Semantische Wahrnehmung für den Griff in die Kiste

Sven Behnke

Institut für Informatik VI
Autonome Intelligente Systeme

universitätbonn ais

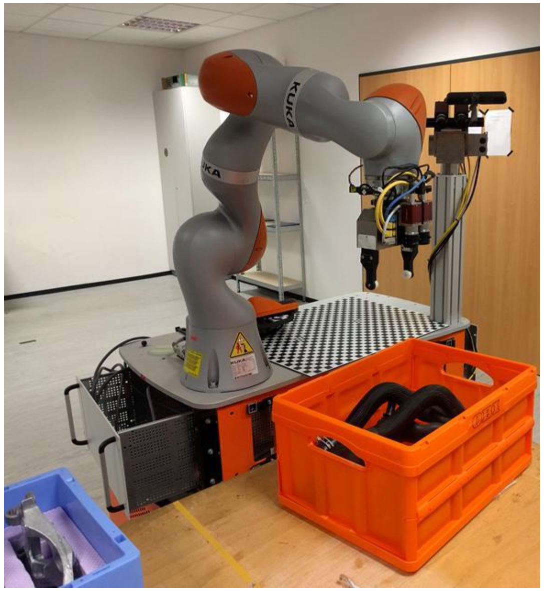
Roboter für den Griff in die Kiste

ActReMa

STAMINA

Amazon Picking Challenge

EuRoC C1



EuRoC C2

Serviceroboter

Dynamaid

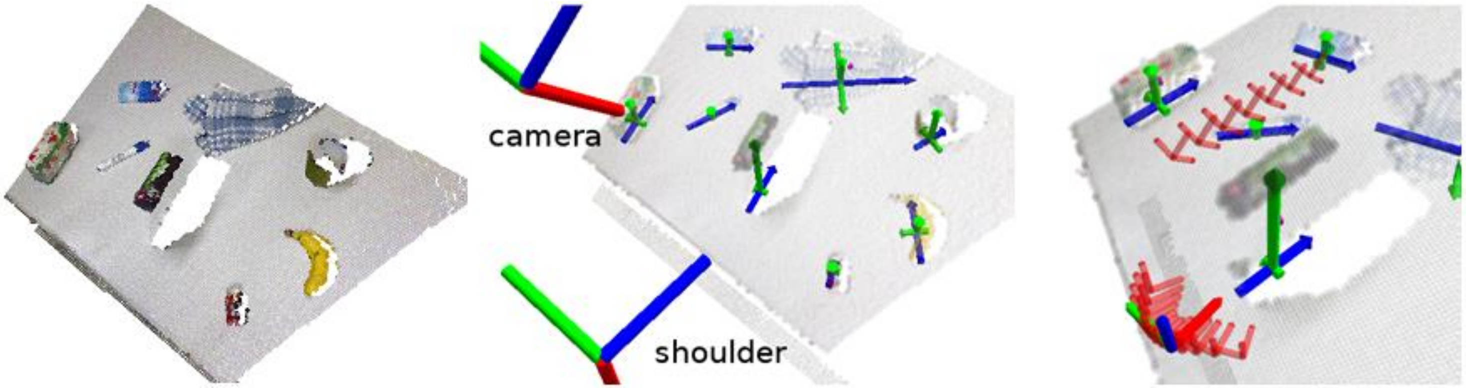
Cosero

[Stückler et al.: Frontiers in AI and Robotics 2016]

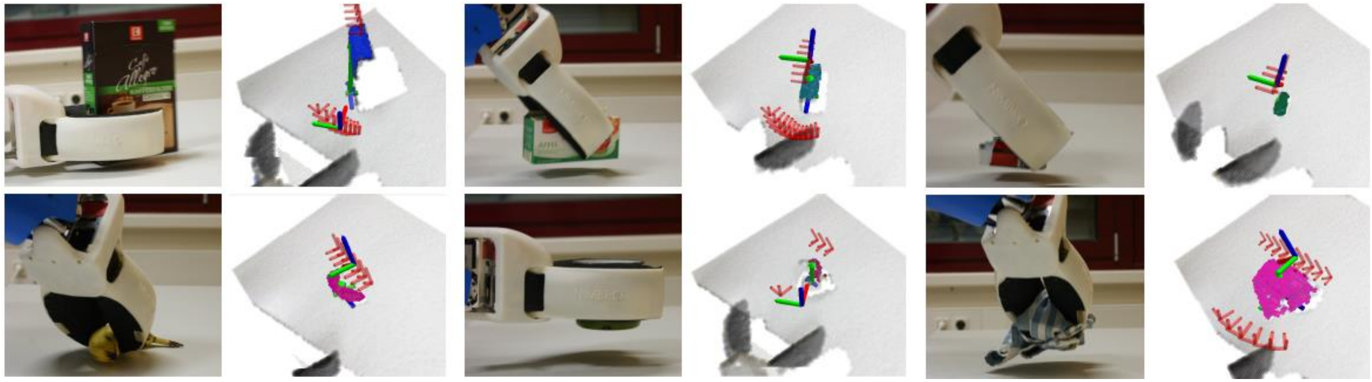
RoboCup 2013 Eindhoven

Greifen unbekannter Objekte

- Detektion von Punktclustern über horizontaler Fläche
- Zwei Griffarten: Von oben und von der Seite



- Flexibles Greifen vieler unbekannter Objekte

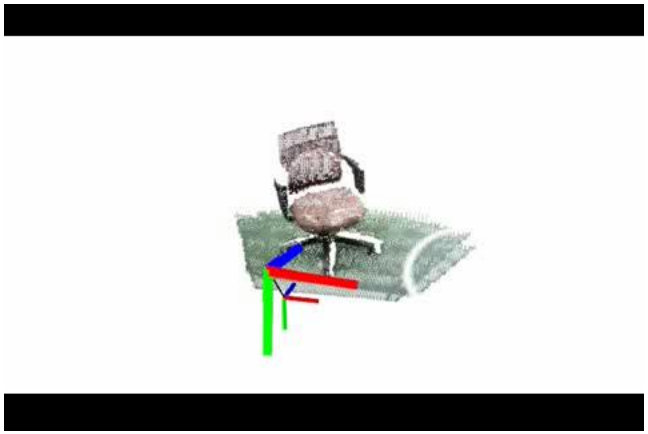


[Stückler, Steffens, Holz, Behnke, Robotics and Autonomous Systems 2012]

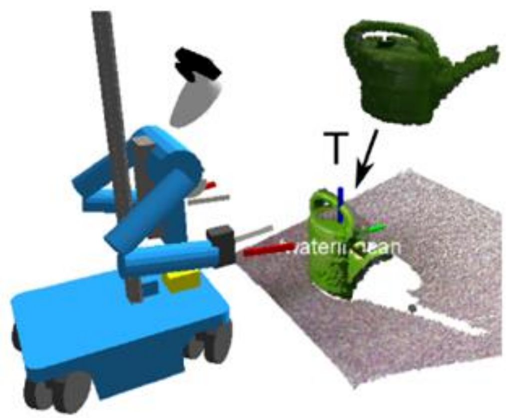
Lernen und Verfolgen von Objektmodellen

- Modeling of objects by RGB-D SLAM

[Stückler, Behnke: Journal of Visual Communication and Image Representation 2013]

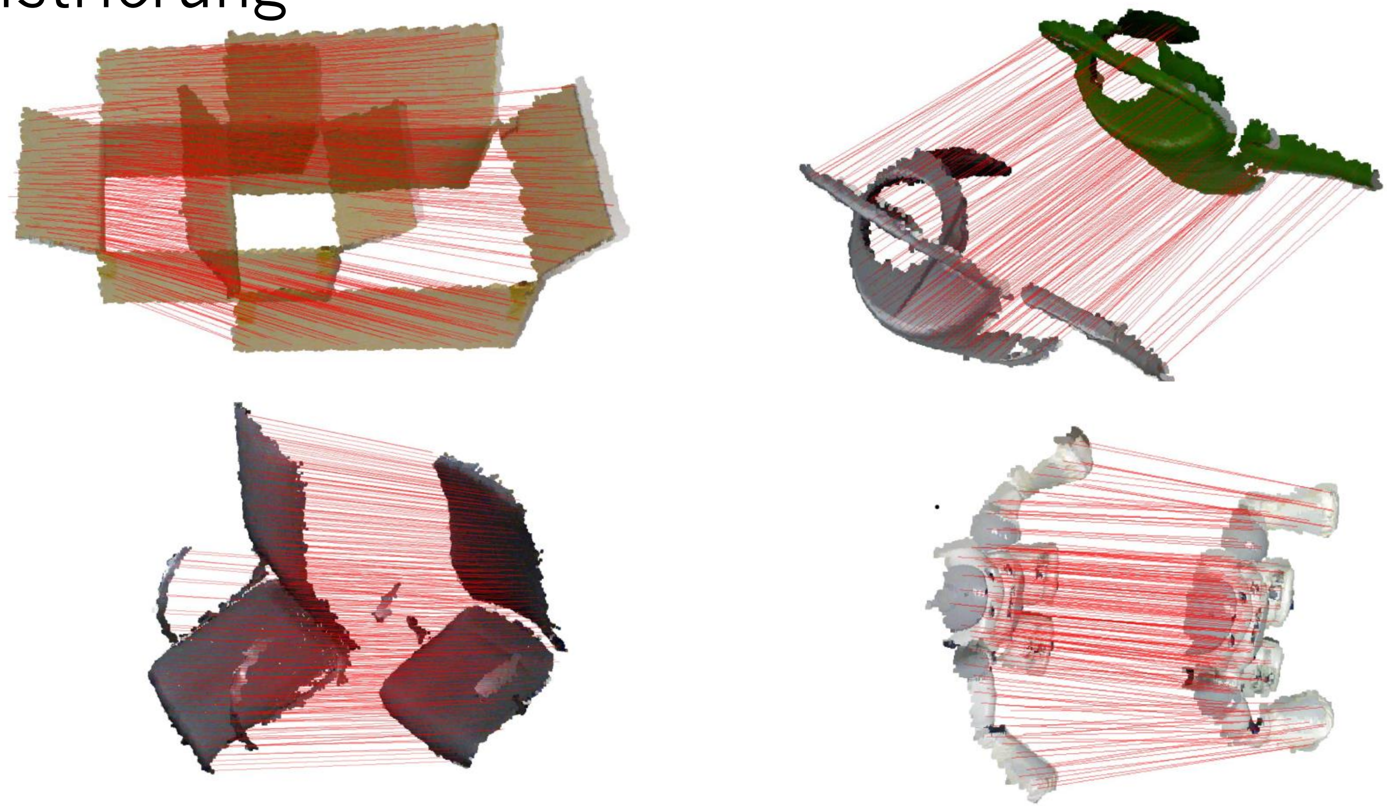


- Real-time registration with current RGB-D image



Deformierbare RGB-D-Registrierung

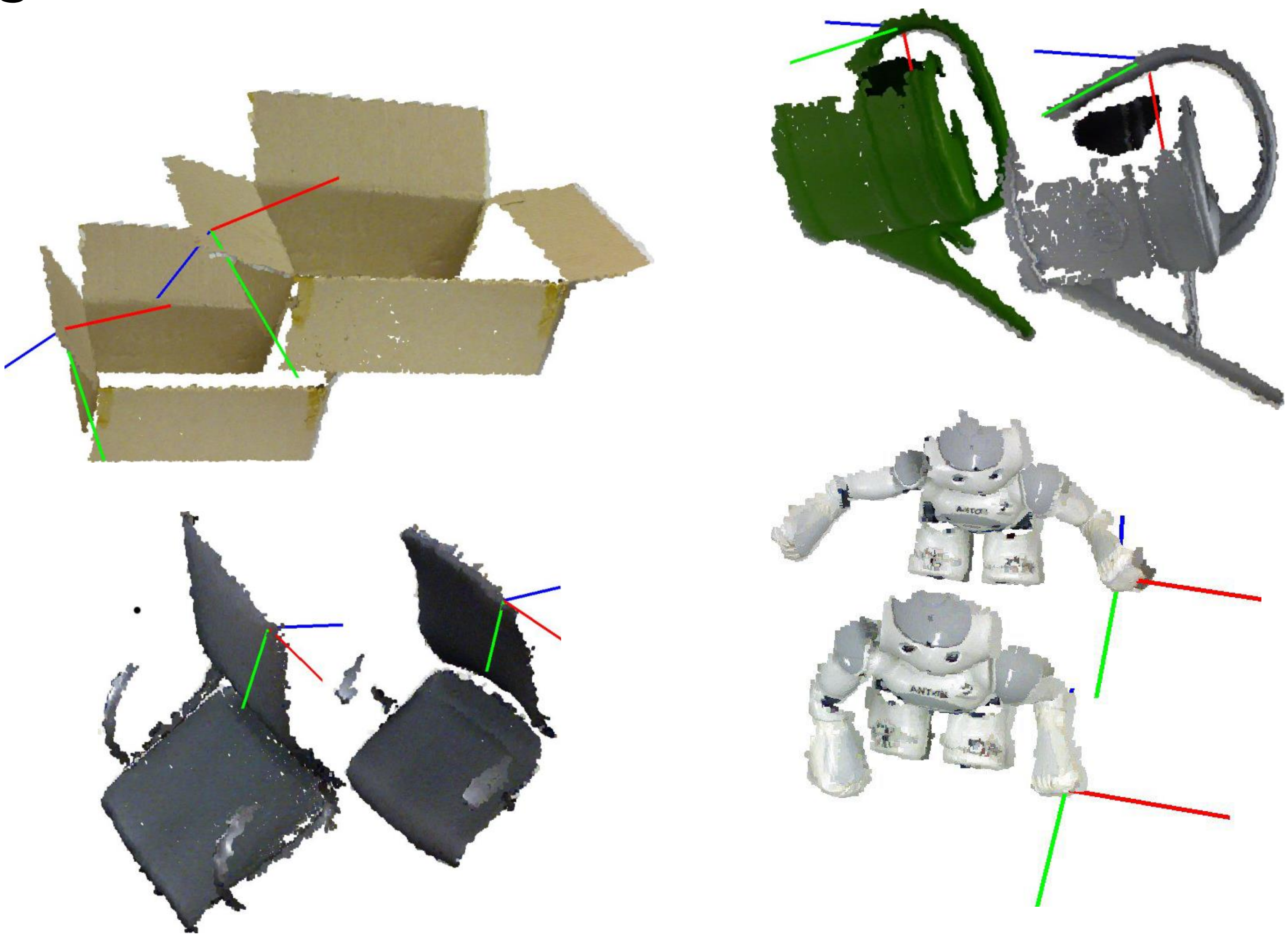
- Basierend auf Coherent Point Drift-Methode
  [Myronenko & Song, PAMI 2010]
- Multiresolutions-Surfel-Map erlaubt Echtzeit-Registrierung



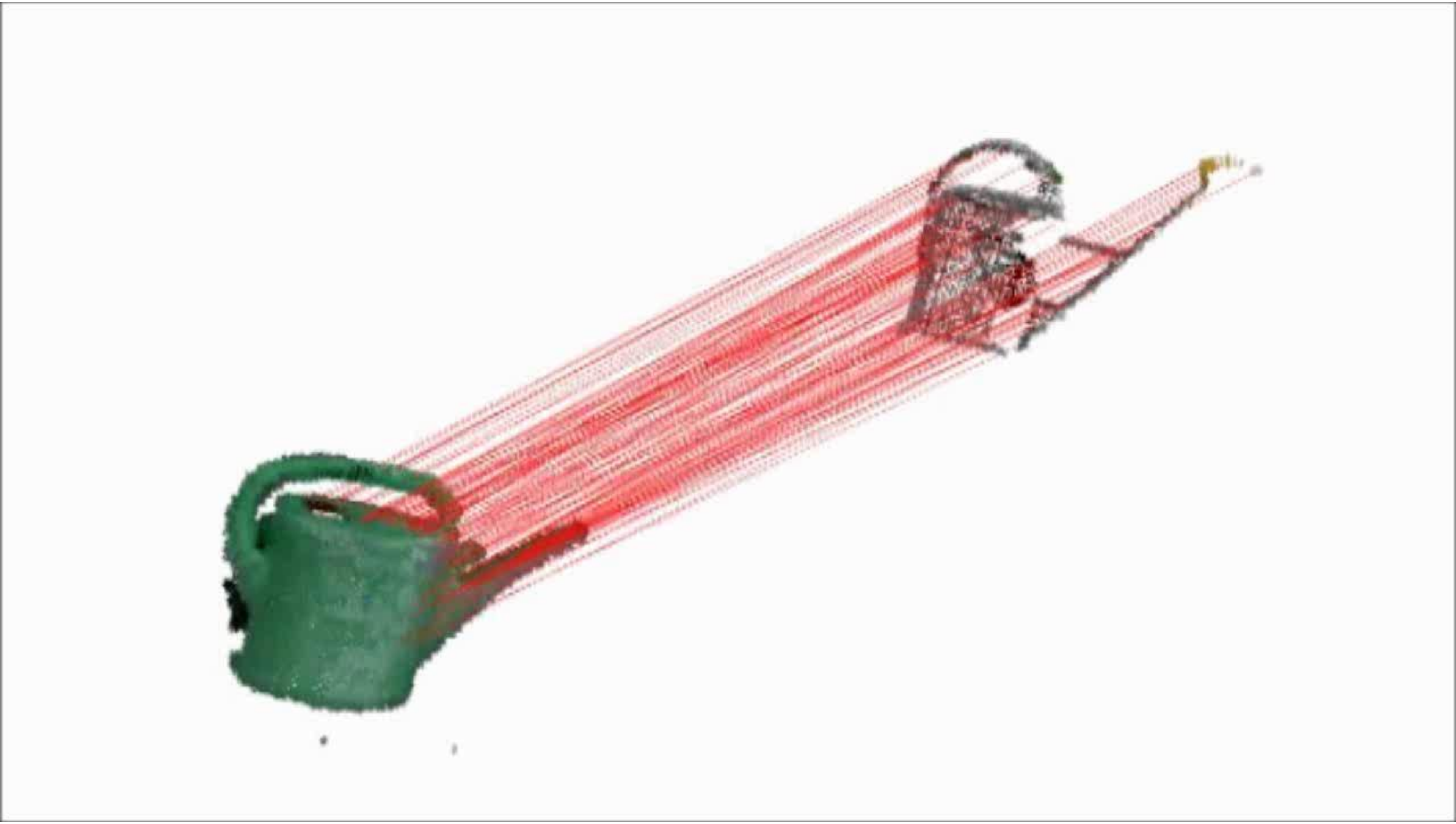
[Stückler, Behnke, ICRA2014]

Transformation von Schlüsselposen

- Abgeleitet aus Deformationsfeld



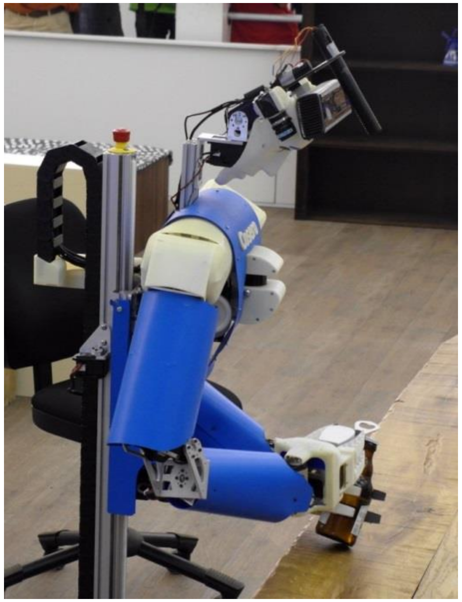
Transfer von Handhabungswissen

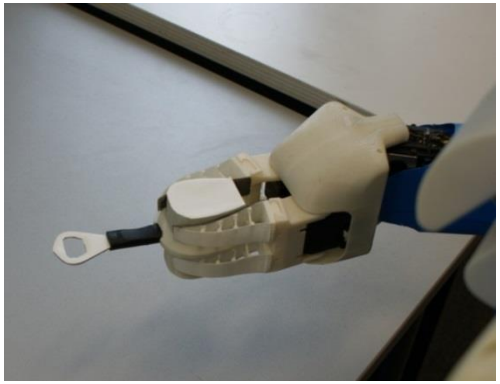


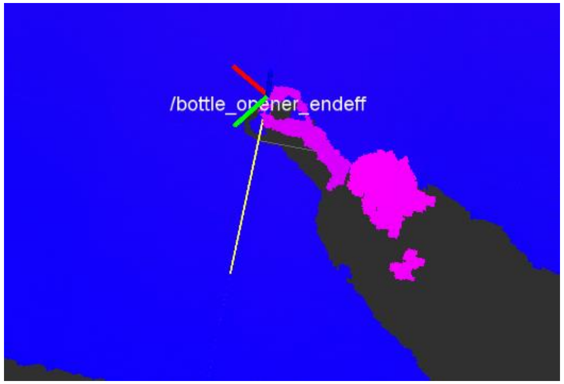
- Demonstration beim RoboCup 2013

Werkzeuggebrauch: Flaschenöffner

- Wahrnehmung von Werkzeugspitze und Kronkorken
- Erweiterung der Armkinematik
- Bewegungsanpassung

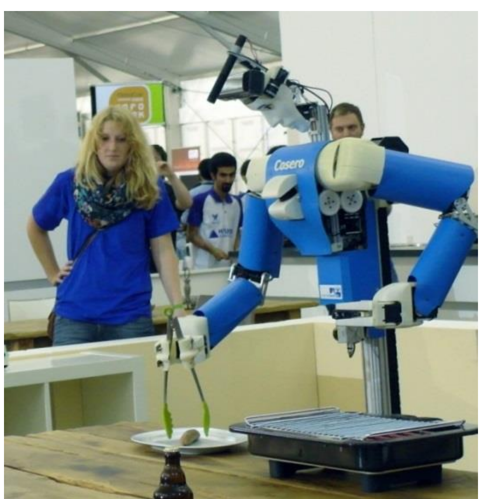






Würstchenzange, Tablett

- Wahrnehmung von Zangenspitze und Würstchen
- Anpassung an Hauptachse des Würstchens

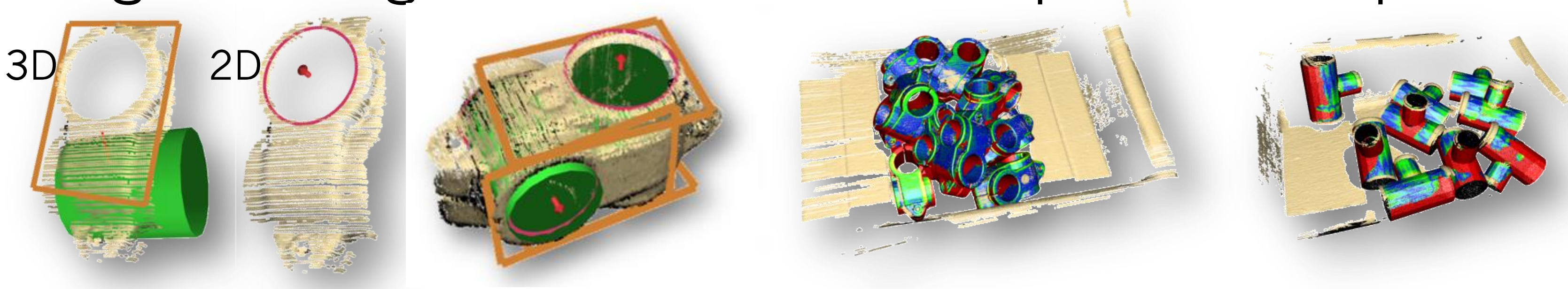


- Unser Team NimbRo hat drei Mal hintereinander die internationalen RoboCup@Home-Wettbewerbe gewonnen

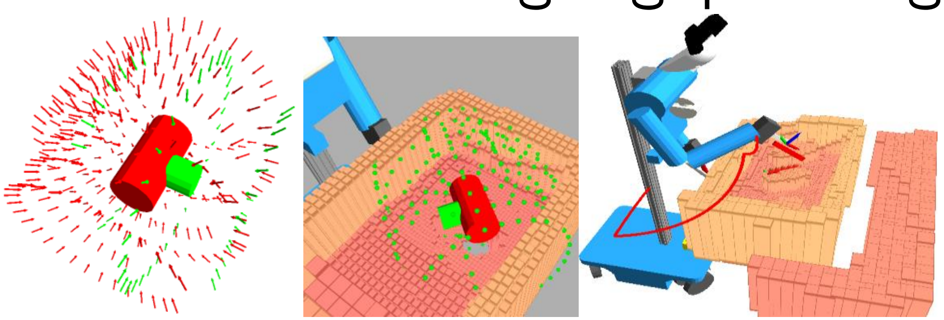
Griff in die Kiste

- Bekannte Objekte
  Kiste

- Registrierung von 2D und 3D Formprimitiv-Graphen



- Greif- und Bewegungsplanung

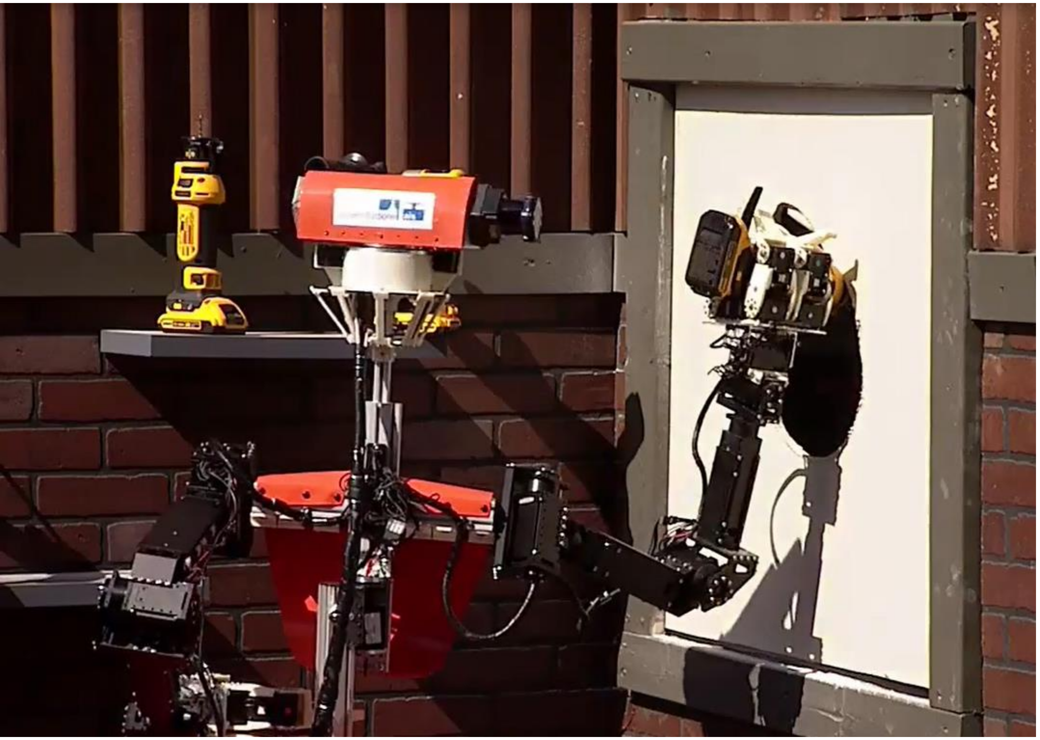


Offline Online

[Nieuwenhuisen et al.: ICRA 2013]

Rettungs- und Explorationsroboter

Mobiler Manipulationsroboter Momaro

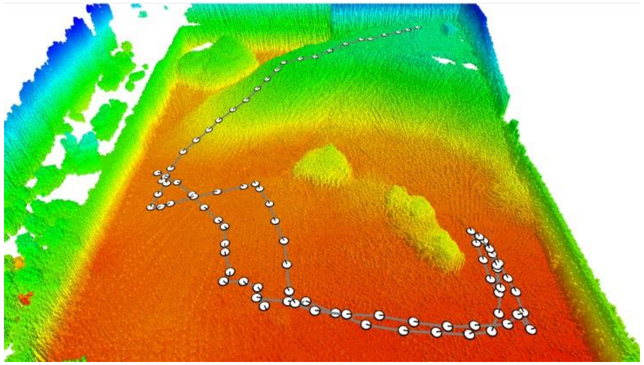


[Schwarz et al.: Frontiers in Robotics and AI 2016, JFR 2017]

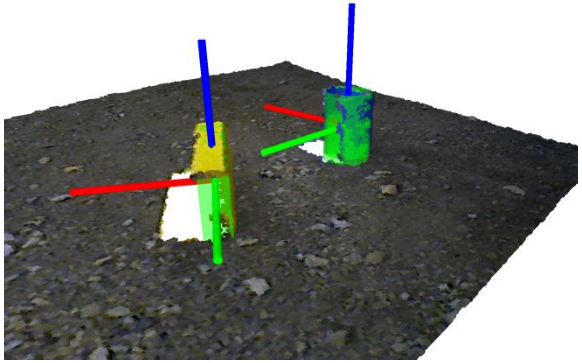
DLR SpaceBot Camp 2015

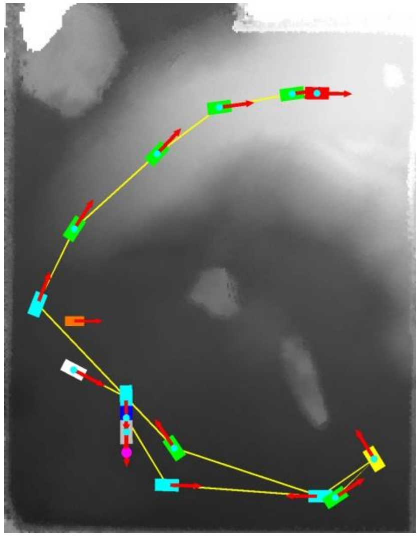
Autonome Missionsausführung

3D Mapping & Localization

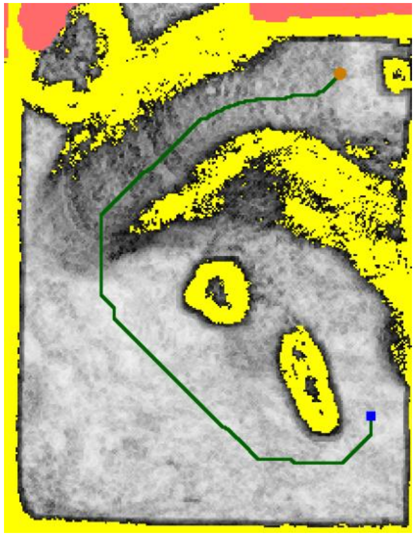


Object perception

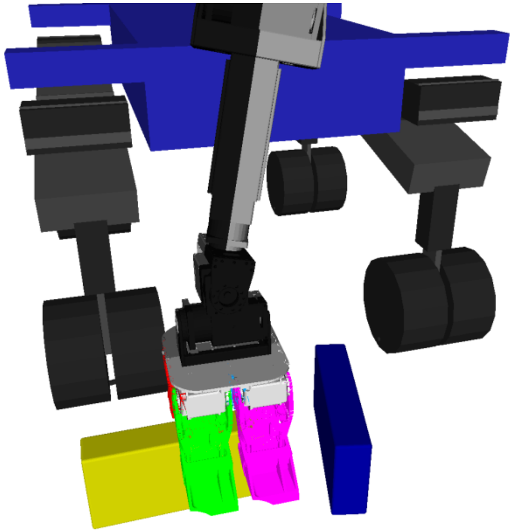




Mission plan



Navigation plan



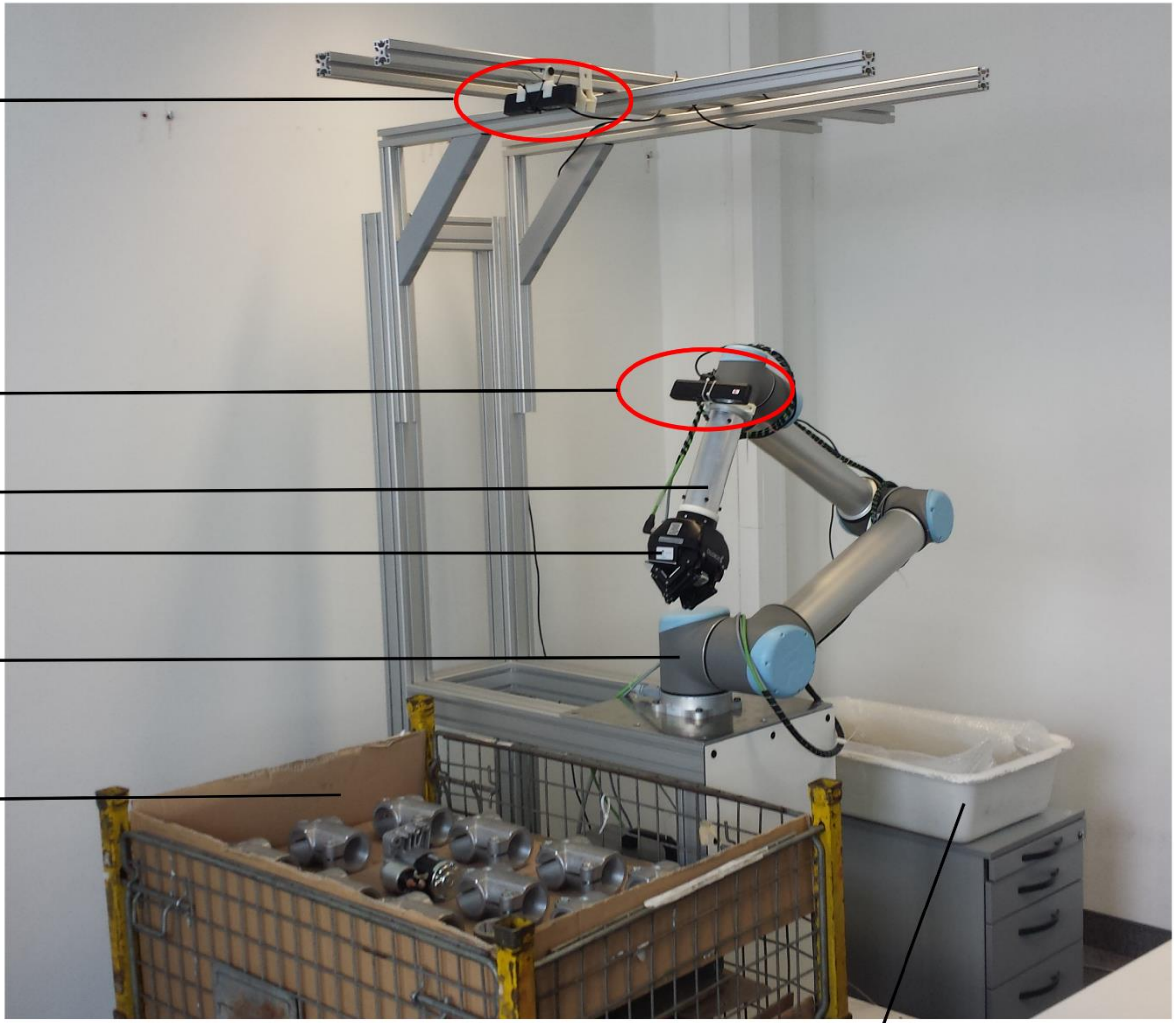
Grasping

[Schwarz et al., Frontiers in Robotics and AI 2016]

Kitting in Automobillogistik

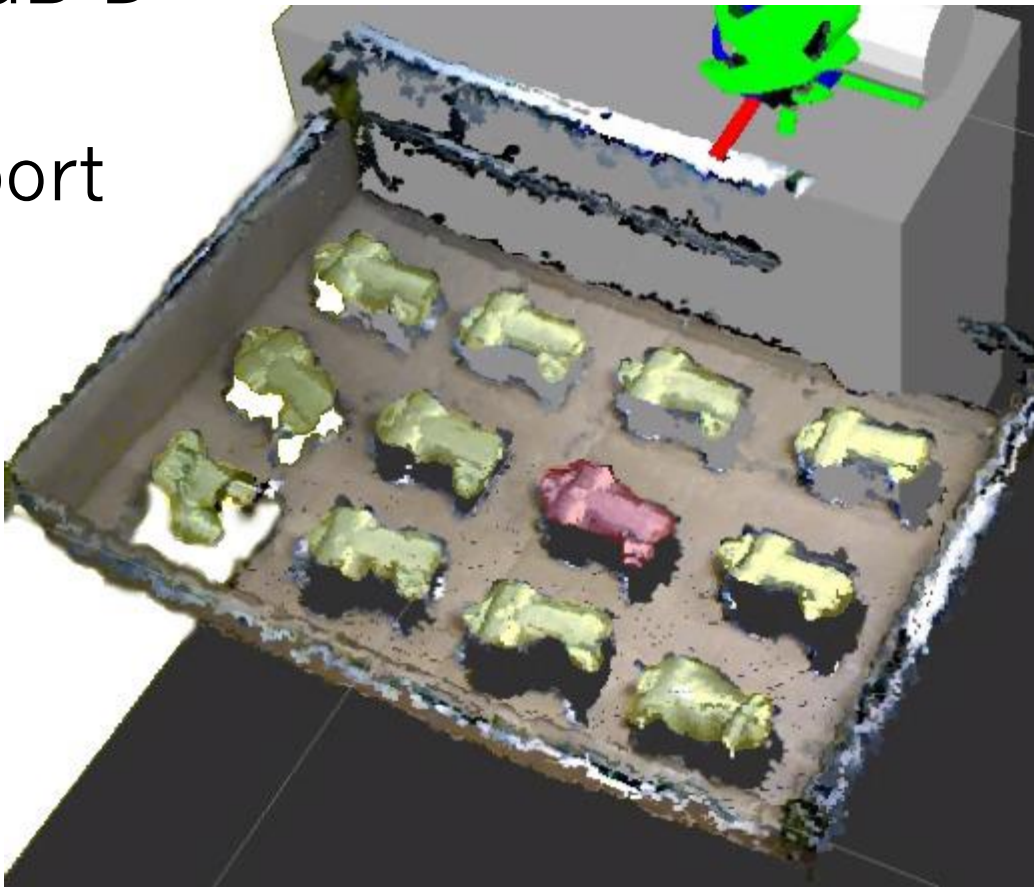
- Many car variants
- Collect the parts needed for the assembly of a particular car in a kit
- Parts in different variants are available in a supermarket
- Robot needs to
  - navigate to the transport boxes,
  - grasp the parts, and
  - place them in the kit

Labor-Demonstrator



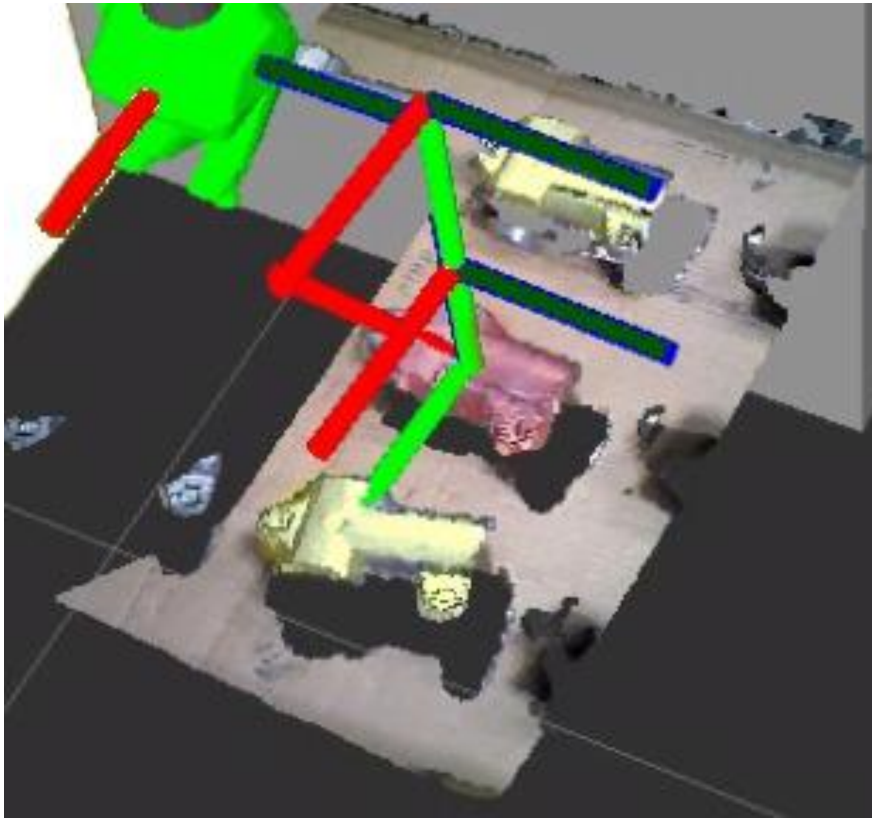
Detektion von Teilen

- Using work space RGB-D camera
- Initial pose of transport box roughly known
- Detect dominant horizontal plane above ground
- Cluster points above support plane
- Estimate main axes



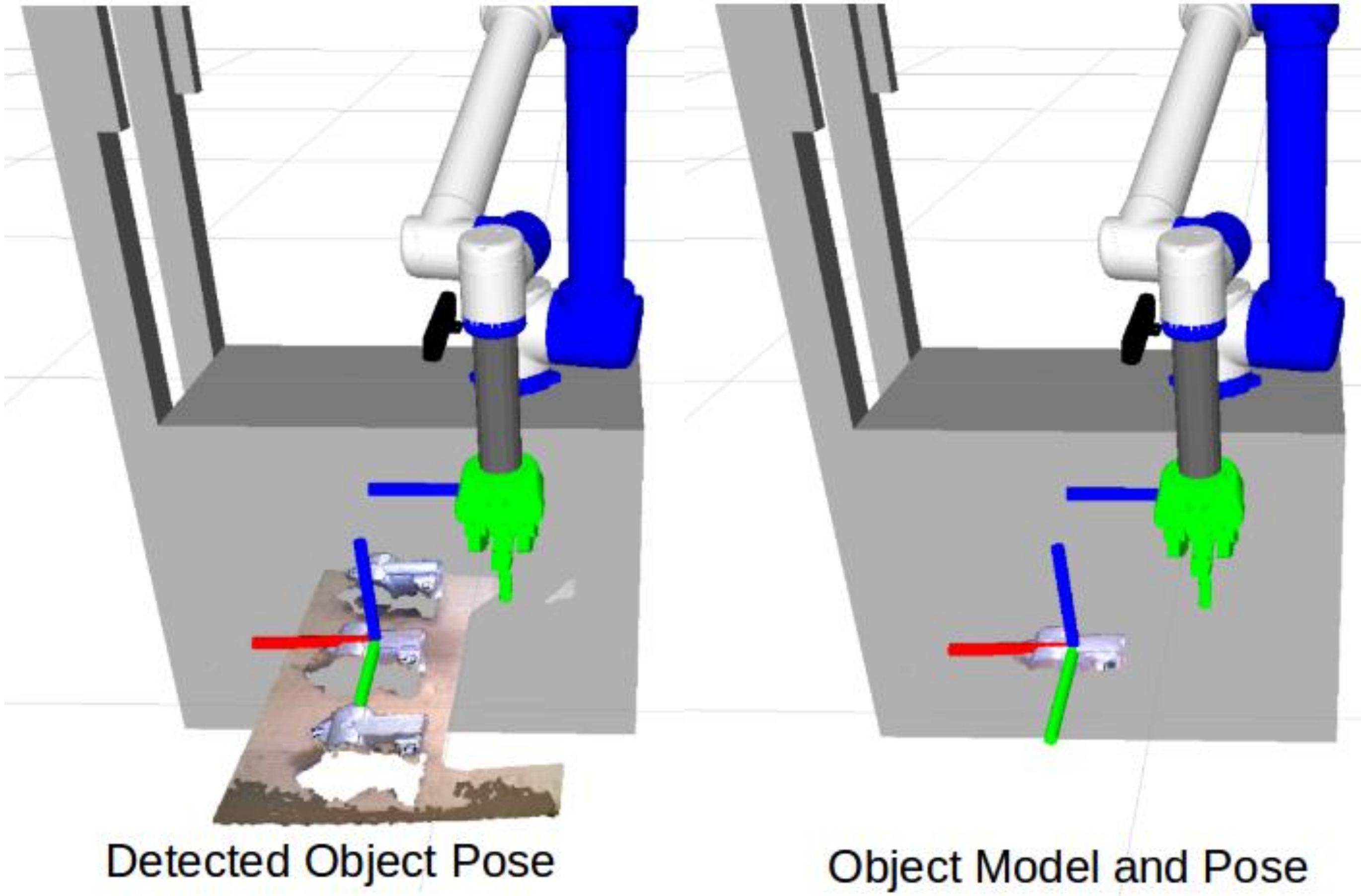
Schätzung der Objektpose

- Wrist RGB-D camera moved above innermost object candidate
- Object views are represented as Multiresolution Surfel Map
- Registration of object view with current measurements using soft assignments
- Verification based on registration quality



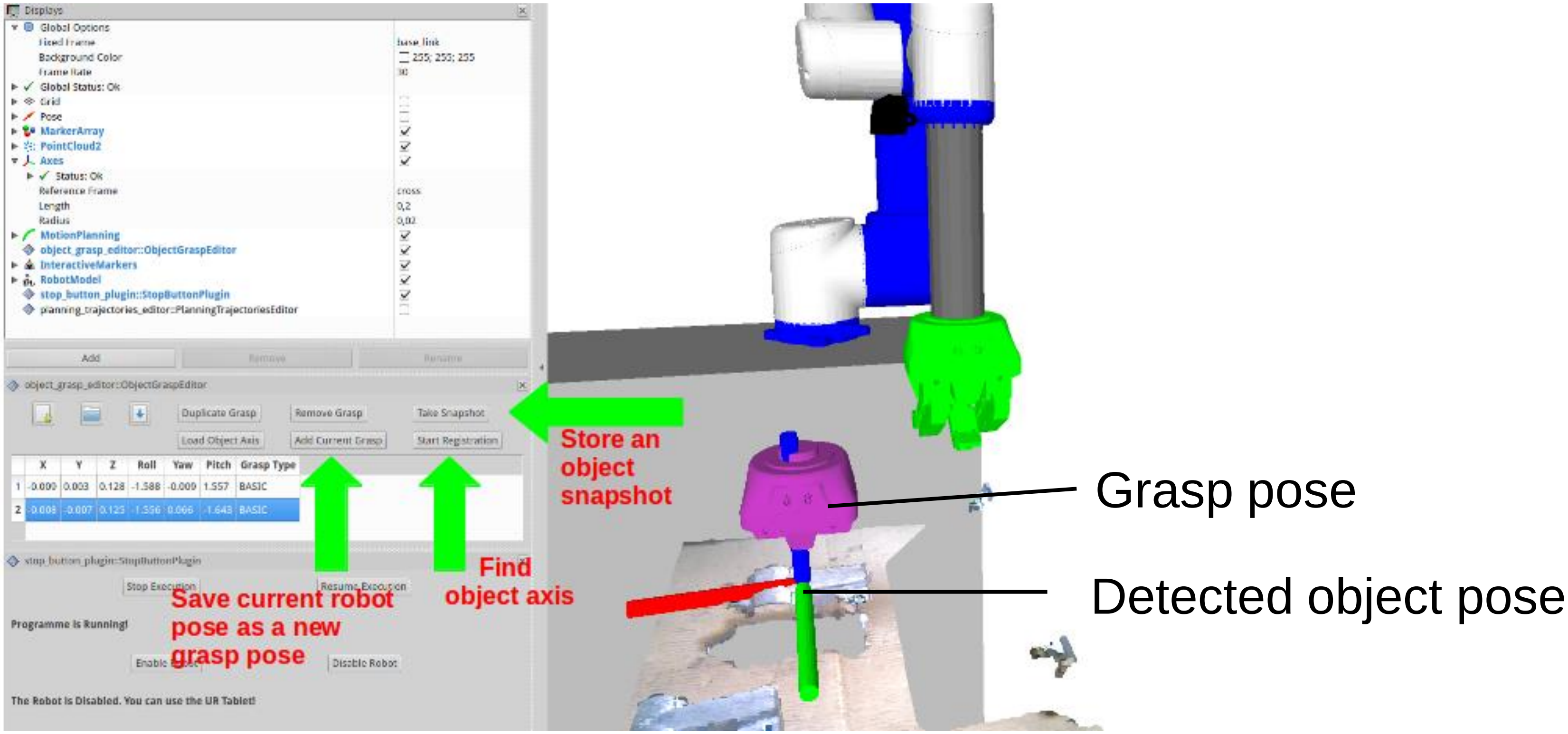
Registriertes Objektmodell

- Registration yields the object pose



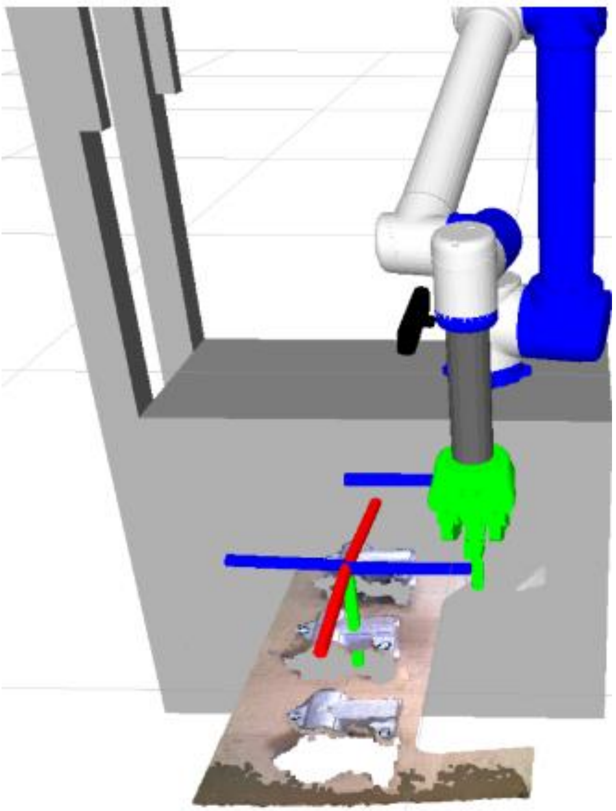
Definition von Griffen

- GUI for object model acquisition and grasp definition, relative to object model

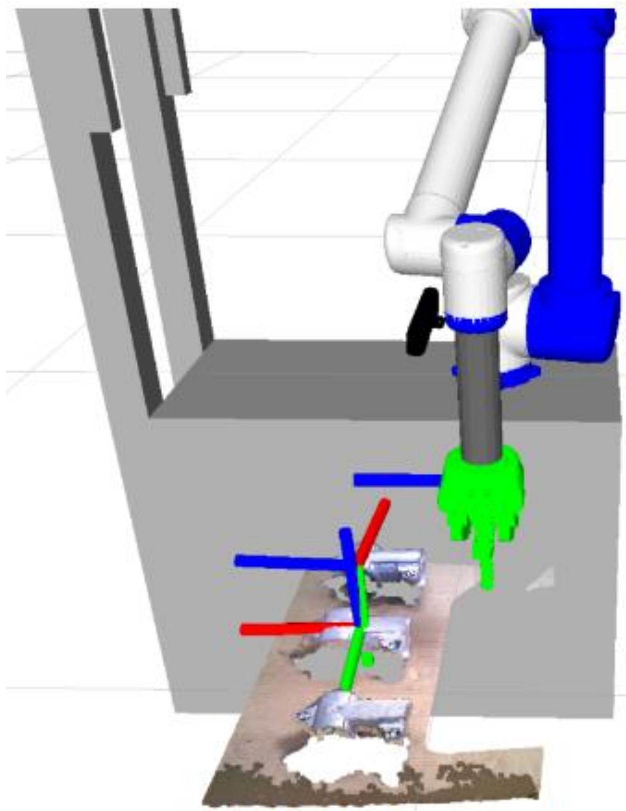


Griff-Auswahl

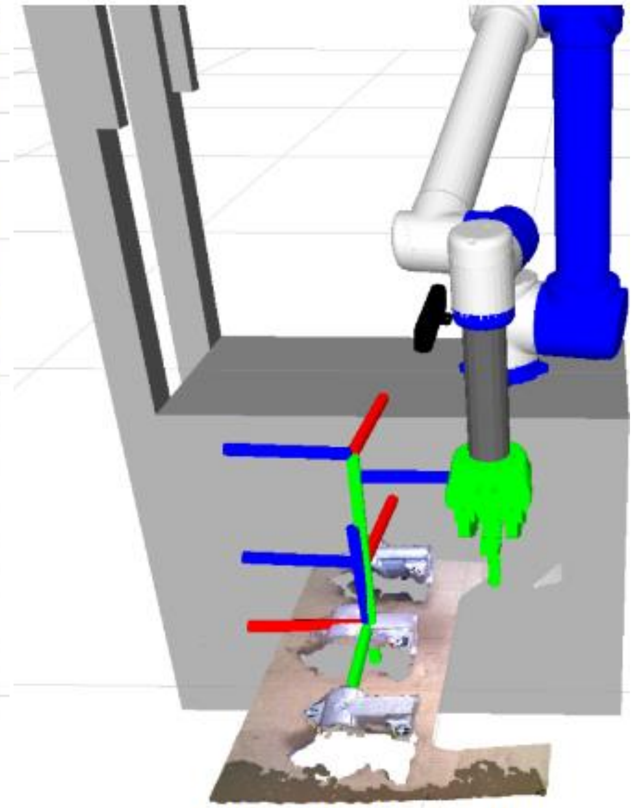
- Grasps are selected according to object pose



Grasp Candidates

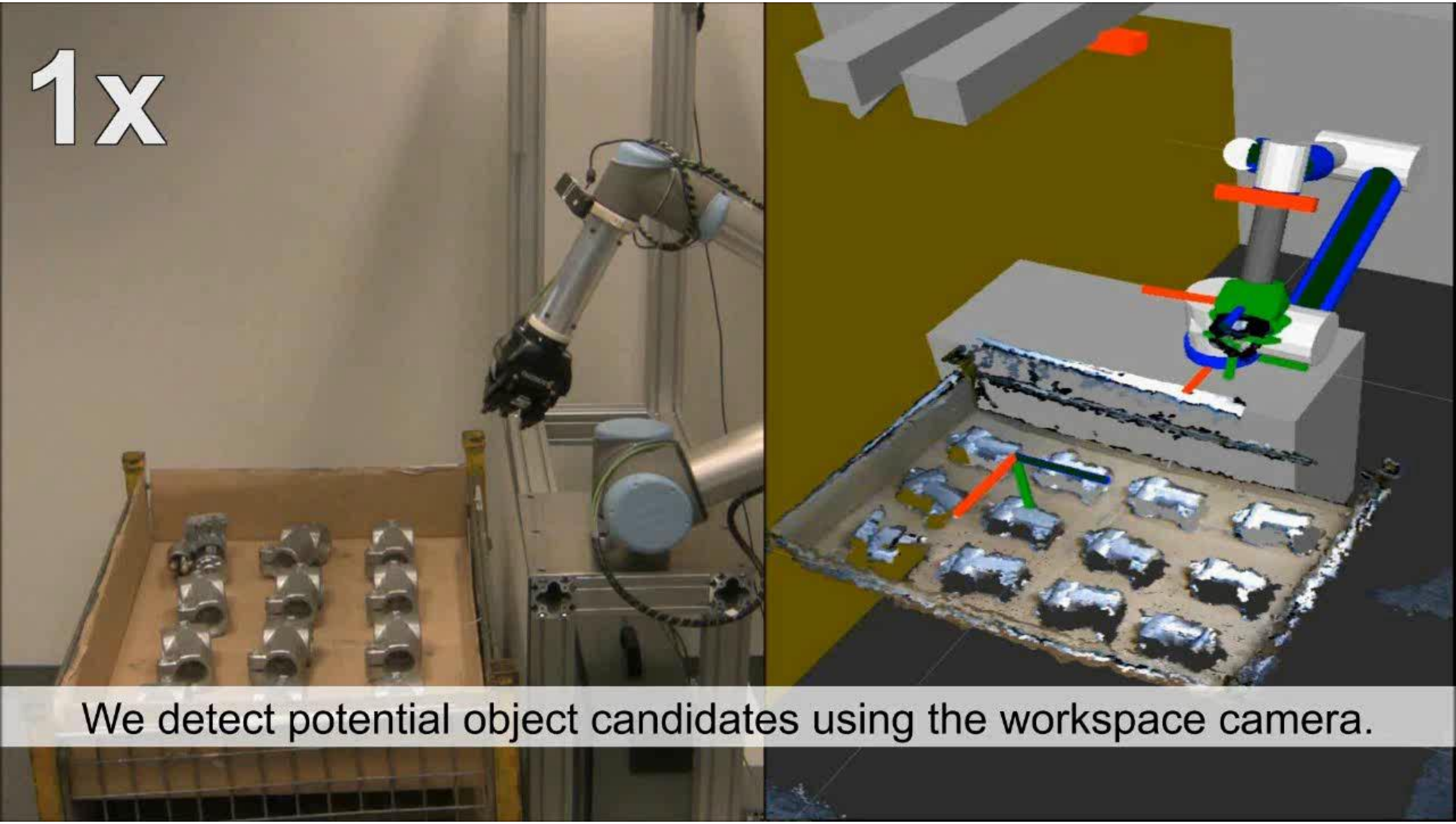


Selected Grasp and Object Pose



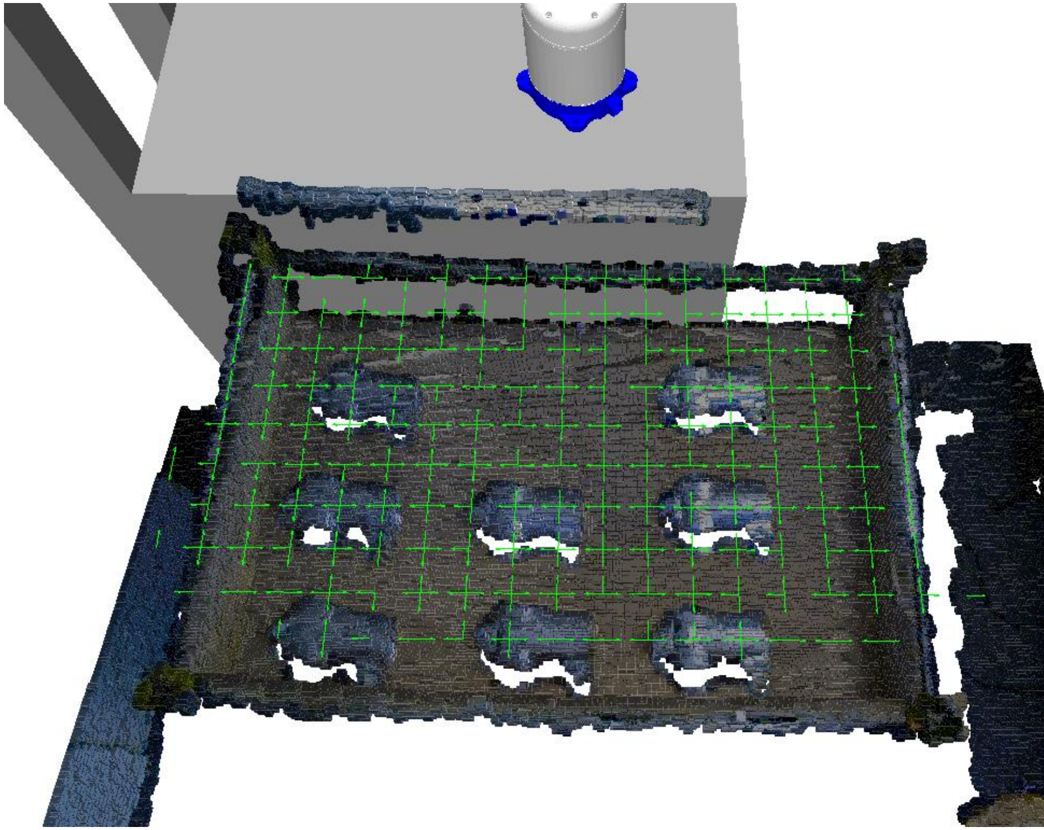
Pre-Grasp, Grasp and Object Pose

Depalettierung von Teilen



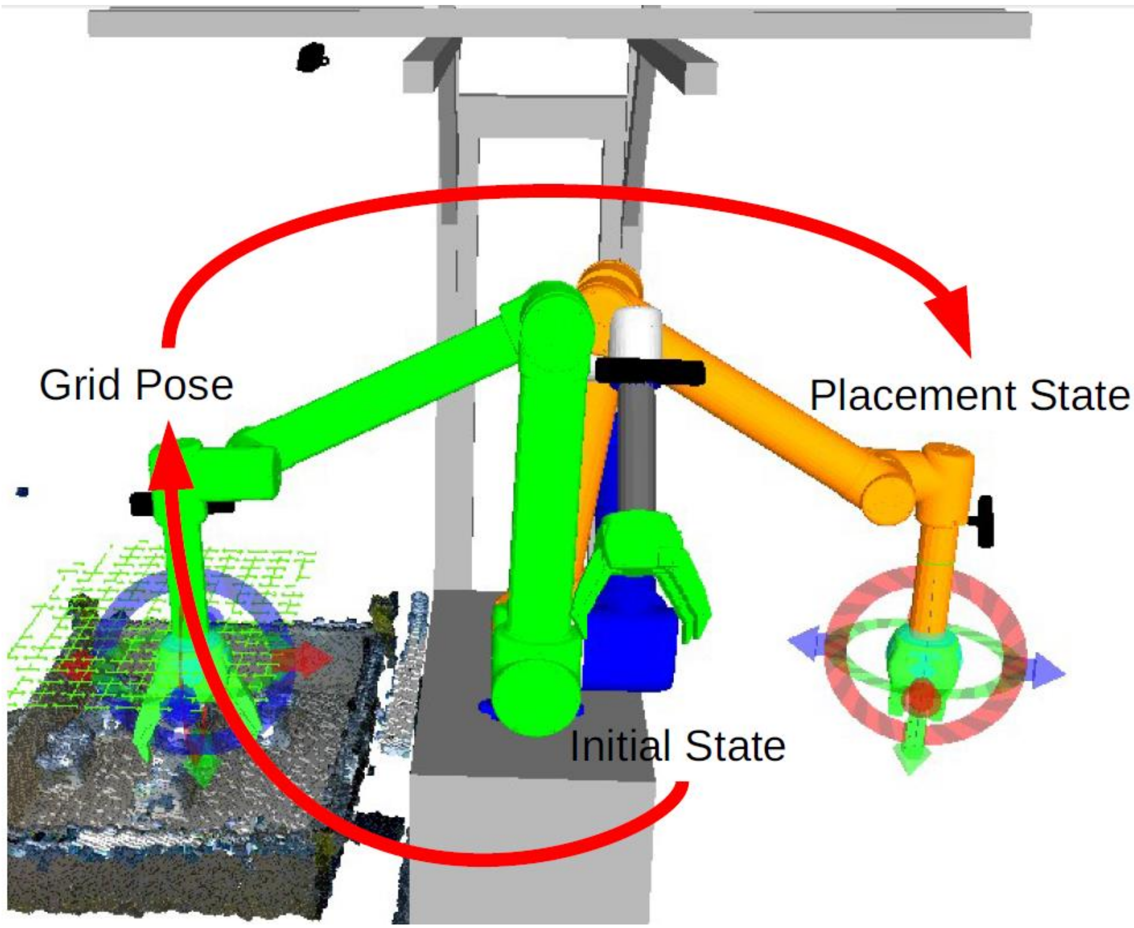
Bewegungsplanung

- Use ROS MoveIt for motion planning and execution
- Predefined poses (initial, placement) and grid of poses above the objects
- Preplanned paths
- Only short trajectories must be planned online



Verbindung von Bewegungssegmenten

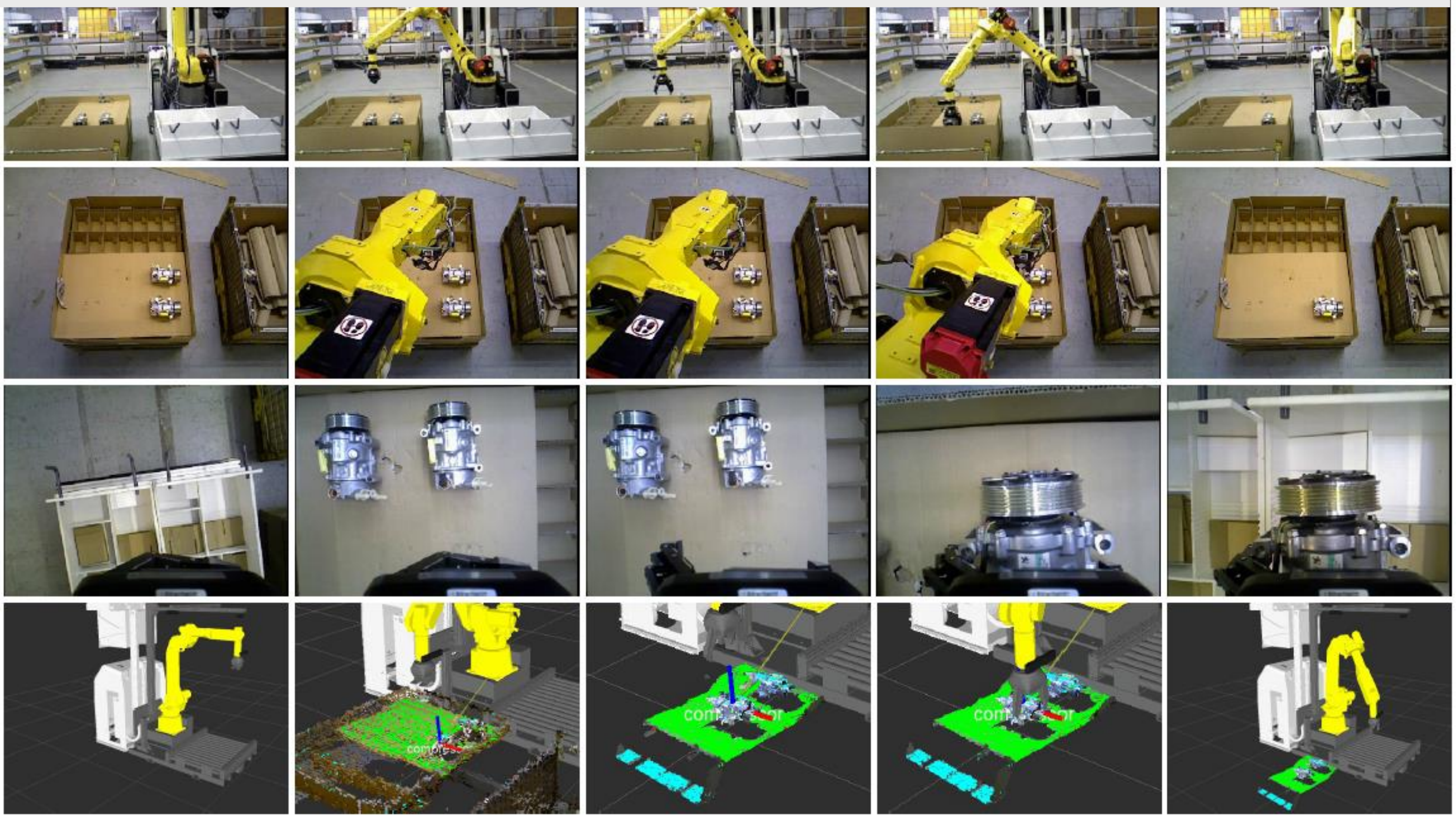
- Interpolation for smooth segment transitions



Depallettierung von Anlassern

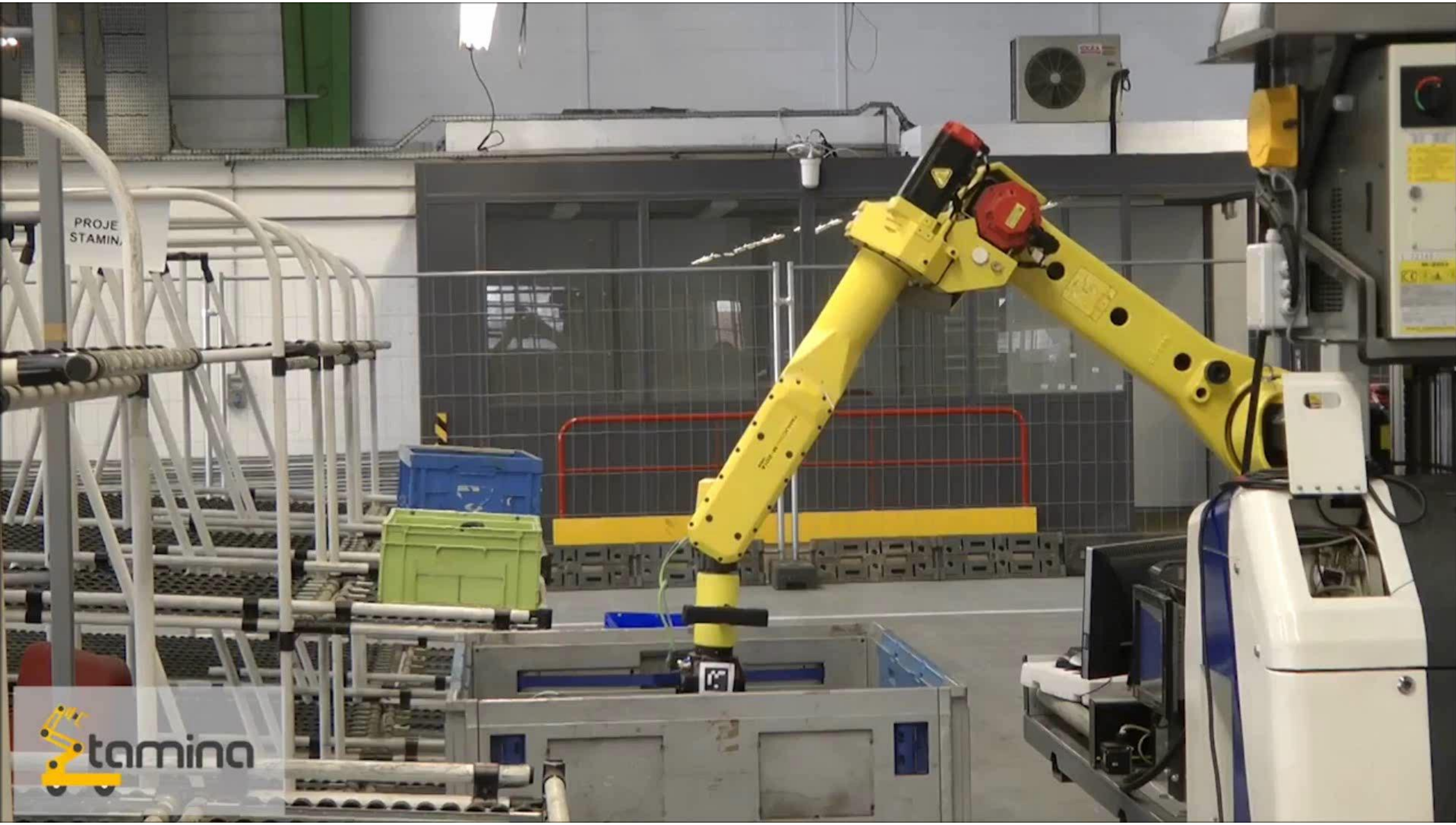
Mobiler Manipulationsroboter

Initialization	Part detection	Approach	Grasping	Placing



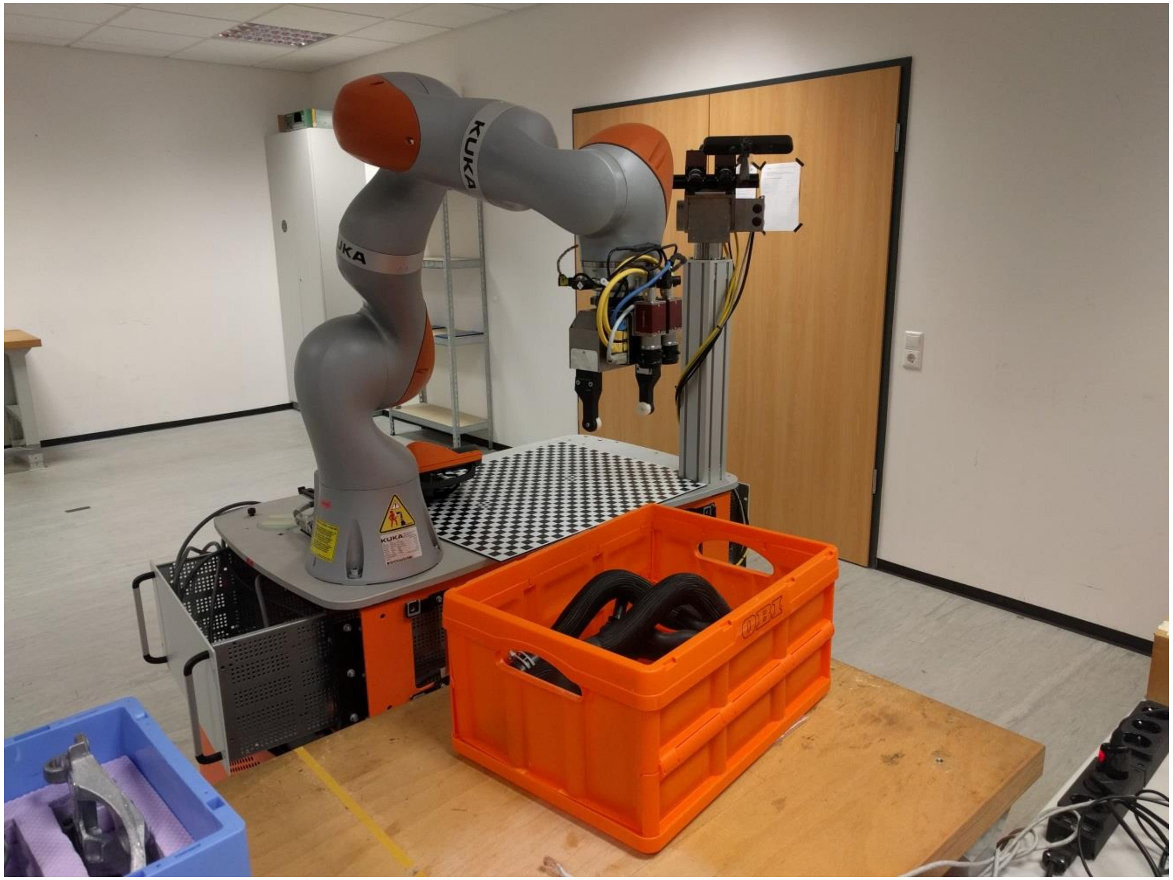
[Holz et al., ETFA 2015]

STAMINA-Abschlussdemonstration



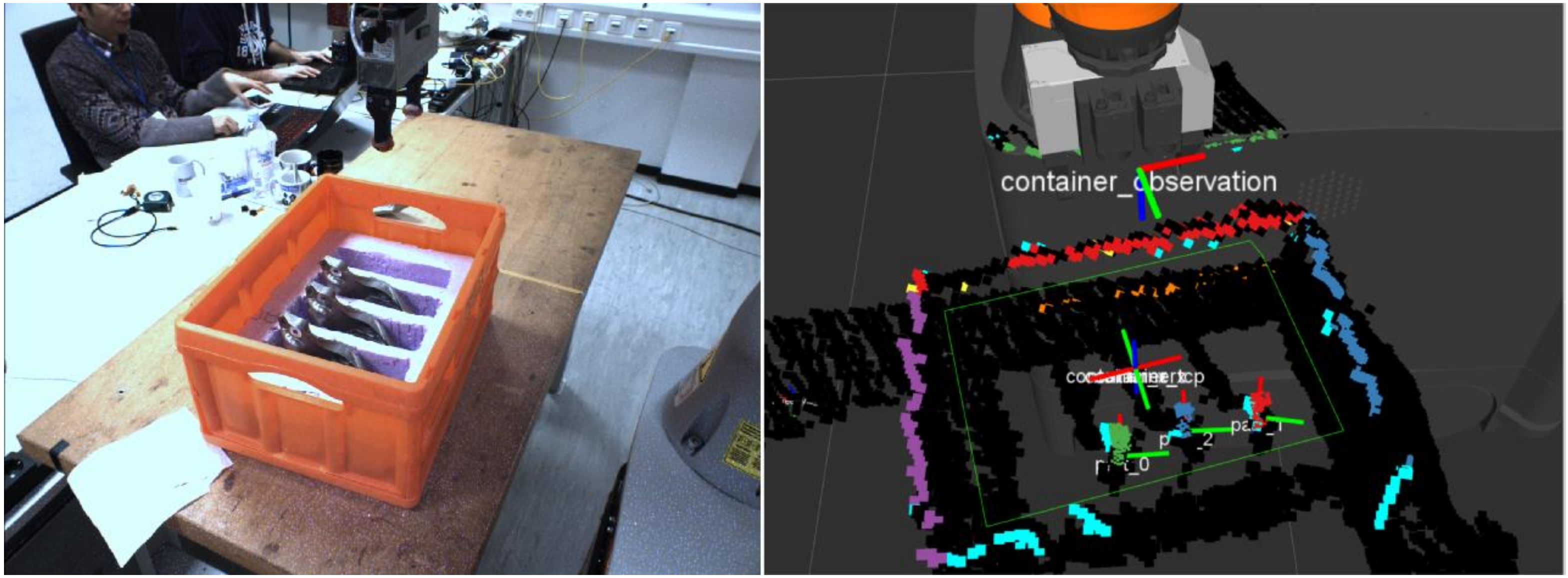
EuRoC Challenge 2: KittingBot

- Kleinerer Roboter: Kuka miiwa
- Zusammenarbeit mit Menschen



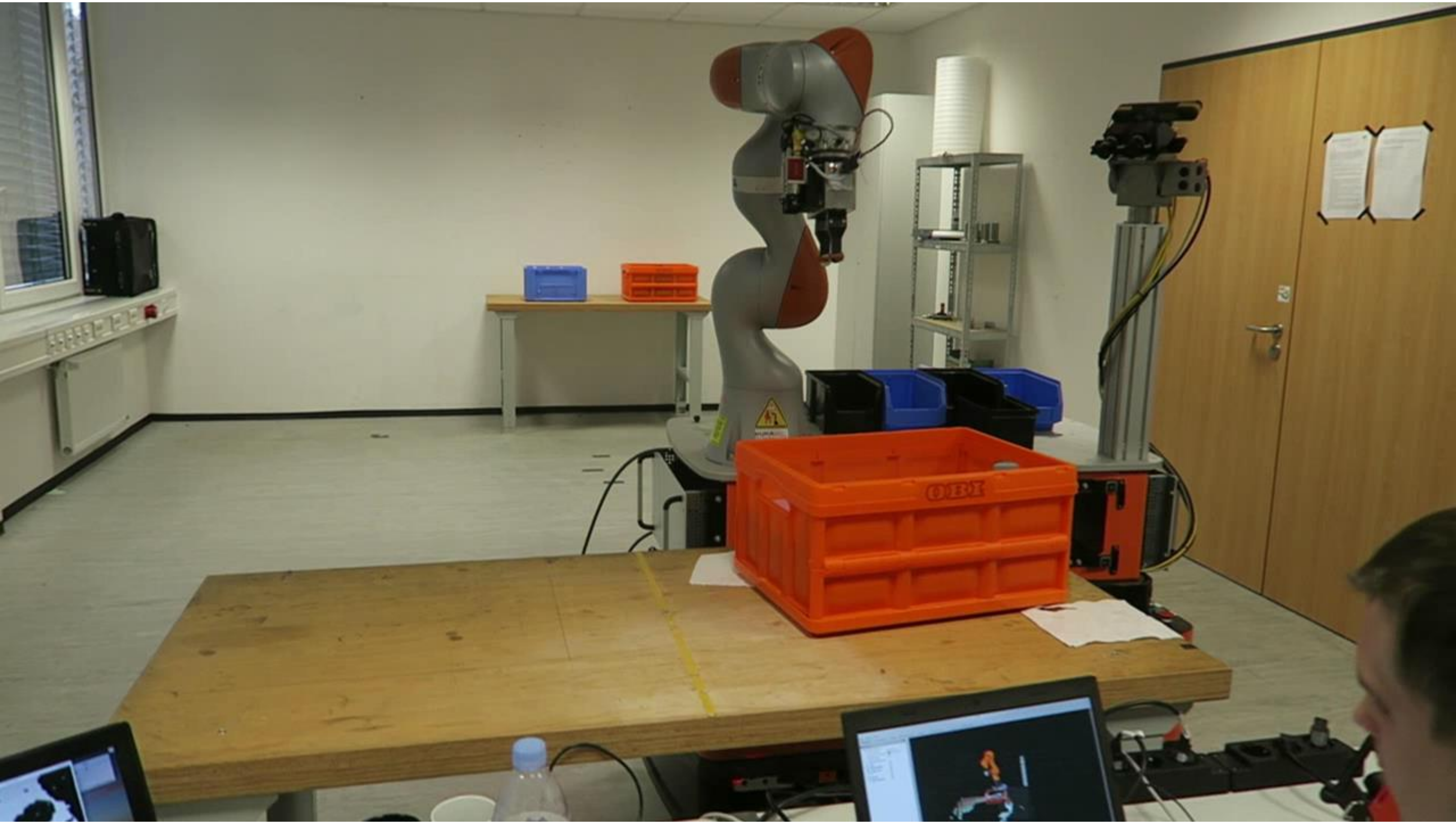
Detektion der Kiste und Posenschätzung

- Detektion von Kanten im Tiefenbild
- Gruppierung zu Linien
- Posenschätzung für oberen Kistenrand



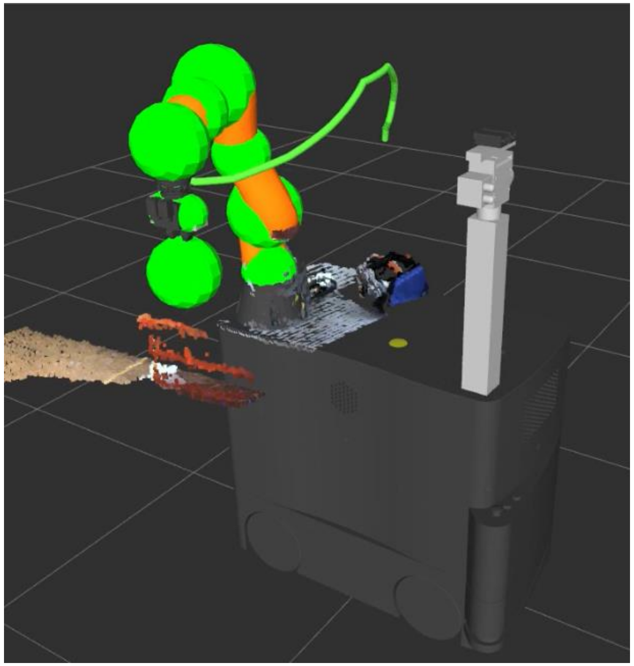
[Holz und Behnke: ISR 2016]

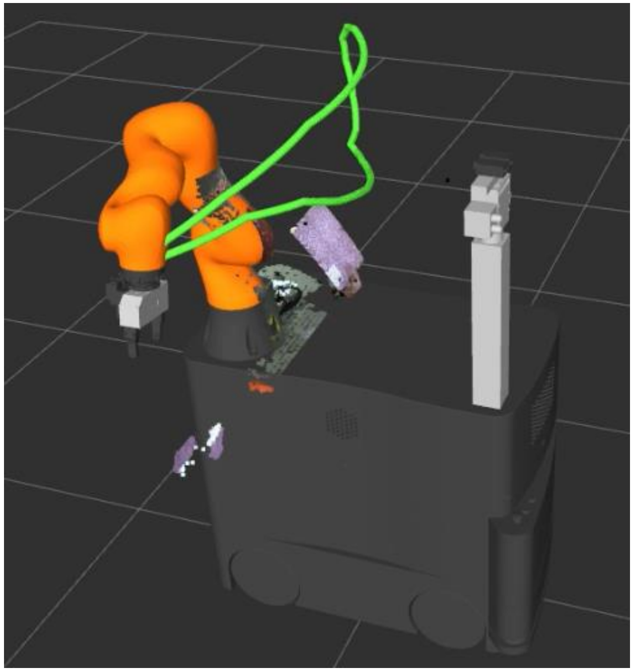
KittingBot Showcase-Demonstration



Online-Trajektorienoptimierung

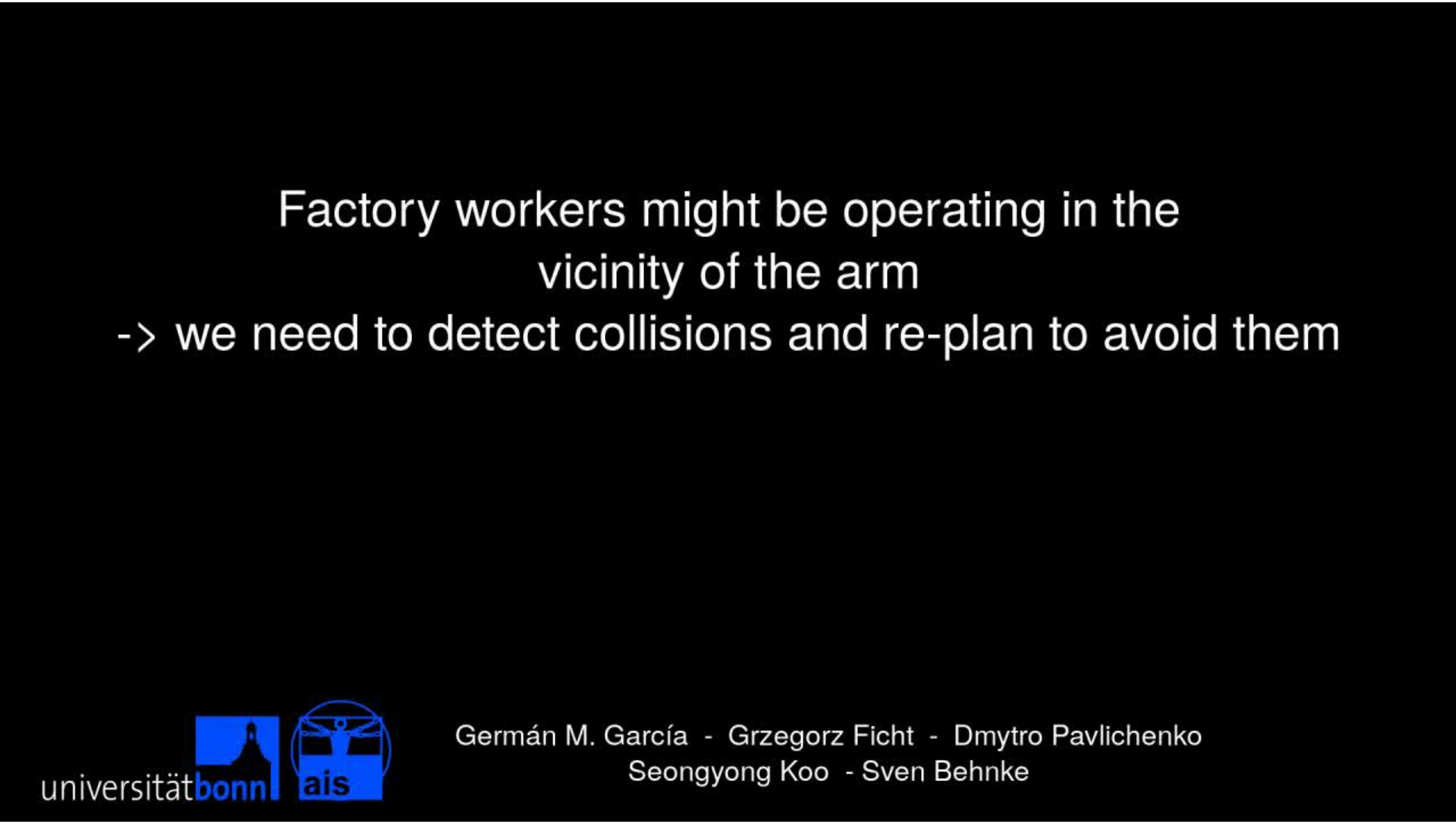
- Kombination mehrerer Ziele
  - Hindernisvermeidung
  - Ausführungsdauer
  - Drehmomente



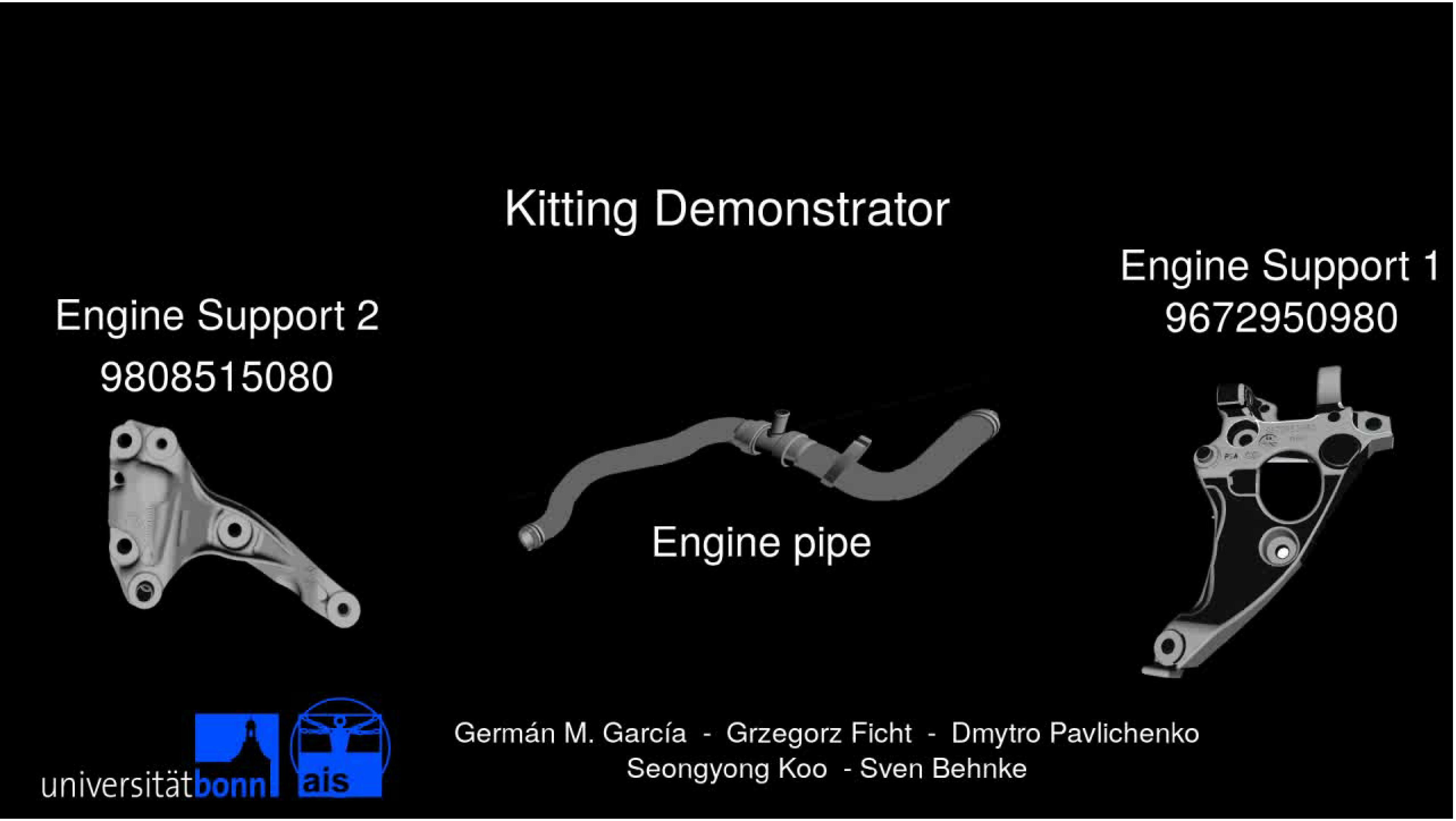


[Pavlichenko and Behnke: IROS 2017]

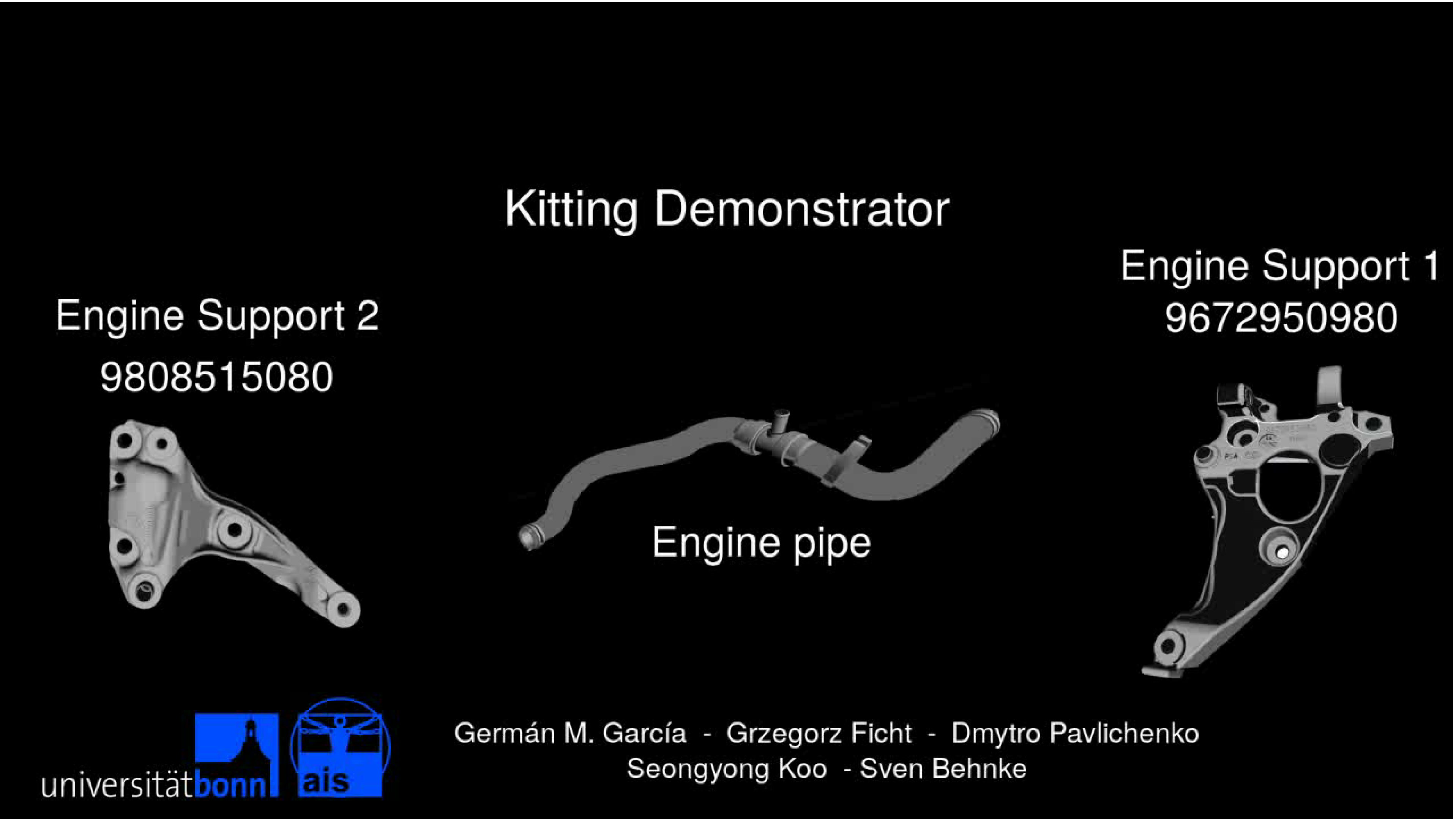
KittingBot: Hindernisvermeidung



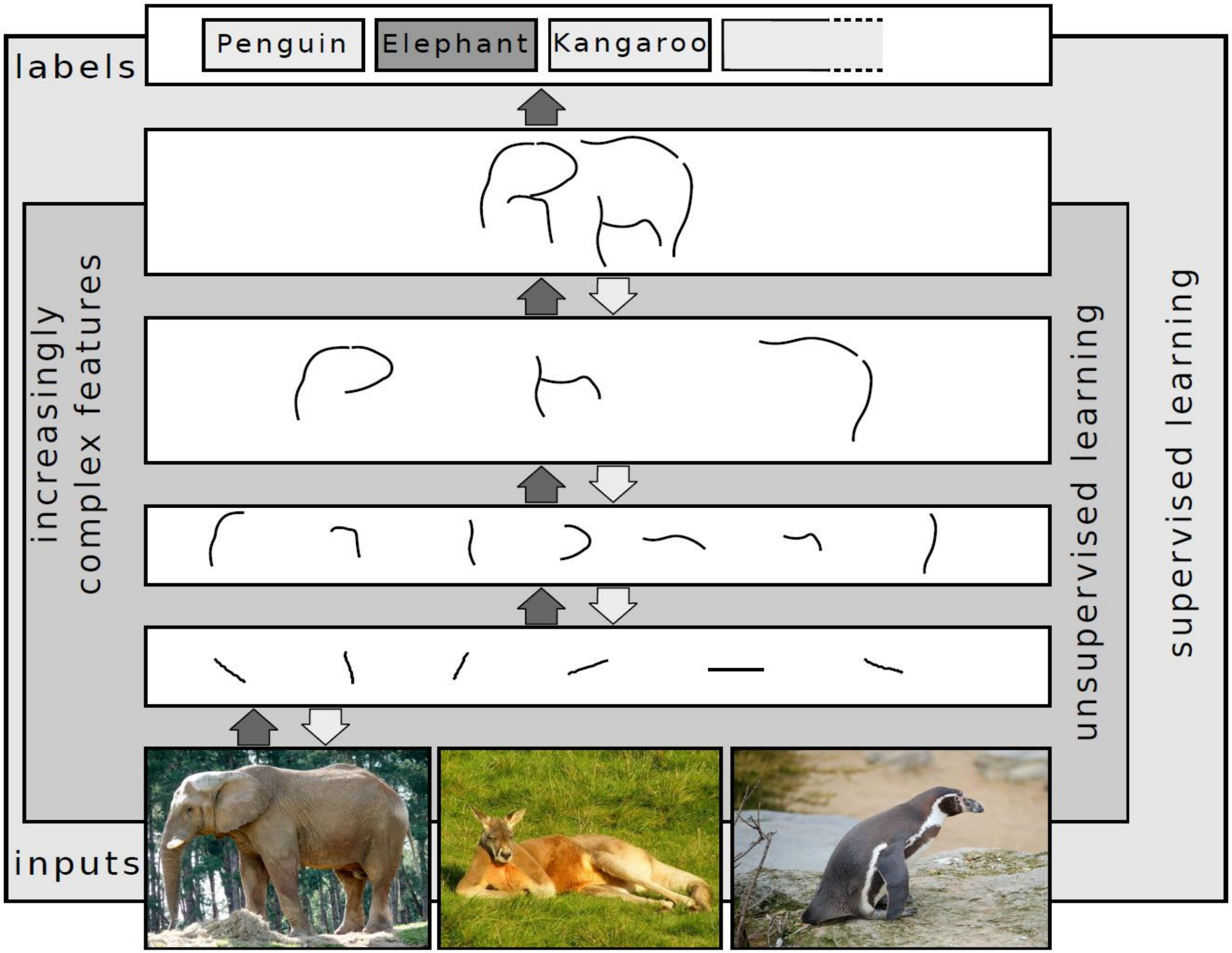
KittingBot Showcase-Demonstration



KittingBot Showcase-Demonstration



Deep Learning



[Schulz and Behnke, KI 2012]

Objektkategorisierung: Besser als Menschen

GT: horse cart
1: horse cart
2: minibus
3: oxcart
4: stretcher
5: half track

GT: birdhouse
1: birdhouse
2: sliding door
3: window screen
4: mailbox
5: pot

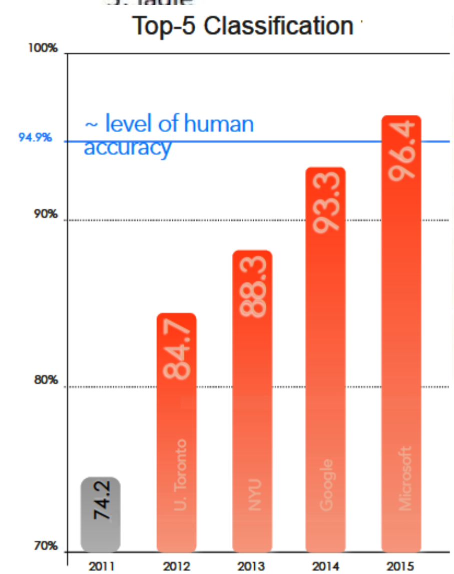
GT: forklift
1: forklift
2: garbage truck
3: tow truck
4: trailer truck
5: go-kart

GT: letter opener
1: drumstick
2: candle
3: wooden spoon
4: spatula
5: ladle

GT: coucal
1: coucal
2: indigo bunting
3: lorikeet
4: walking stick
5: custard apple

GT: komondor
1: komondor
2: patio
3: llama
4: mobile home
5: Old English sheepdog

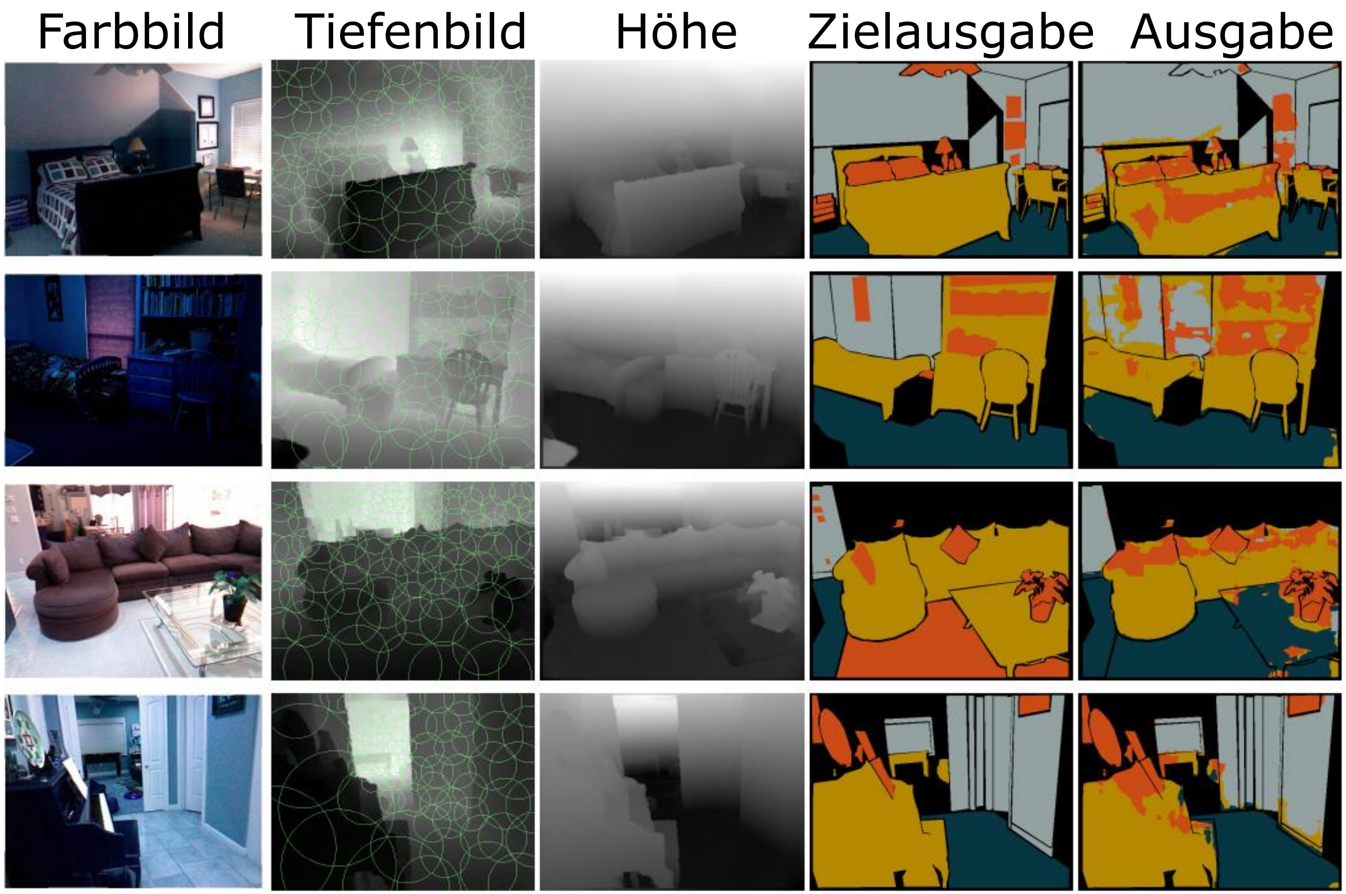
GT: yellow lady's slipper
1: yellow lady's slipper
2: slug
3: hen-of-the-woods
4: stinkhorn
5: coral fungus



[He et al. 2015]

Kategorisierung von Oberflächen

- RGB-D-Eingaben, Höhe über Boden geschätzt
- Skalierung der Eingabe mit der Tiefe

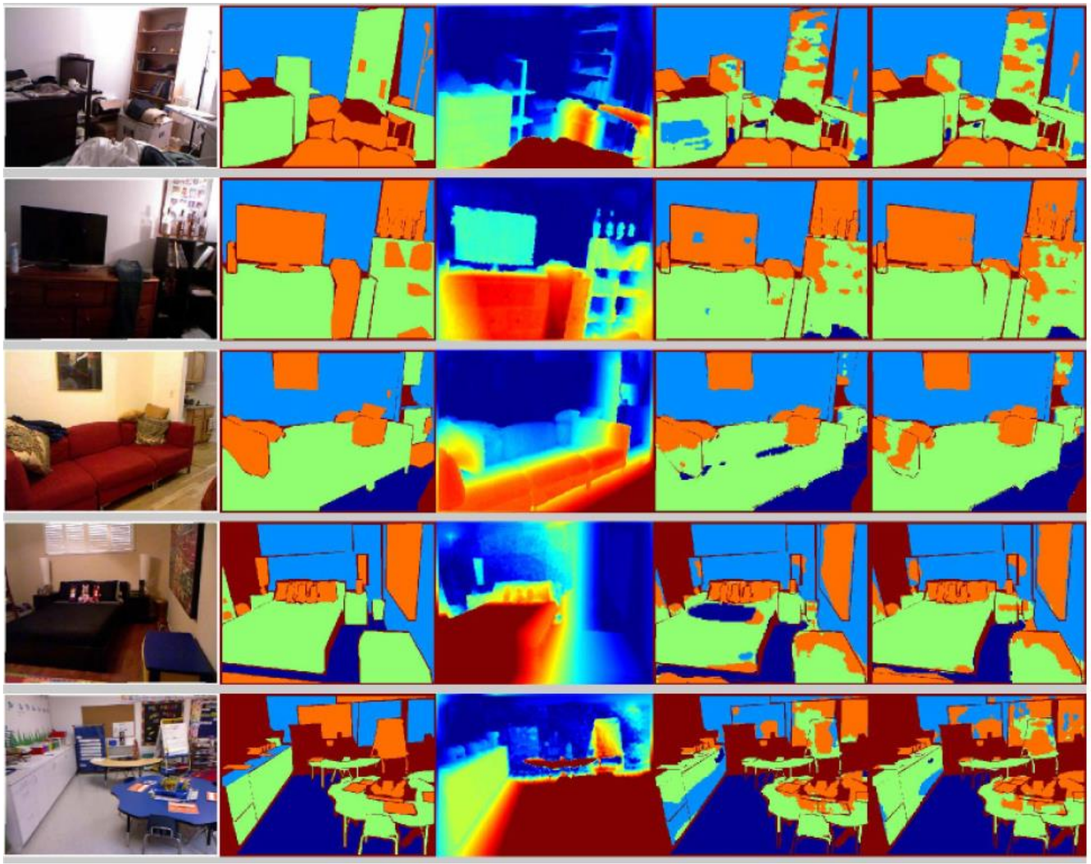


[Schulz, Höft, Behnke, ESANN 2015]

Geometrische und Semantische Merkmale für RGB-D Objektklassensegmentierung

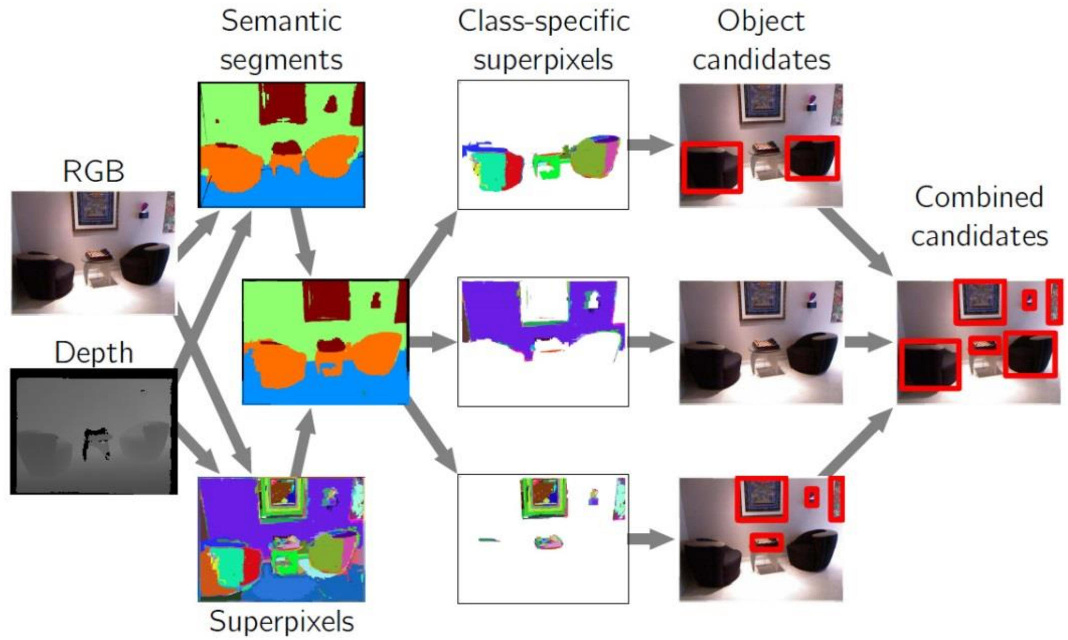
- Neues **geometrisches** Merkmal: Wandabstand
- **Semantische** Merkmale vortrainiert aus ImageNet
- Beide helfen signifikant

[Husain et al. RA-L 2016]



Semantische Segmentierung als Prior für Objektdetektion

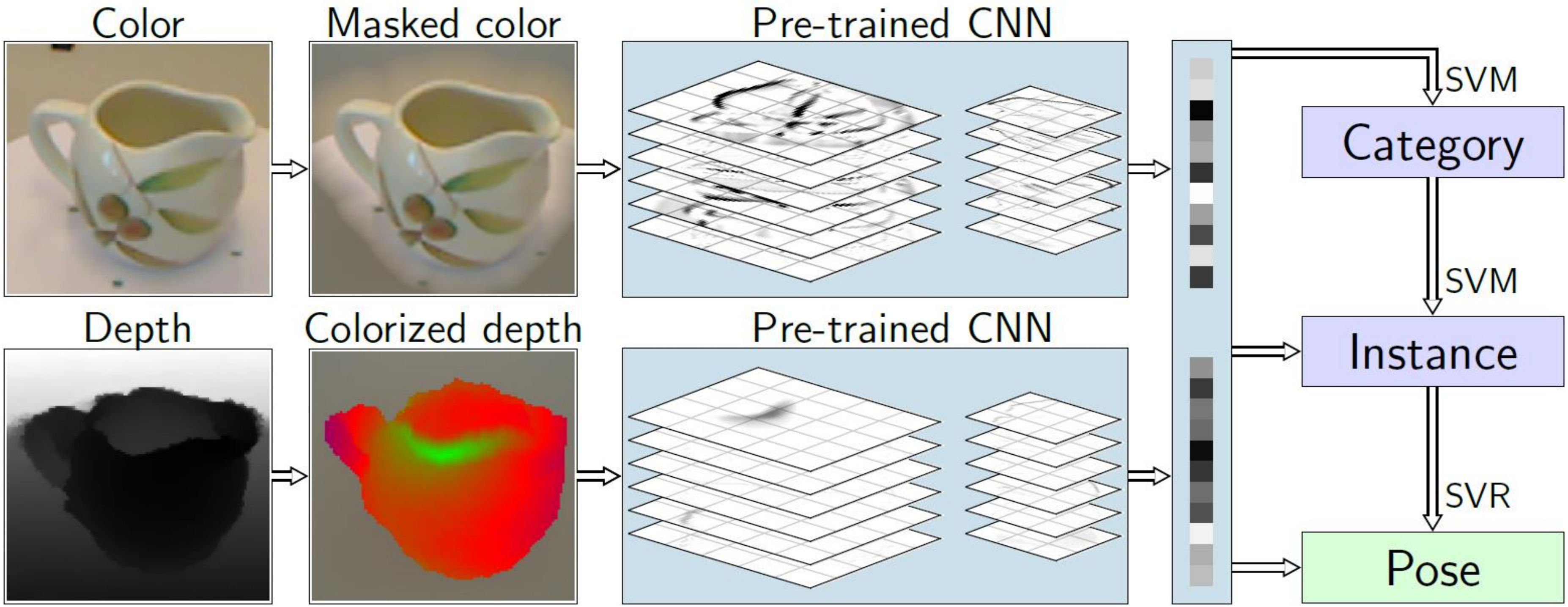
- Combine bottom-up object discovery and semantic priors
- Semantic segmentation used to classify color and depth superpixels
- Higher recall, more precise object borders



[Garcia et al. ICPR 2016]

RGB-D Objekterkennung und Posenschätzung

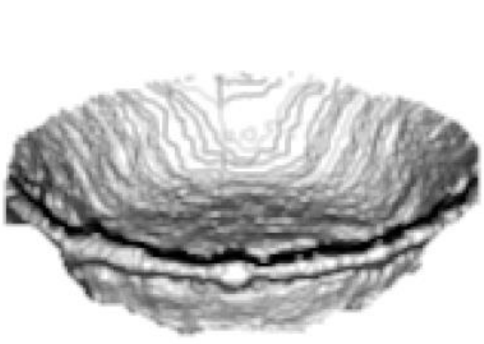
- Vortrainierte Merkmale von ImageNet

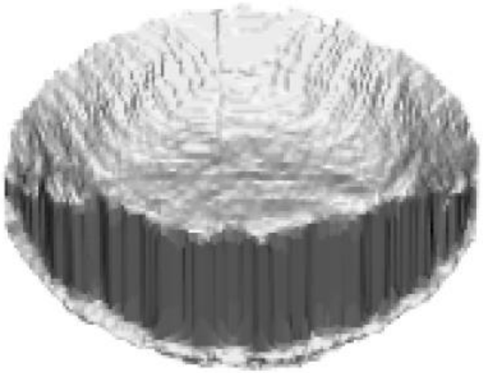


[Schwarz, Schulz, Behnke, ICRA2015]

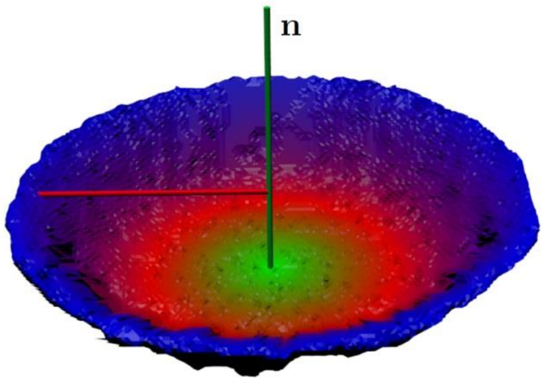
Kanonische Ansicht, Einfärbung

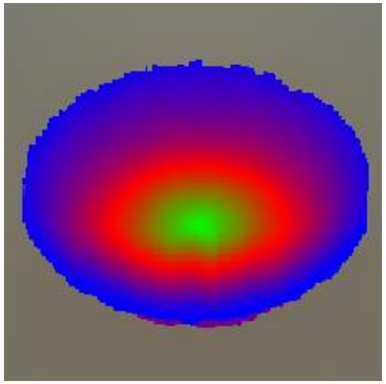
- Objektansichten aus verschie-denen Höhen
- Rendern einer kanonischen Ansicht





- Einfärbung anhand Distanz von Mittelachse

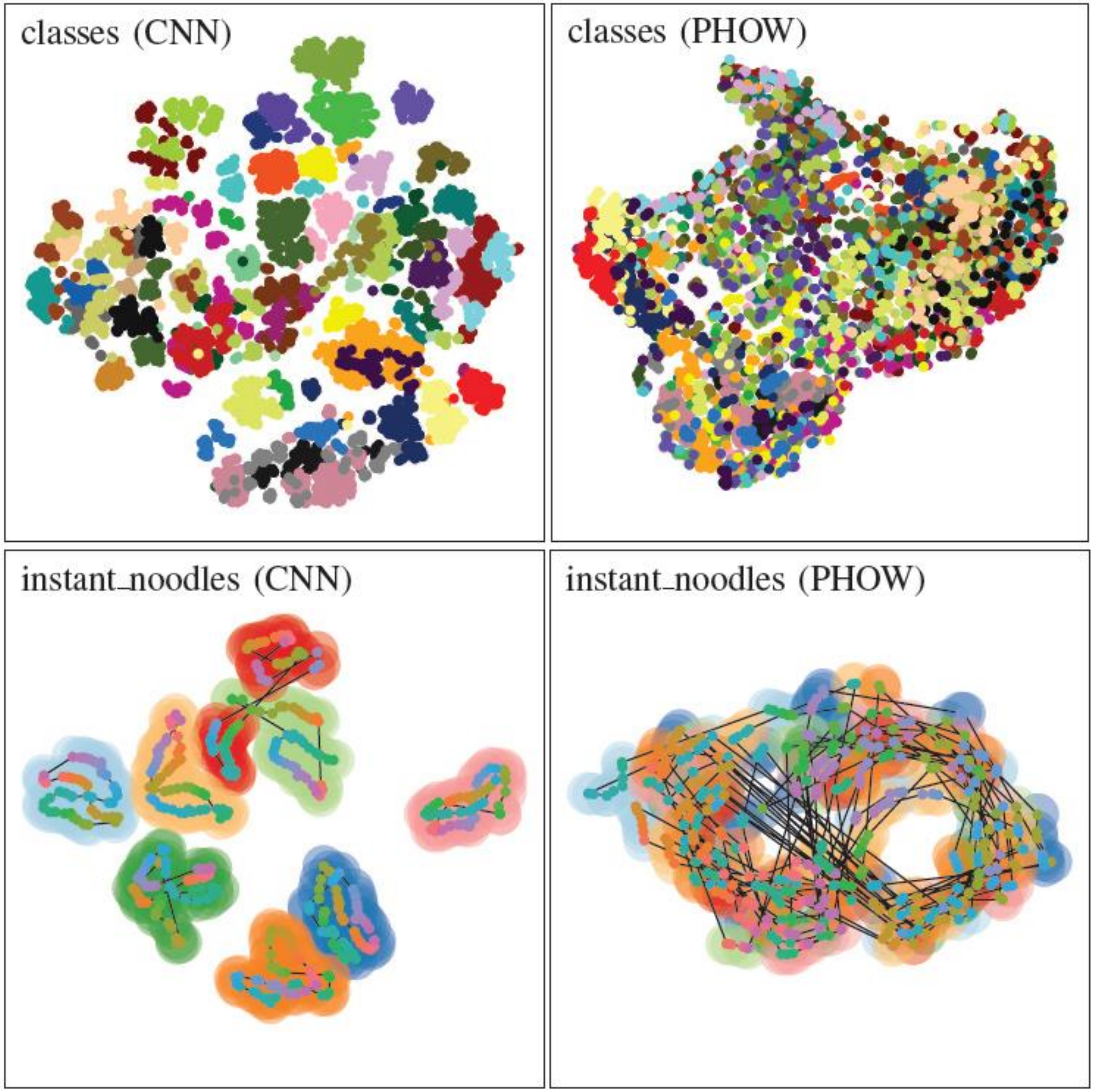




[Schwarz, Schulz, Behnke, ICRA2015]

Merkmale Entwirren die Daten

- t-SNE Einbettung



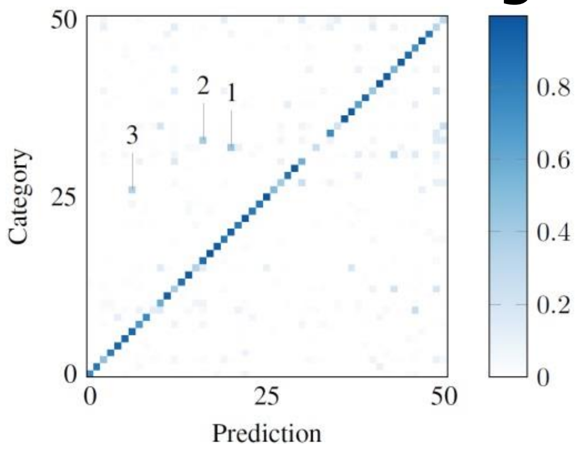
[Schwarz, Schulz, Behnke, ICRA2015]

Erkennungsrate

- Verbesserte Kategorie- und Instanzerkennung

Method	Category Accuracy (%) RGB	Category Accuracy (%) RGB-D	Instance Accuracy (%) RGB	Instance Accuracy (%) RGB-D
Lai *et al.* [1]	74.3 ± 3.3	81.9 ± 2.8	59.3	73.9
Bo *et al.* [2]	82.4 ± 3.1	87.5 ± 2.9	**92.1**	92.8
PHOW[3]	80.2 ± 1.8	—	62.8	—
Ours	$\mathbf{83.1 \pm 2.0}$	88.3 ± 1.5	92.0	**94.1**
Ours	$\mathbf{83.1 \pm 2.0}$	$\mathbf{89.4 \pm 1.3}$	92.0	**94.1**

- Verwechslungen

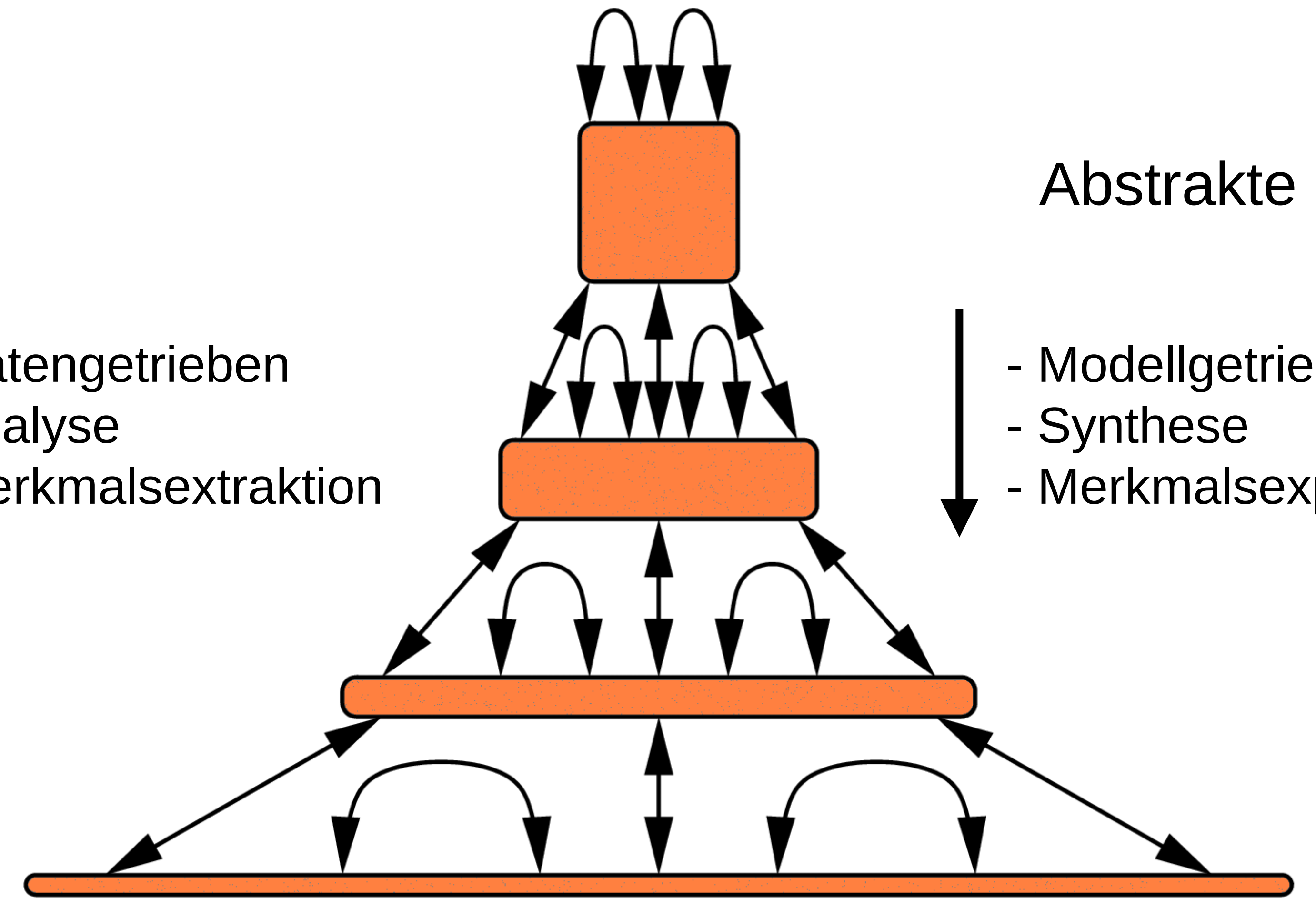


1: Kännchen / Kaffetasse

2: Pfirsich / Schwamm

[Schwarz, Schulz, Behnke, ICRA2015]

Neurale Abstraktionspyramide



Abstrakte Merkmale

- Datengetrieben
- Analyse
- Merkmalsextraktion

- Modellgetrieben
- Synthese
- Merkmalsexpansion

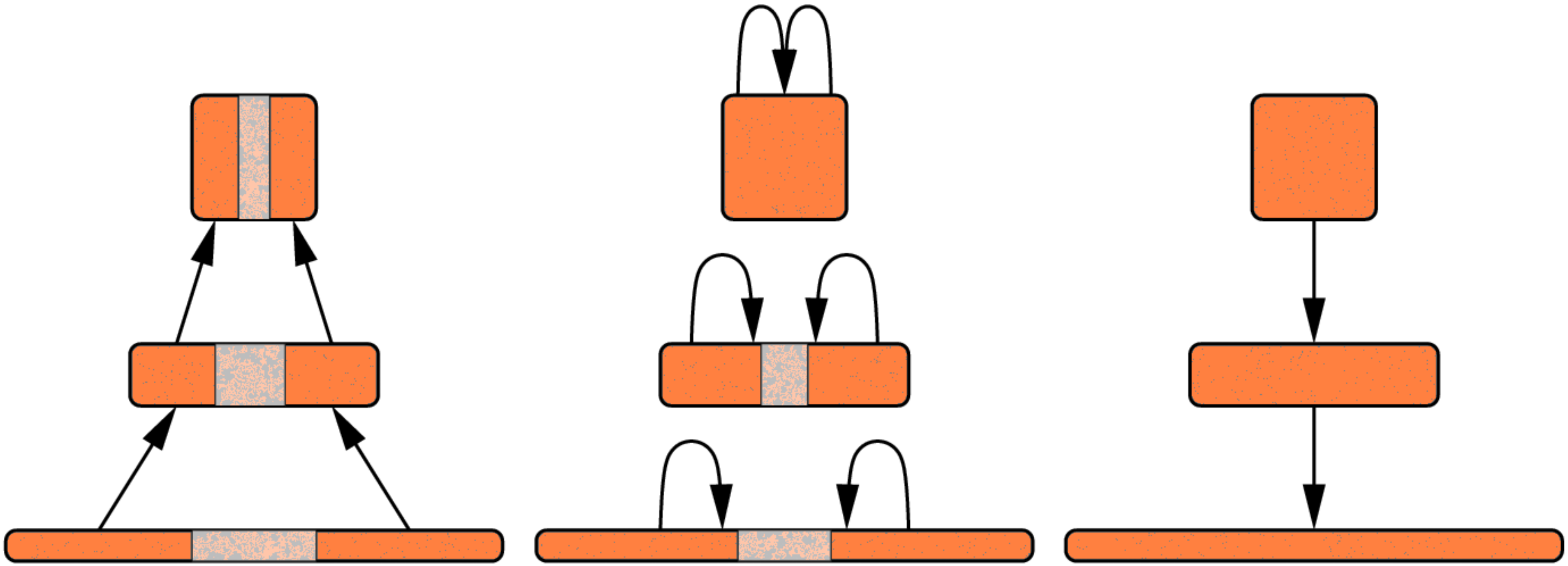
Signale

- Gruppierung - Wettbewerb - Vervollständigung

[Behnke, LNCS 2766, 2003]

Iterative Interpretation

- Interpretiere die einfachsten Stellen zuerst

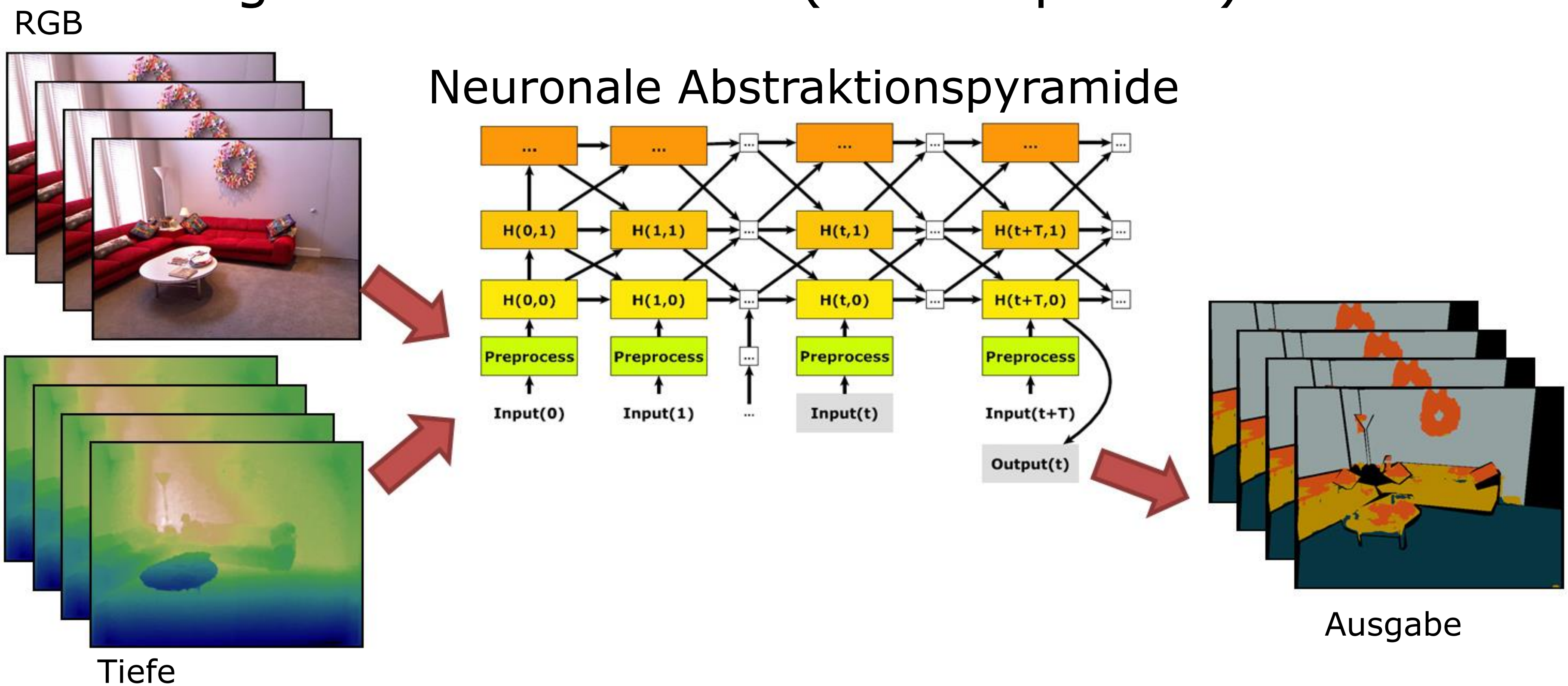


- Nutze Teil-Interpretationen als Kontext zur Auflösung von Mehrdeutigkeiten

[Behnke, LNCS 2766, 2003]

Objektklassensegmentierung von RGB-D-Video

- Eingabe: RGB-D-Video (NYU Depth V2)



- Rekursive Berechnung ermöglicht effiziente zeitliche Integration

[Pavel, Schulz, Behnke, Neural Networks 2017]

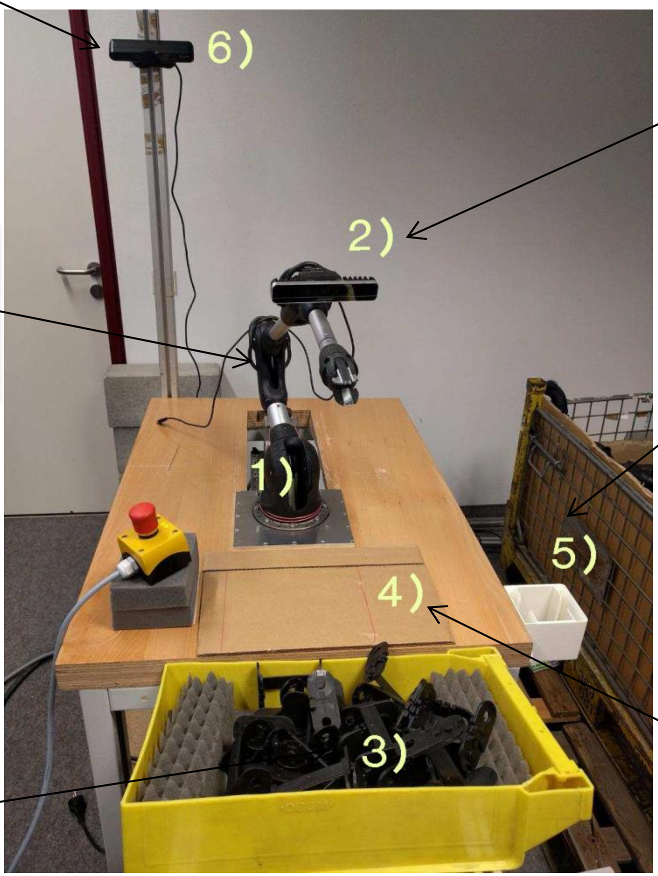
EuRoC Challenge 1: Robolink Feeder

ASUS Xtion RGB-D workspace camera

SR300 RGB-D wrist camera

Cable-driven 6DOF igus-robolink® manipulator

Energy chain part feeder



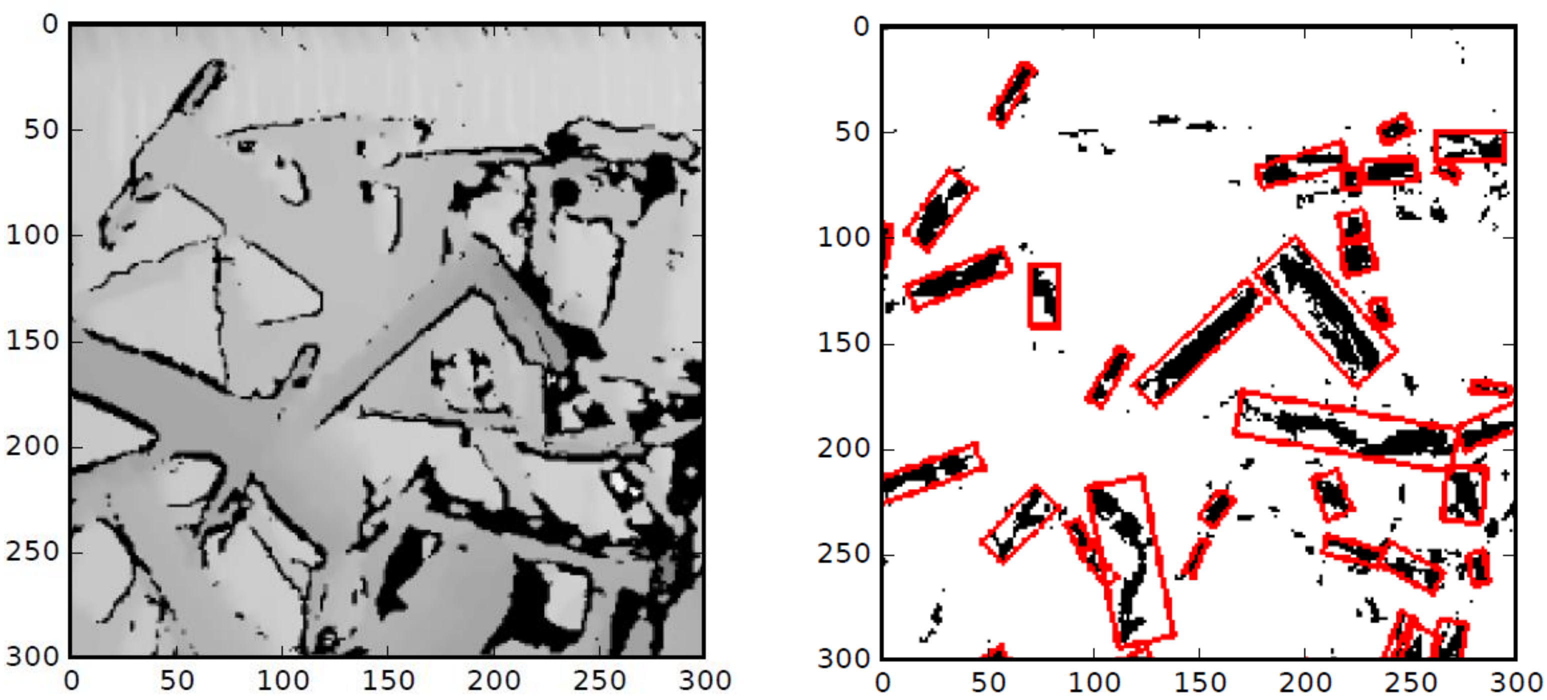
Place for regrasping

Pile of the chain parts

[Koo et al. CASE 2017]

Detektion von Greifgelegenheiten

- Analyse des Tiefenbilds
- Detektion schmaler hervorstejhende Bereiche



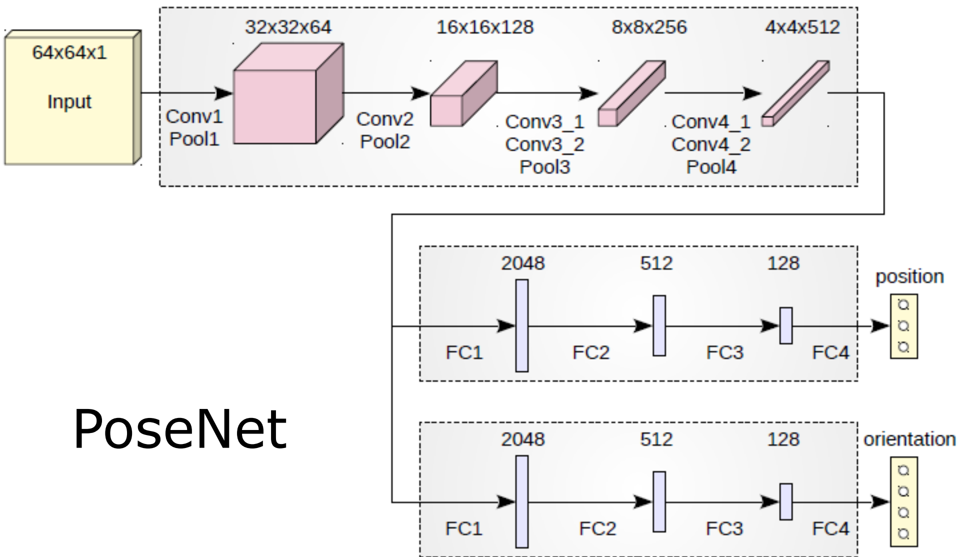
[Koo et al. CASE 2017]

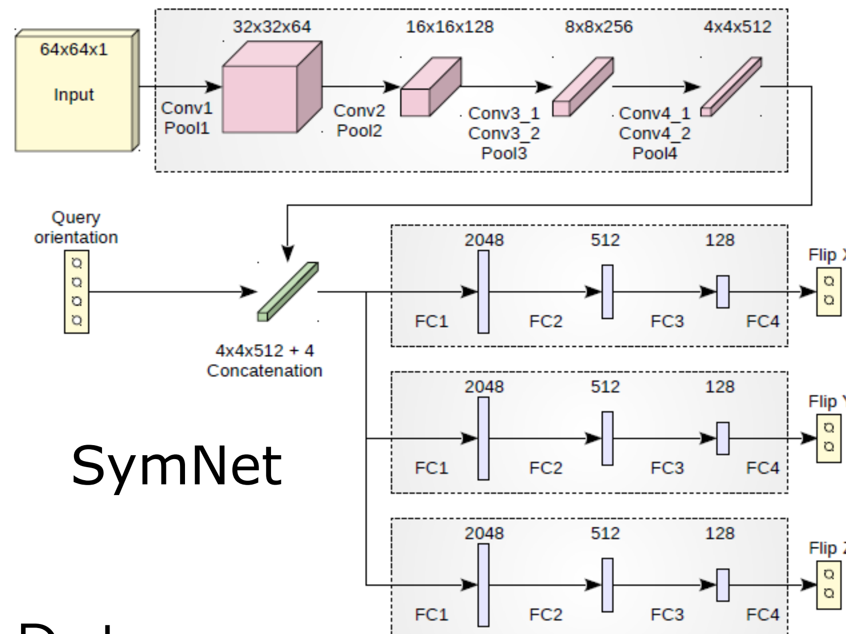
Robolink Feeder: Griff in die Kiste

[Koo et al. CASE 2017]

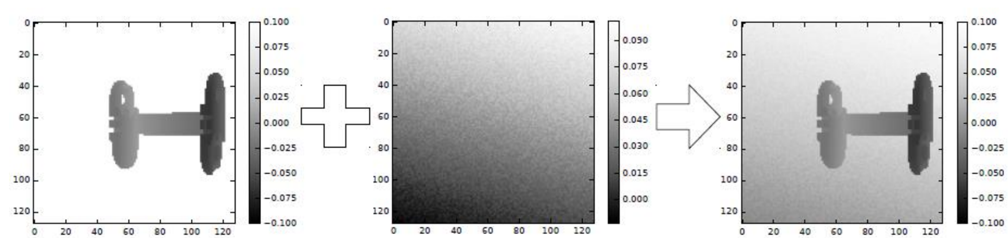
Posenschätzung für Teile

- Zwei konvolutionale neuronale Netze





- Training mit synthetischen Daten



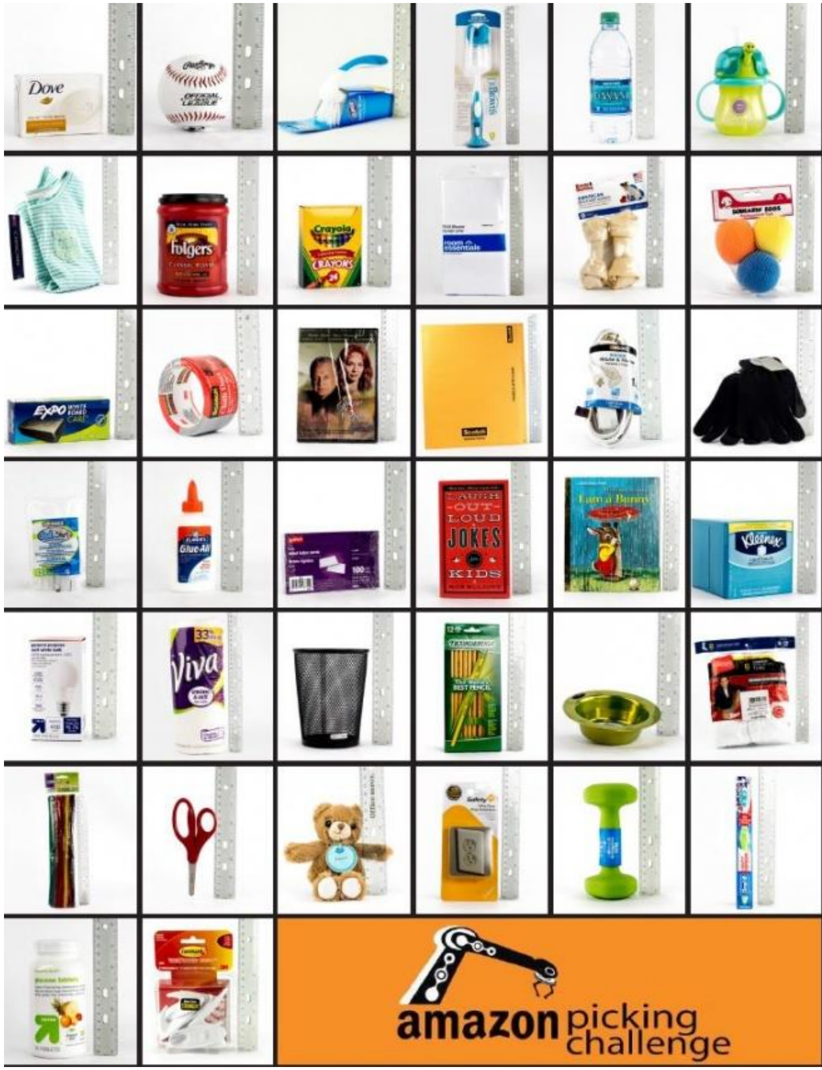
[Koo et al. CASE 2017]

Robolink Feeder: Umgreifen und Platzierung

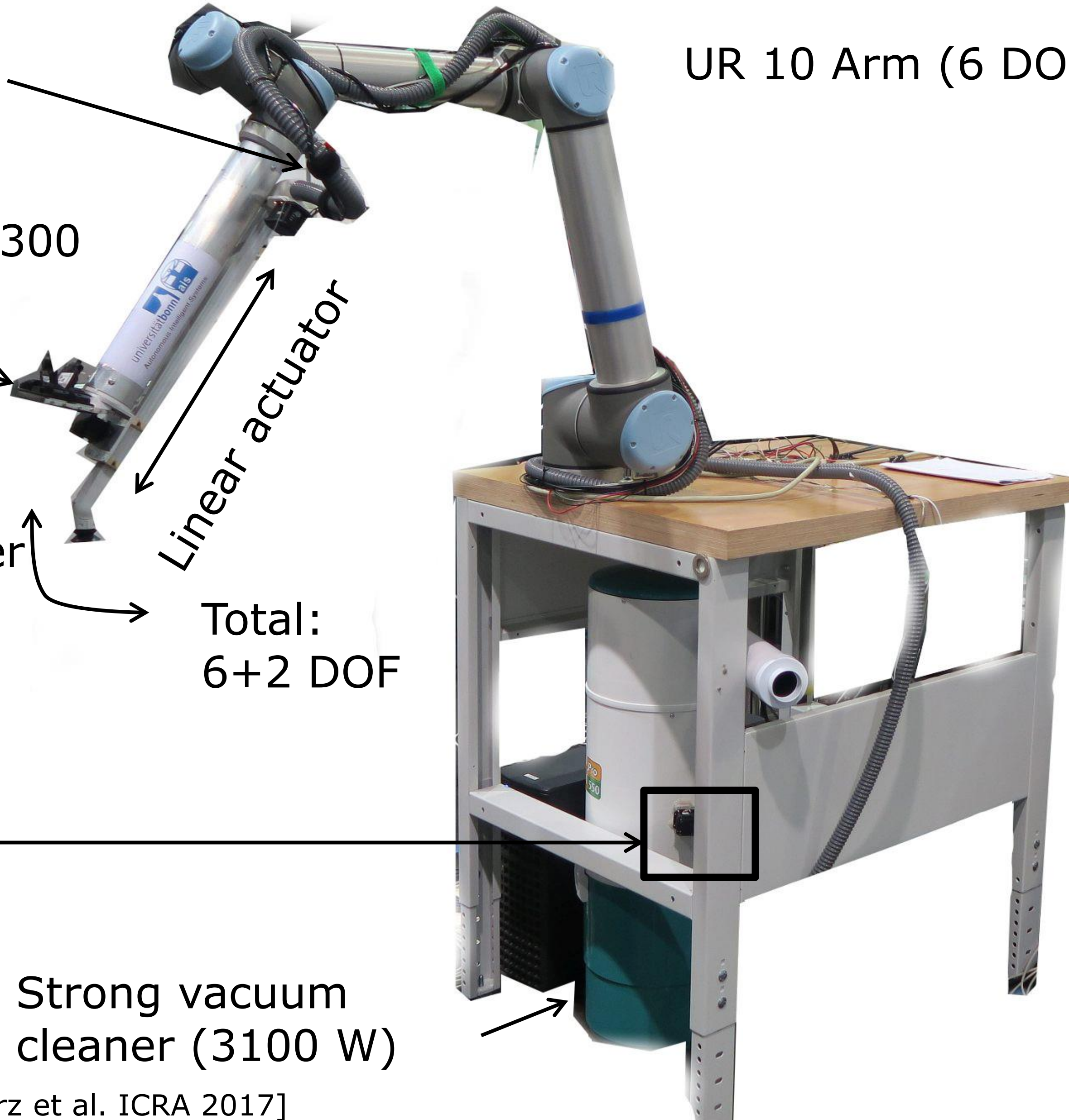
[Koo et al. CASE 2017]

Amazon Picking Challenge 2016

- Große Objektvielfalt
- Problematische Eigenschaften
  - Transparent
  - Glänzend
  - Deformierbar
  - Schwer
- Einlagern
- Auslagern



System



Suction strength control

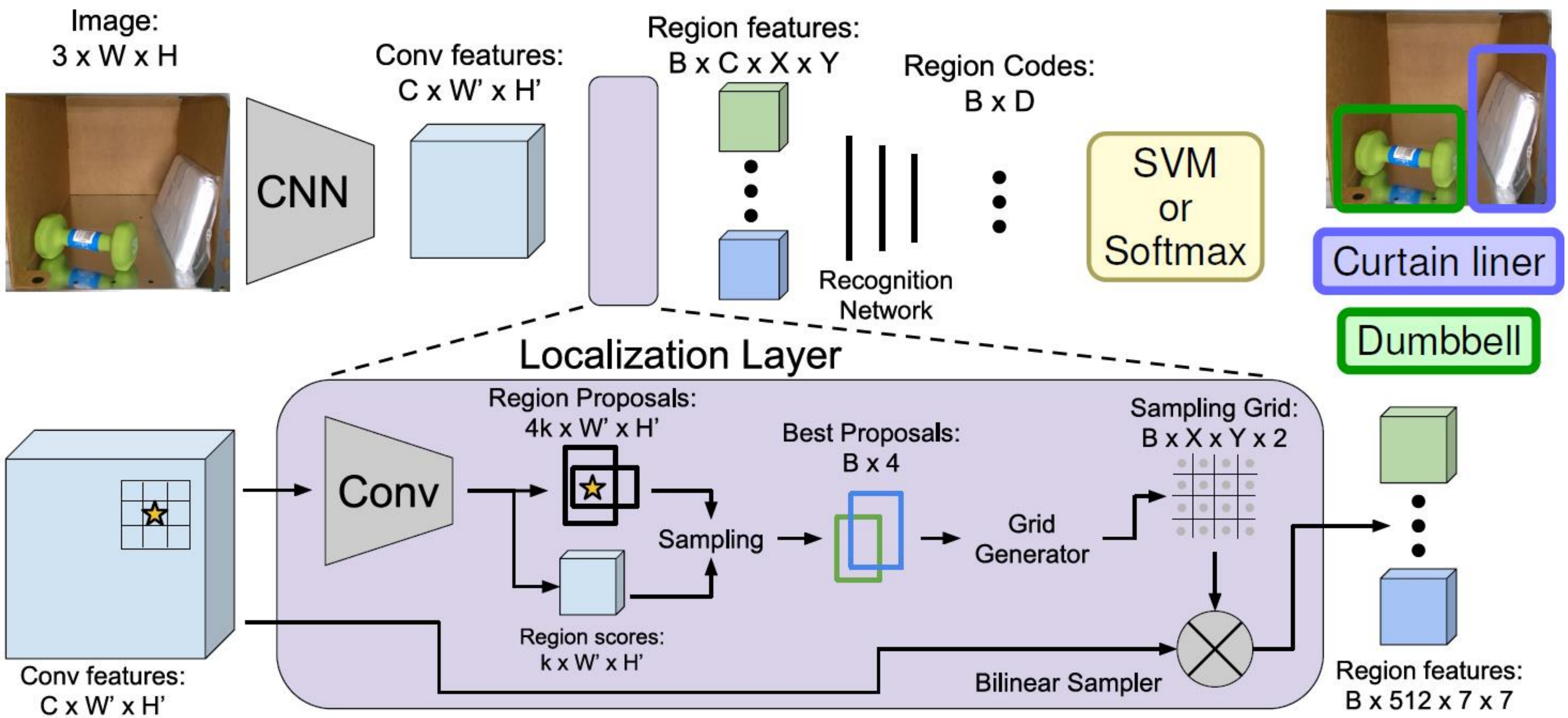
[Schwarz et al. ICRA 2017]

RGB-D-Kameras

- 2x Intel RealSense SR300
- Fusion of three depth estimates per pixel (including RGB stereo)

[Schwarz et al. ICRA 2017]

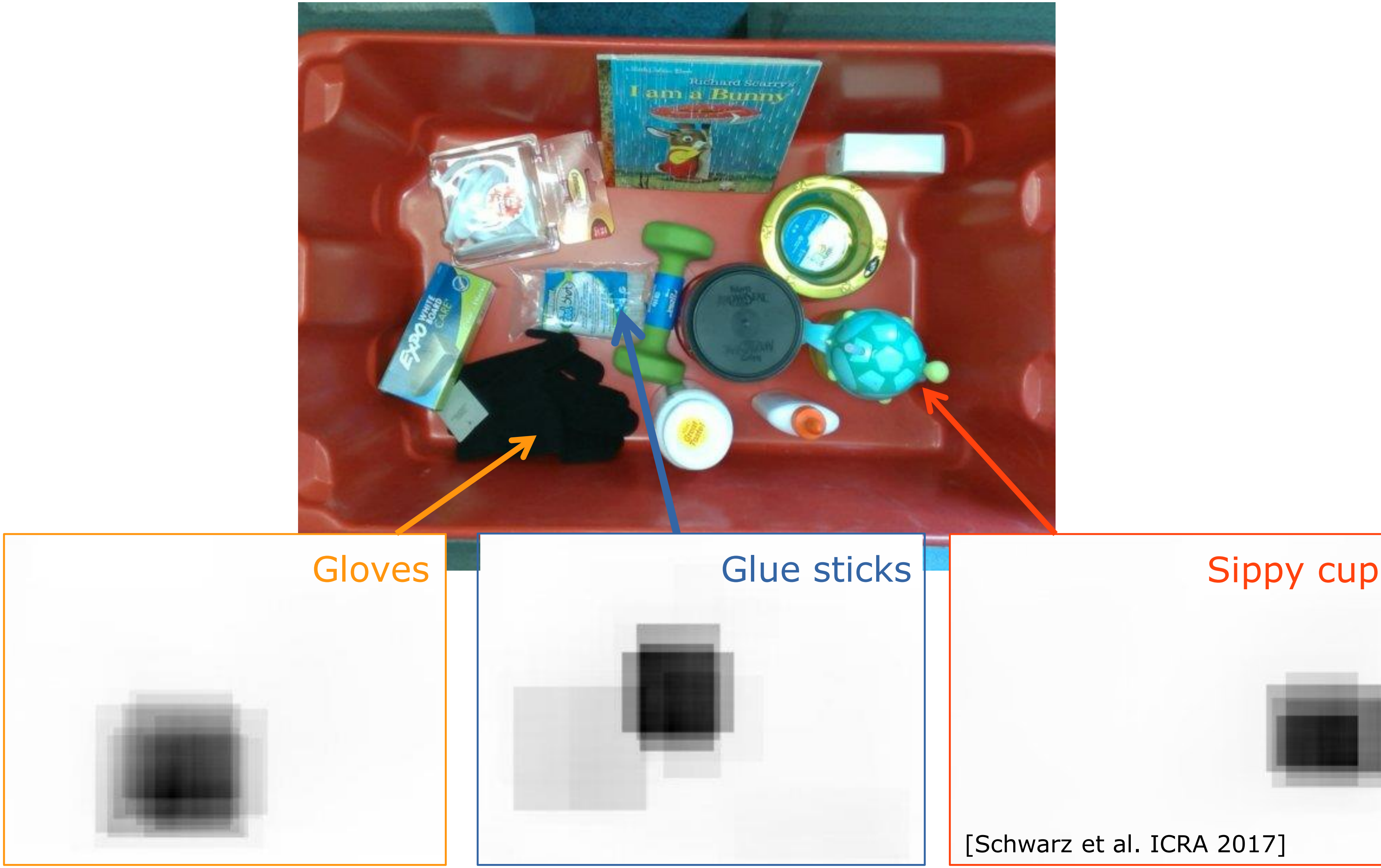
Objektdetektion



[Adapted from Johnson et al. CVPR 2016]

[Schwarz et al. ICRA 2017]

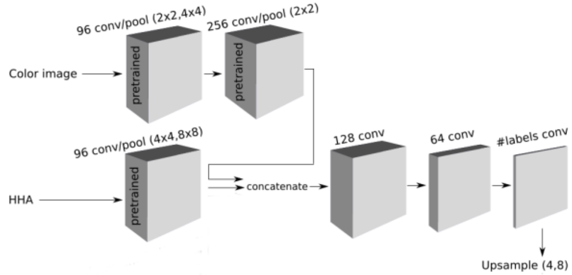
Beispiel-Detektionen



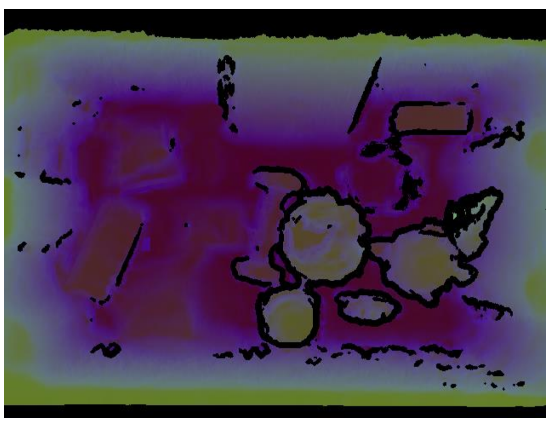
[Schwarz et al. ICRA 2017]

Semantische Segmentierung

- Tiefes Konvolutionales Netzwerk



RGB



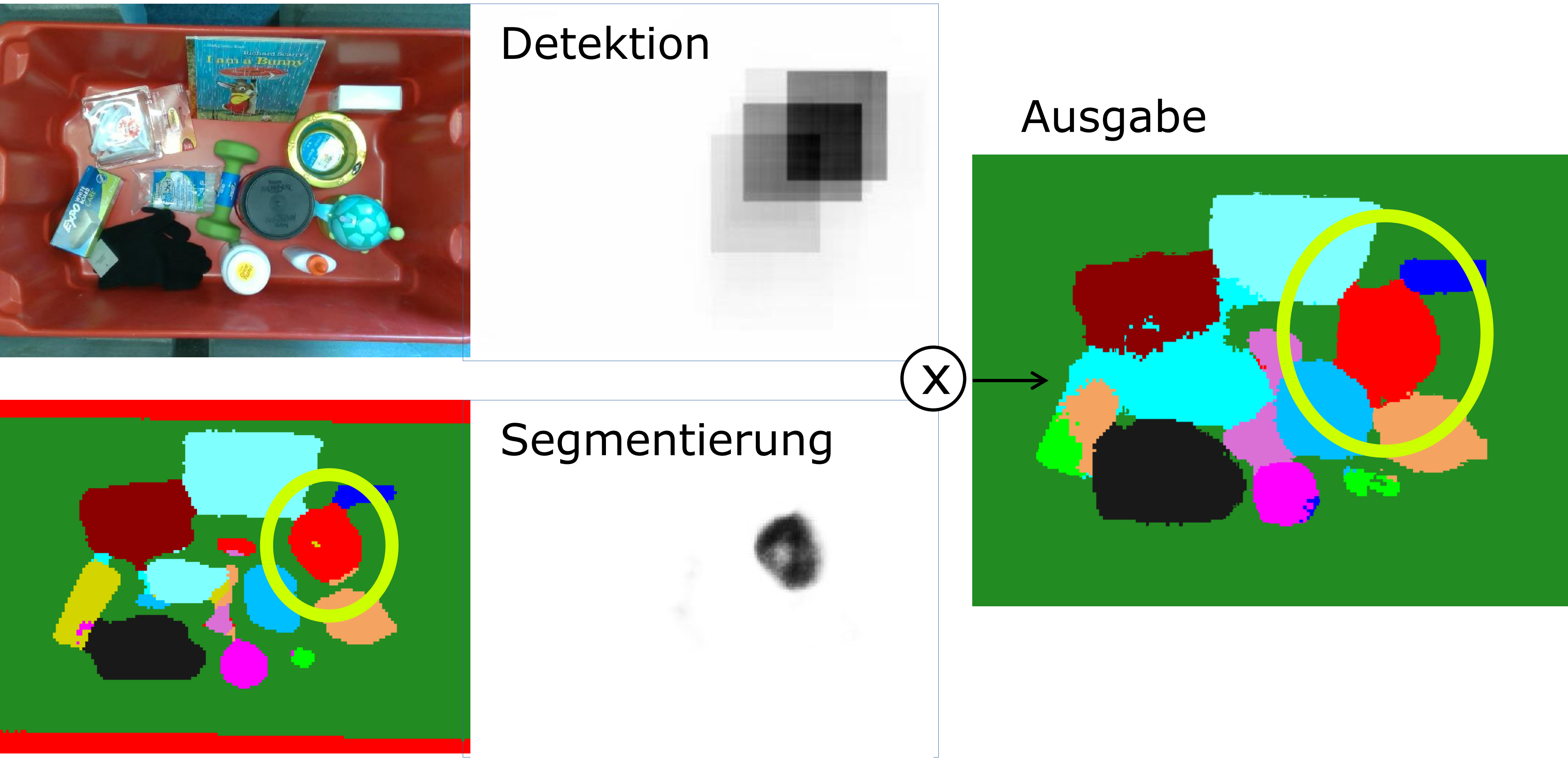
HHA

Ausgabe

[Husain et al. RA-L 2016]

Kombination von Detektion und Segmentierung

- Pixelweise Multiplikation

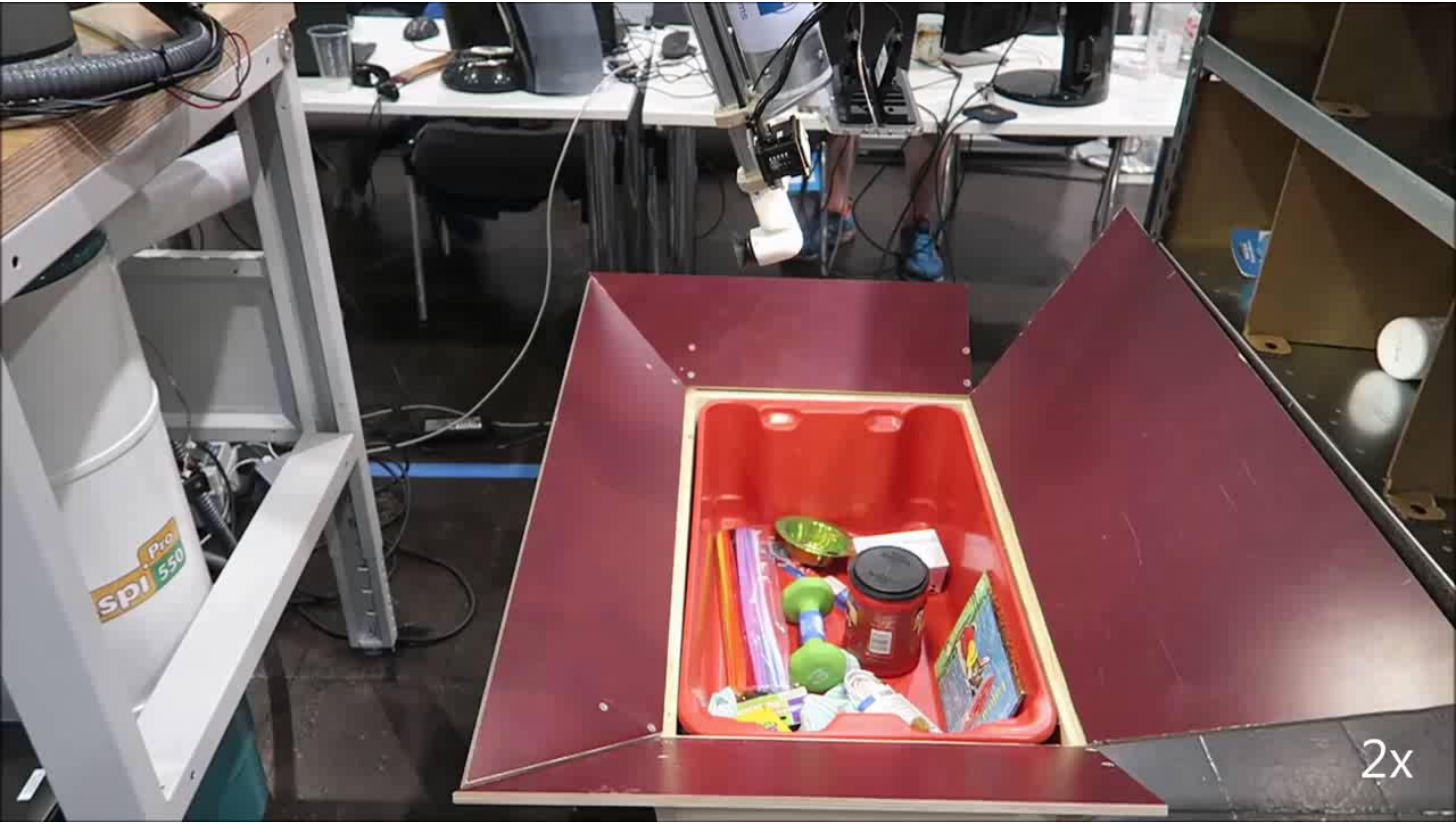


Auswahl der Saugpose

- Center grasp for "standing" objects:
  - Find support area for suction close to bounding box center

- Top grasp for "lying" objects:
  - Find support area for suction close to horizontal bounding box center

Stowing



Picking

6D-Posenschätzung

- Capture item on turn table
- Build 3D model
- Generate proposals
- Register to test image

[Aldoma et al., ICRA 2013]

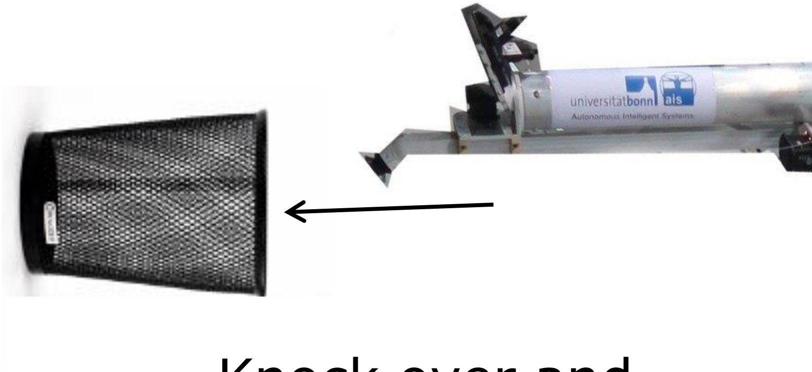
Schwierige Produkte

- Heavy / Large

Ensure that grasp is on **center of mass**!

- Many holes / Meshes

Grasp one ball



Knock over and suck on bottom

Greifen des Stiftbechers

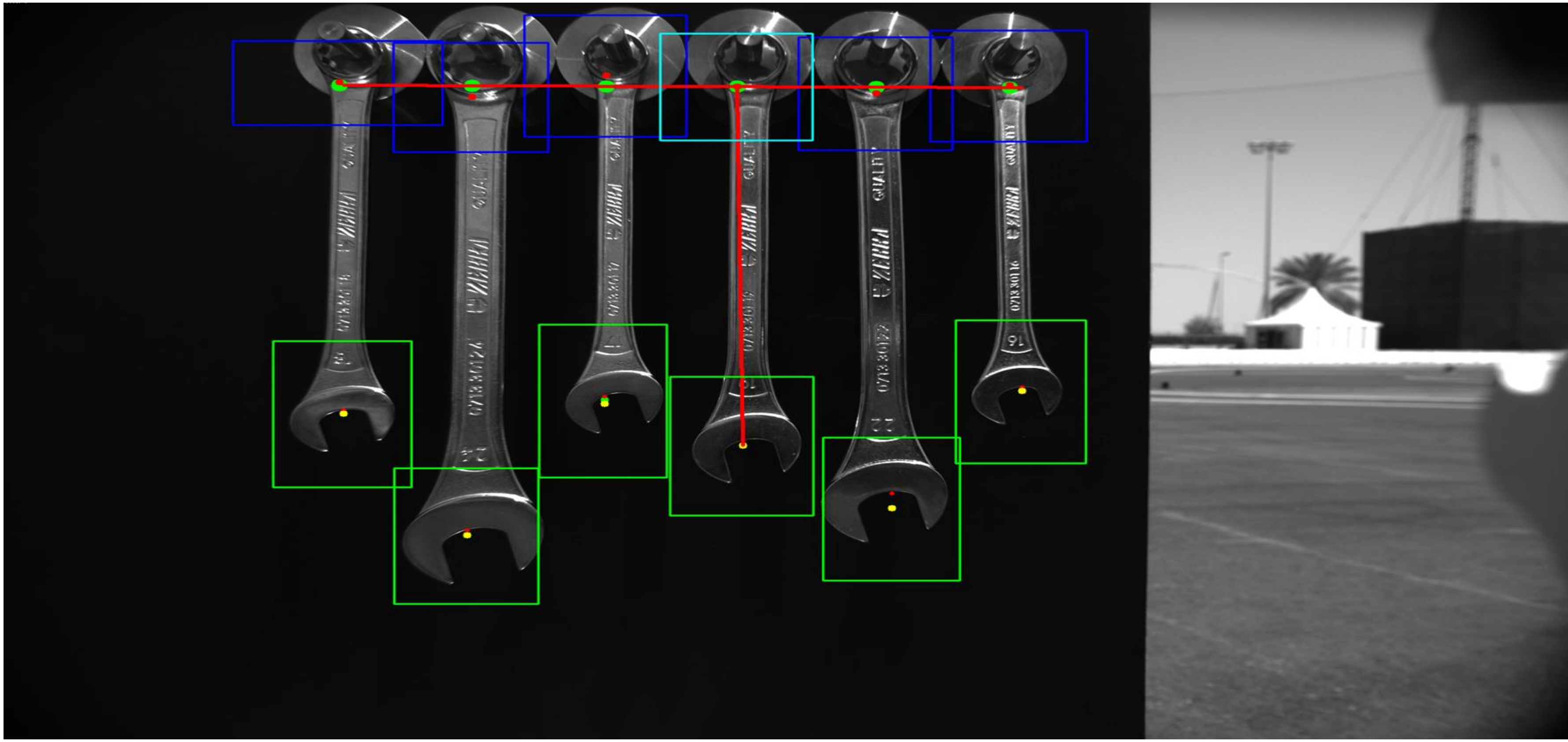
Team NimbRo Picking

- 2nd place stowing, 3rd place picking

MBZIRC Challenge 2

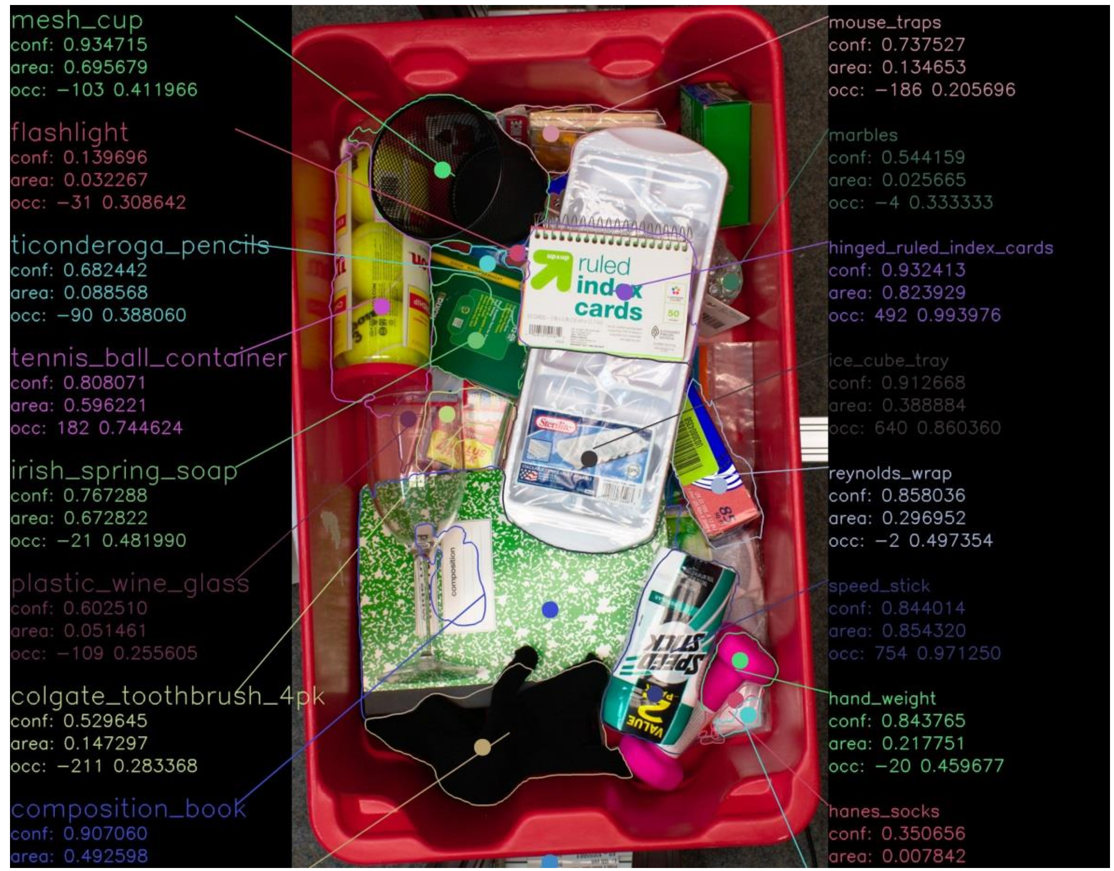
Wahrnehmung der Schraubschlüssel

- Detektion von Maul und Ring
- Assoziation der Teile, Auswahl anhand Länge



Amazon Robotics Challenge 2017

- Höherer Schwierigkeitsgrad
- Training mit gerenderten Szenen



Zusammenfassung

- Methoden zur Manipulation von Objekten und Werkzeuggebrauch entwickelt
  - Haushaltsroboter
  - Industrieautomatisierung
  - Suche und Rettung
  - Raumfahrtszenarien
- Herausforderungen
  - Variabilität der Objekte
  - Räumliche Beschränkungen
  - Aufgaben-Nebenbedingungen
- Forschungsbedarf
  - Flexible Greifer
  - Wahrnehmung
  - Manipulationsplanung
  - Lernen

Vielen Dank für Ihre Aufmerksamkeit!

Fragen?