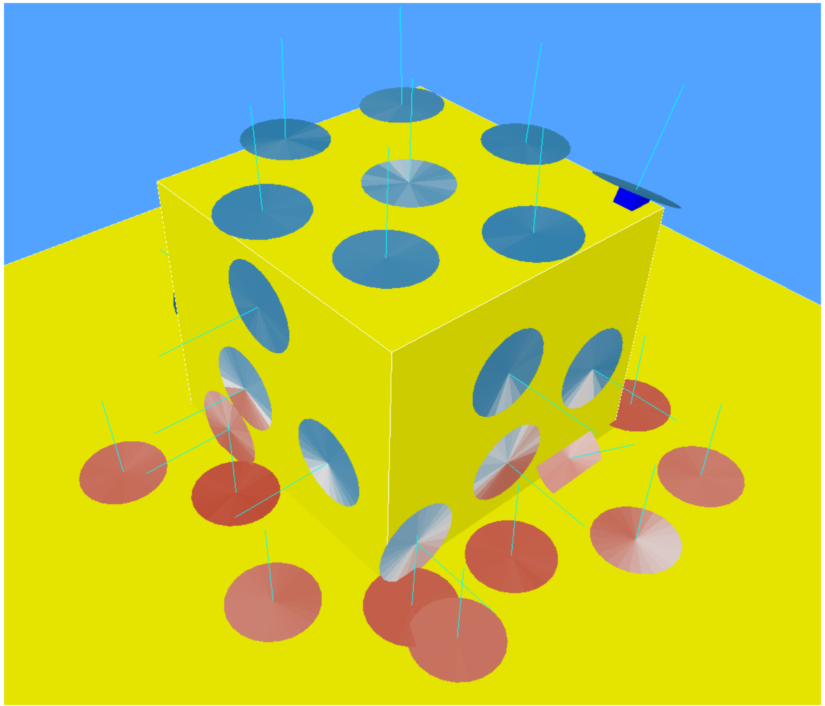


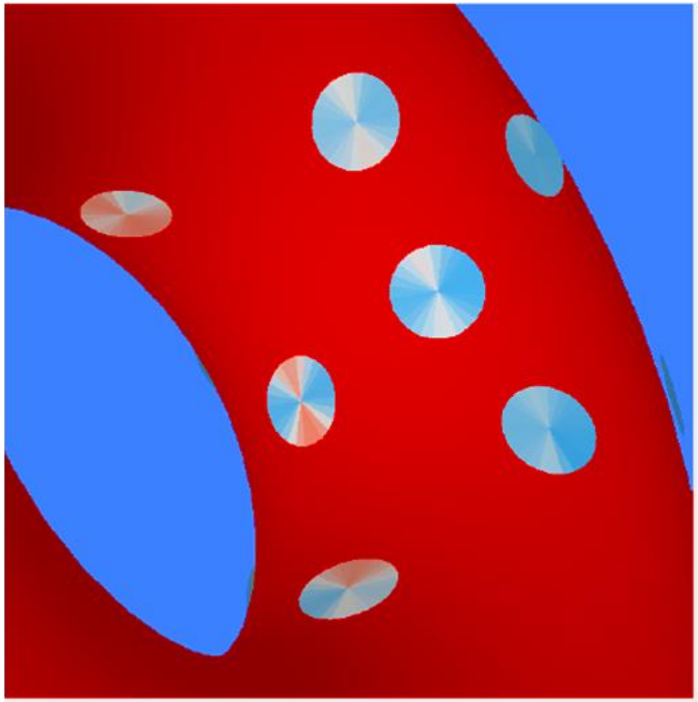
With CCF



Convexity/concavity features (CCF)

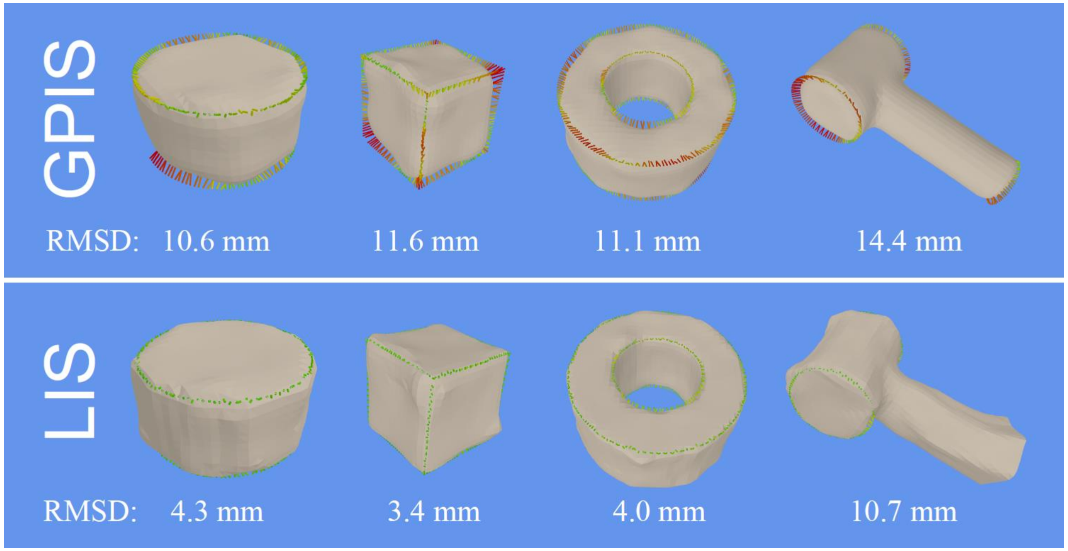
- Blue: convex
- Red: concave
- Contact can be convex in one direction and concave in another.



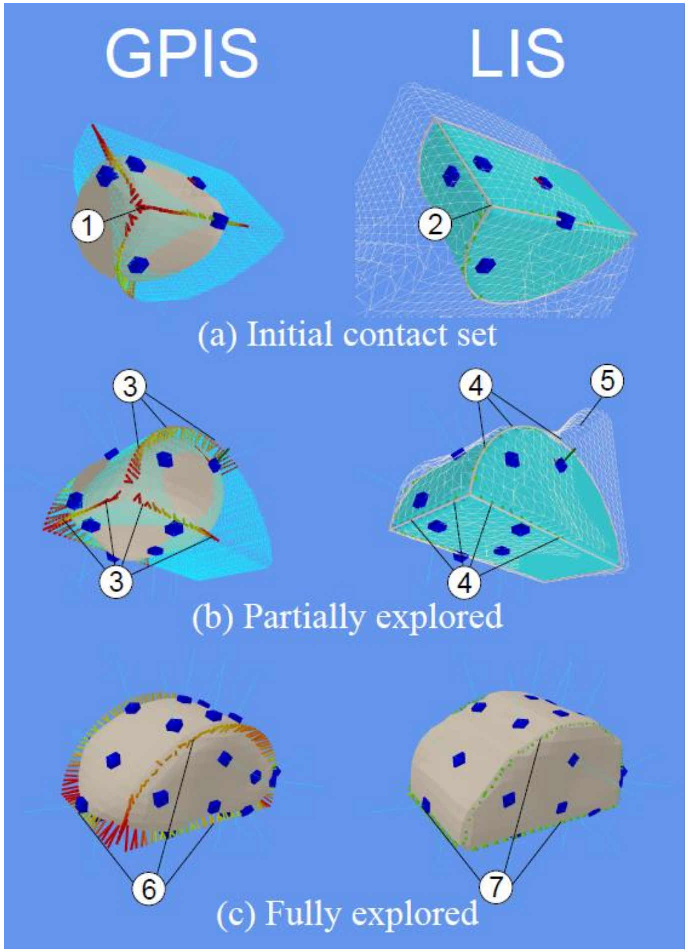


Evaluation

- Gaussian Process Implicit Surfaces (GPIS) vs. Local Implicit Surfaces (LIS)
- Estimation Quality
  - Corners ①, ②
  - Edges ③, ④
  - Fully explored ⑥, ⑦

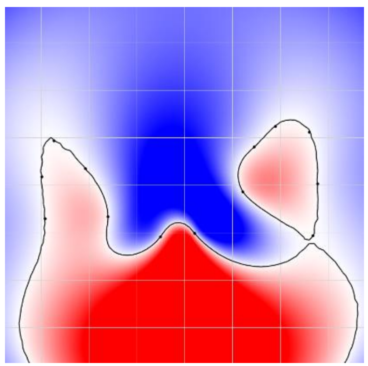


*) RMSD: Root-Mean-Square-Deviation

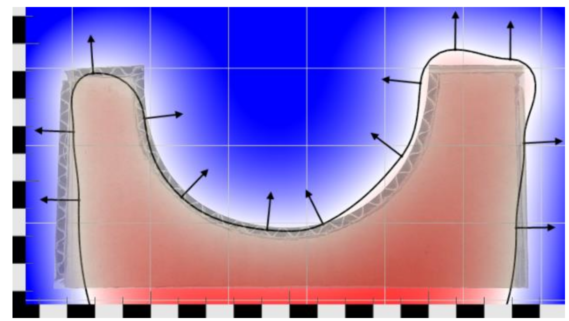


The "Sense" of Surface Orientation

- In addition to contact points, the **local surface orientation** is an important property and typically not easy to obtain



An object reconstructed from sparse contact position samples alone



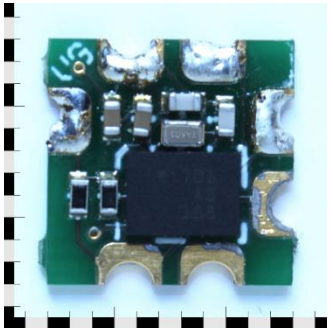
The same object reconstructed from **position and surface orientation** samples

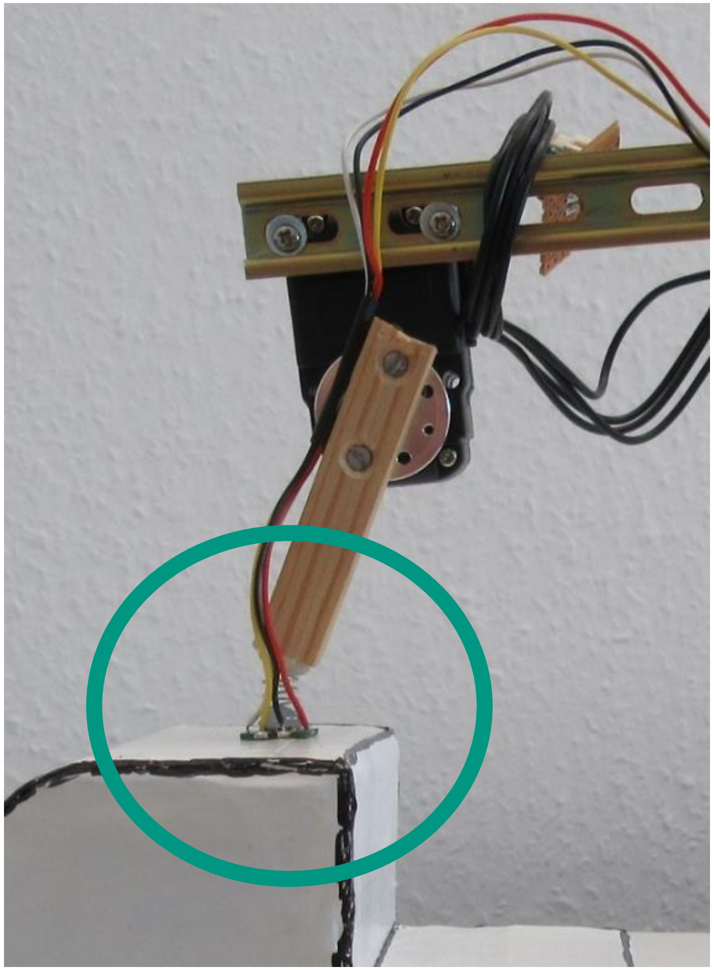
- New sensor for **direct measurement of local surface orientation**

Humanoids 2016 – Interactive Session ThPoS.5
Kaul et al. *The Sense of Surface Orientation - a New Sensor Modality for Humanoid Robots*

Sensor prototype

- A state-of-the-art MEMS **inertial orientation sensor** mounted onto a robotic end-effector with a flexible coil spring
- The spring ensures **automatic alignment** with the contacted surface
- Local surface orientation can be **measured directly**

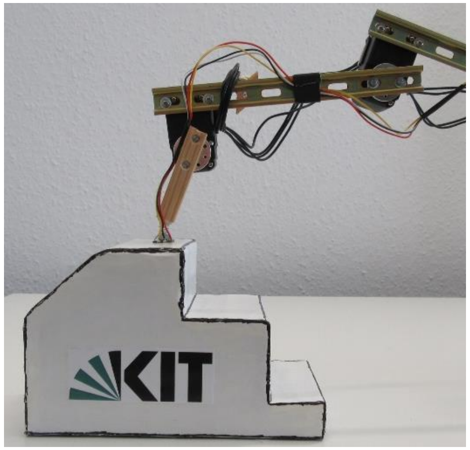




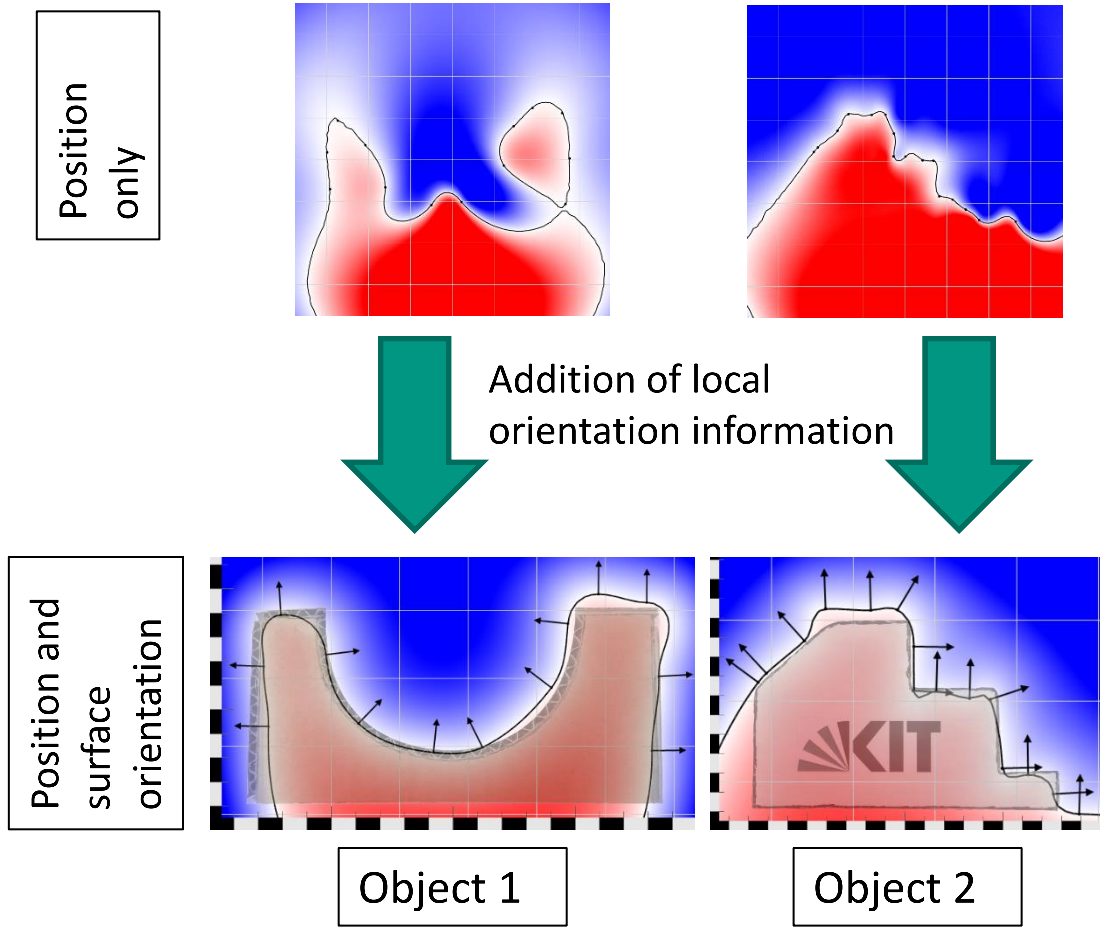
Bosch Sensortec BNO055 integrated orientation sensor

Left: Product description
Right: Custom breakout board (scale in mm)

Evaluation



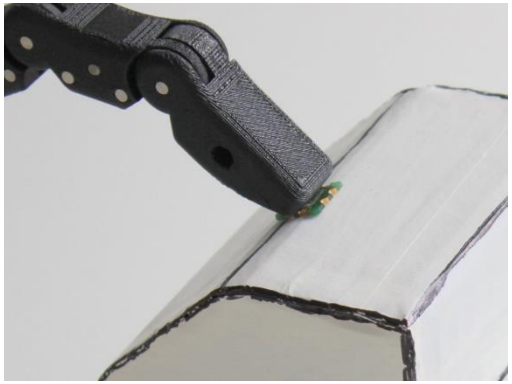
- **Two objects** explored with a 4 DOF robot arm
- Incorporation of measured local surface orientation **significantly improves shape reconstruction**



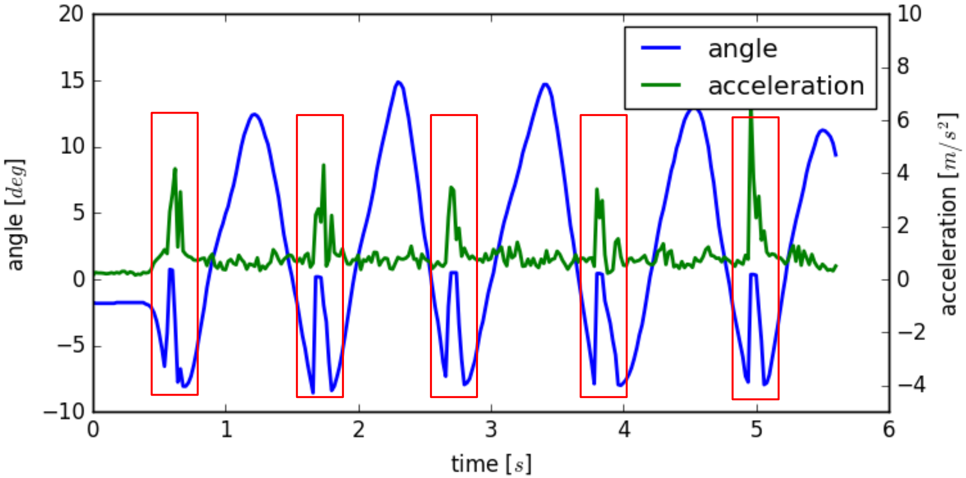
One scale segment equals 1cm

- Extended **Gaussian Processes Implicit Surfaces (GPIS)** for shape reconstruction

Contact detection



Future application



- IMU-Data „from the fingertip“ can be used for **other applications**, e.g. **contact detection**
- Contact with an object causes significant, almost instant changes in the **acceleration** signal, and due to the self-alignment also in the **orientation** signal
- The graph shows both, for consecutively making and breaking contact five times

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