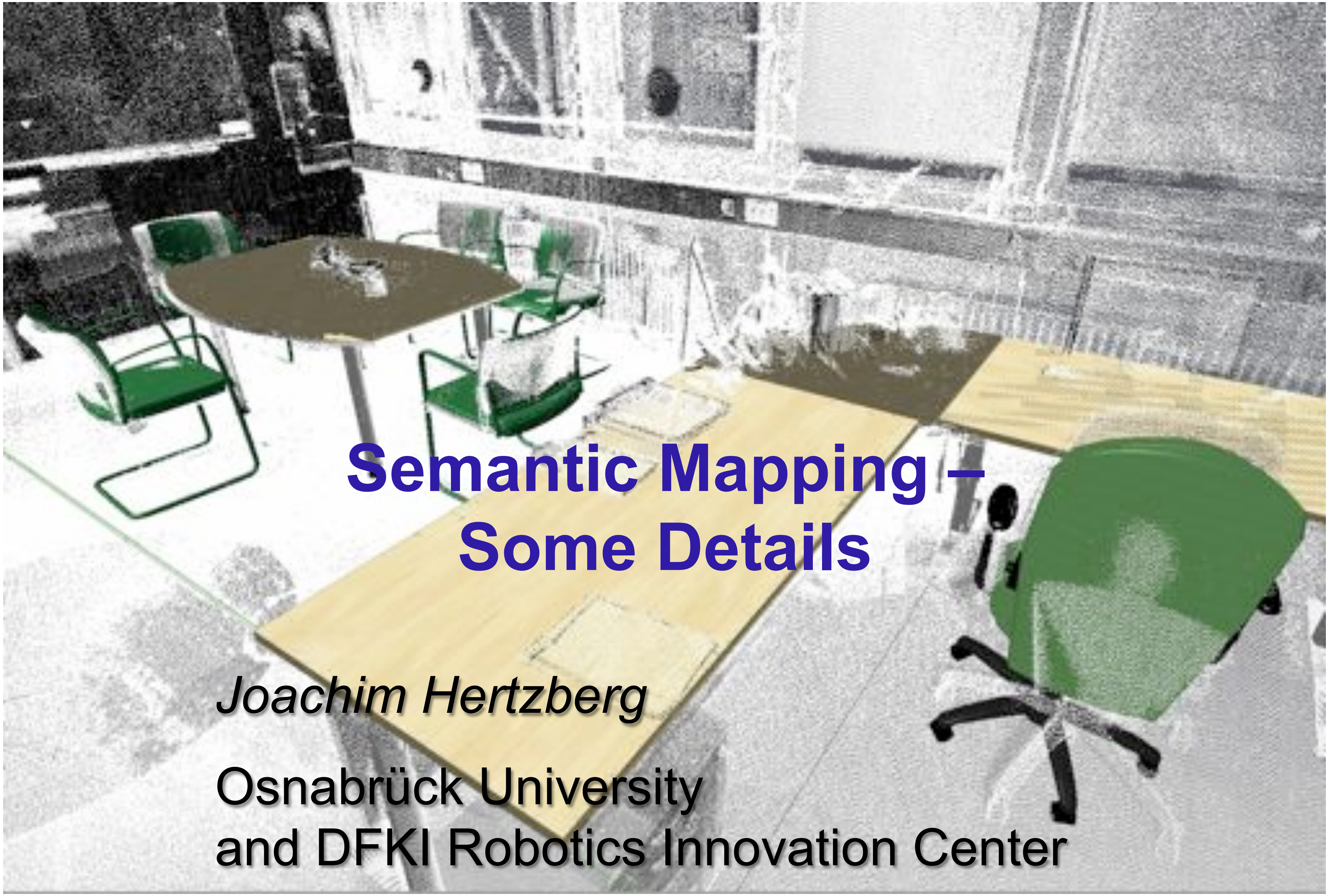

Semantic Mapping – Some Details

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(Own) Material

- H. Surmann, A. Nüchter, J. Hertzberg.
  An Autonomous Mobile Robot with a 3D Laser Range Finder for 3D Exploration and Digitalization of Indoor Environments.
  J. Robotics and Autonomous Systems 45:181-198, 2003
- A. Nüchter, J. Hertzberg.
  Towards Semantic Maps for Mobile Robots.
  J. Robotics and Autonomous Systems 56(11):915-926, 2008
- M. Günther, T. Wiemann, S. Albrecht, J. Hertzberg.
  Building Semantic Object Maps from Sparse and Noisy 3D Data.
  Proc. IROS-2013, pp. 2228-2233
- M. Günther, T. Wiemann, S. Albrecht, J. Hertzberg.
  Model-Based Furniture Recognition for Building Semantic Object Maps
  J. Artificial Intelligence, forthcoming

Semantic Map

A semantic map for a mobile robot is a map that contains, in addition to spatial information about the environment, assignments of mapped features to entities of known classes. Further knowledge about these entities, independent of the map contents, is available for reasoning in some knowledge base with an associated reasoning engine.

☛ A semantic (spatial) map exists only in relation to a KB!

There is More to Semantic Mapping than Labeling Objects in a Given Map!

- Reasoning in the domain theory allows hypotheses to be generated
- Hypotheses may need to be checked
- The area (space and the objects in it) get actively explored
- Exploration means “going there”, but possibly exploring (manipulating, inspecting, …) objects, too

Overview

1. Pose Planning in Autonomous (Semantic) Mapping

2. Some More on CAD Model Matching

3. Open Issues

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3D SLAM with 6D Poses

What's Missing for Autonomous SLAM?

- Online registration of 3D Scans
  - (some) literature, including (quite some) own
- Online pose correction according registration transformation
  - (some) literature, including (quite some) own
- Online loop detection
  - literature, including (some) own
- Online planning of next pose/path to optimize mapping
  - **only very little literature**
  - including (some) own and today's paper
  - criteria:
    - fill up geometry map
    - verify object hypotheses
    - … and many more

All in Integration in a(nother) Castle

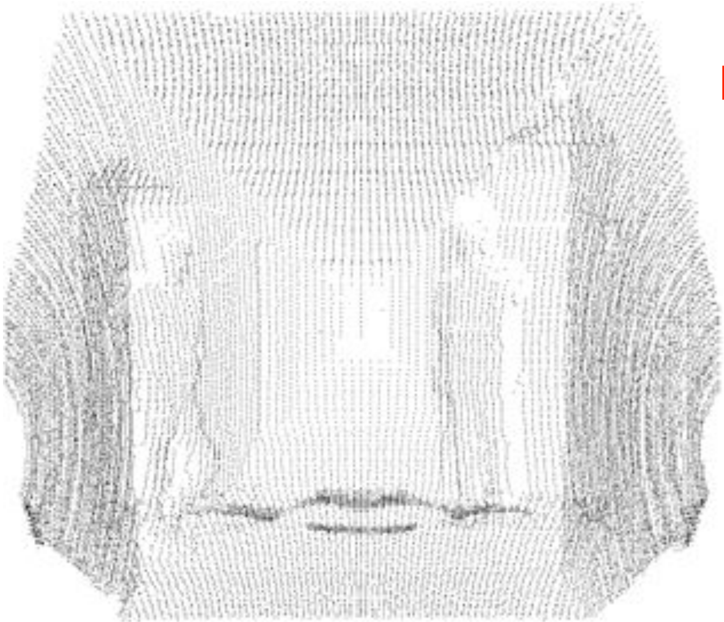
3D-SPLAM (1/5)

Planning

Raw Material

3D-Scan/s

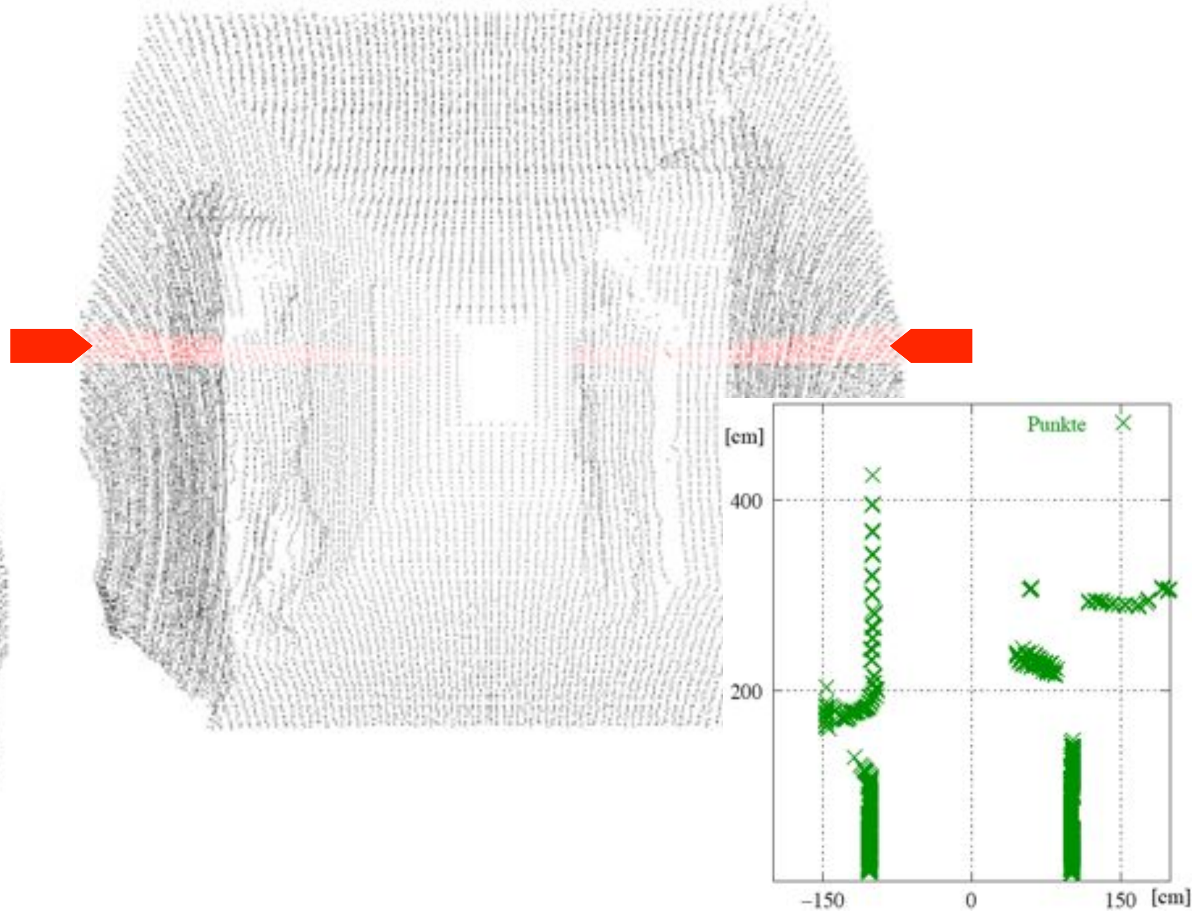
Expl.: corridor scene,

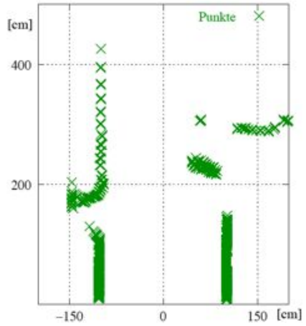


Extract 2D Slice

Reduction to 2D

Expl.: all points with y=150±2cm



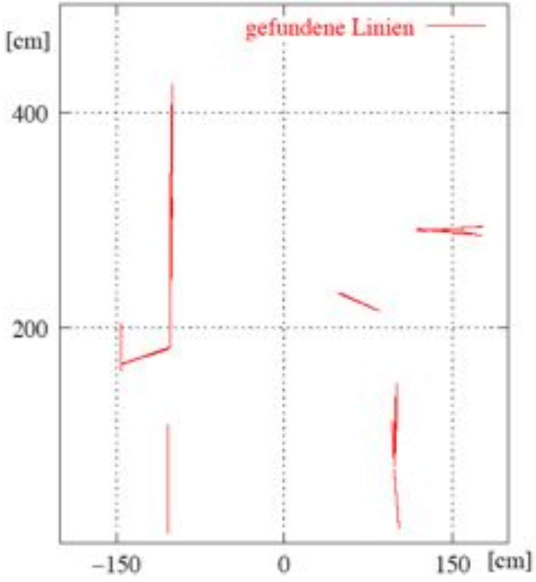


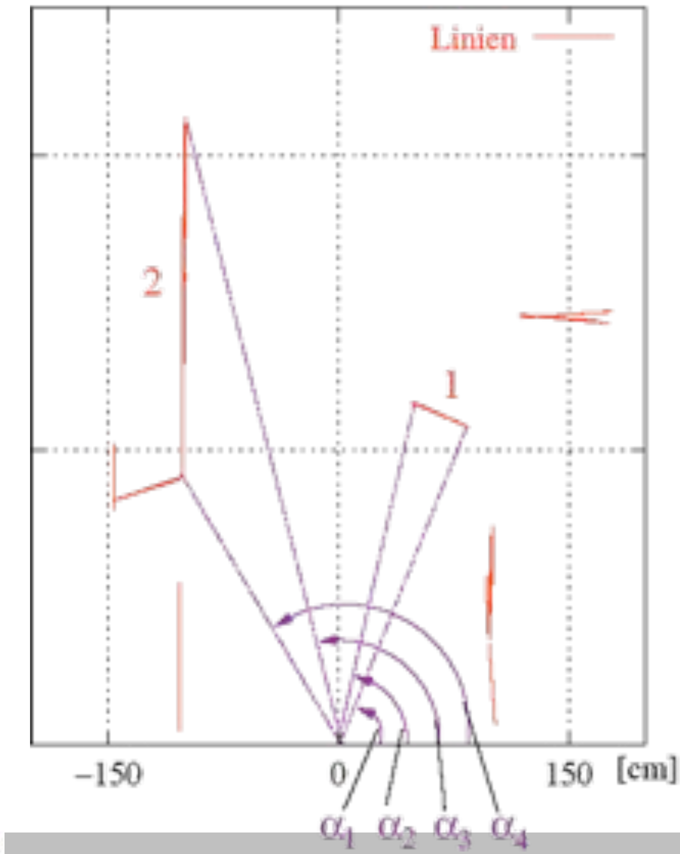
3D-SPLAM (2/5)

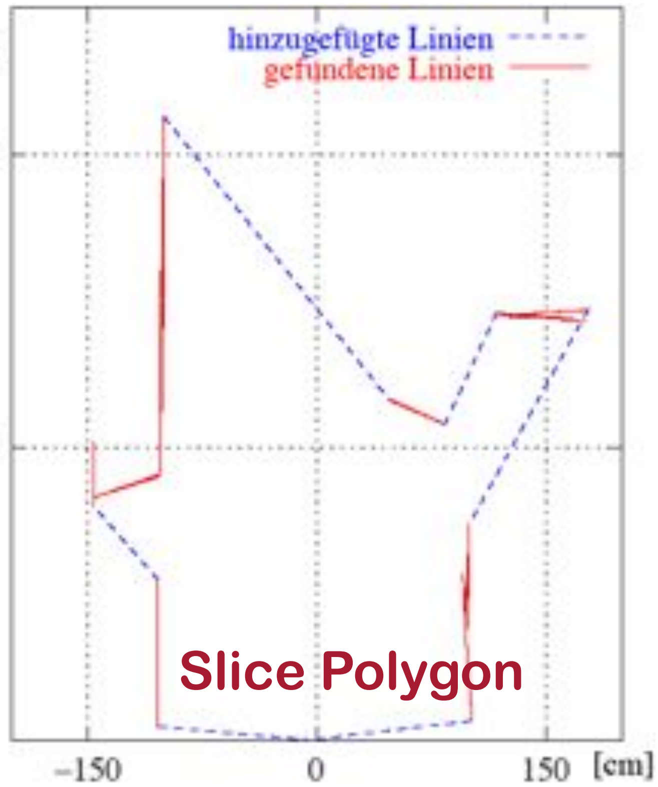
Sort and complete lines

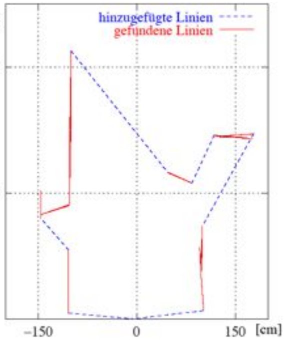
Polar angels α_i of the line ends induce unique order.
Connect neighboring scan lines by added **artificial** ones ↪ **Slice Polygon**

Points to lines









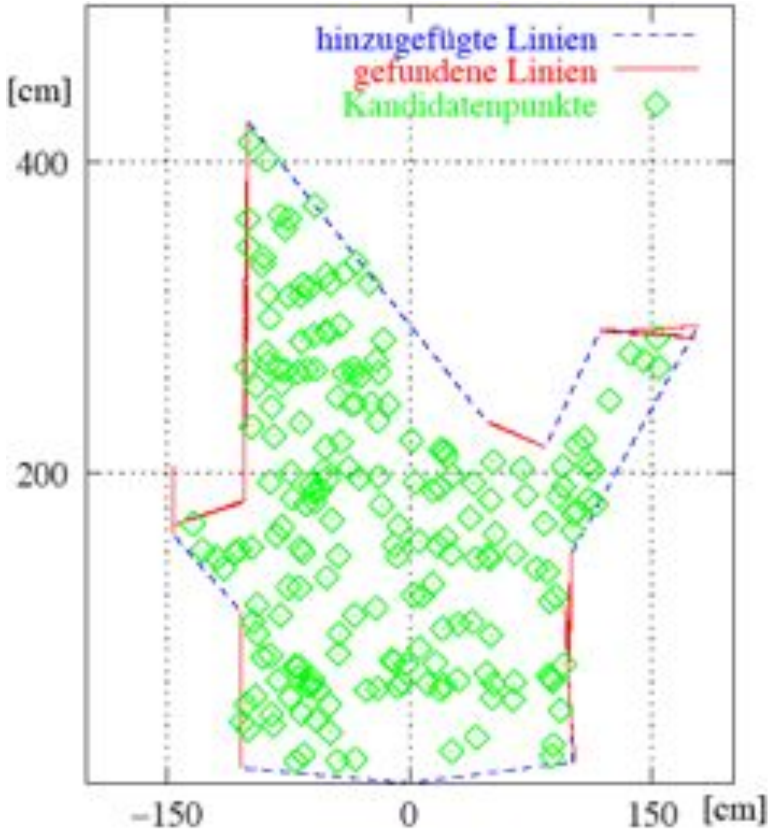
3D-SPLAM (3/5)

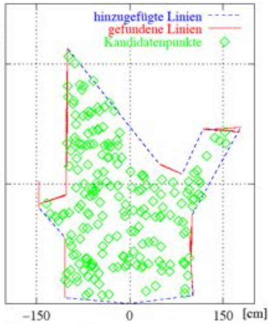
Draw scan position candidates

Uniformly distributes *Random Sampling* in slice polygon, fixed number of test positions

The slice polygon …

- … borders the area mapped until now
- … touches un-mapped area with its artificial lines
- … is not necessarily free of “gaps” and “holes”

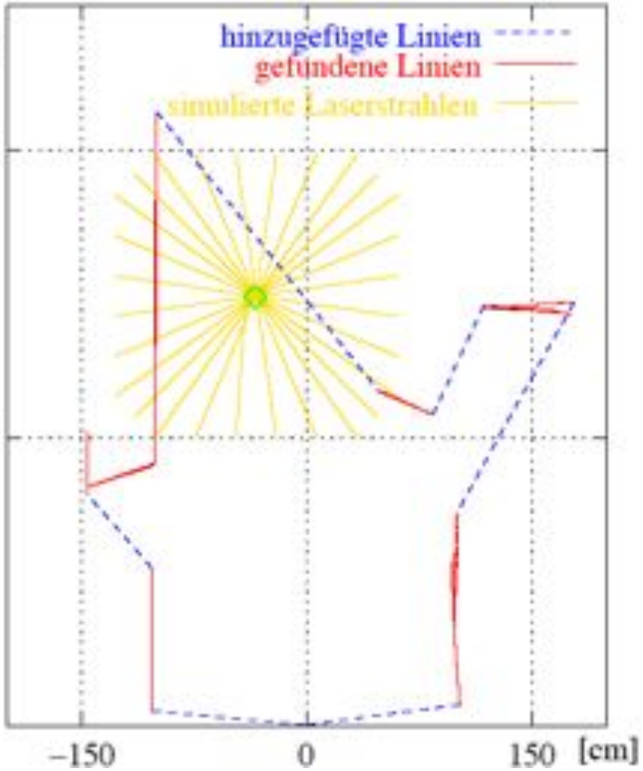




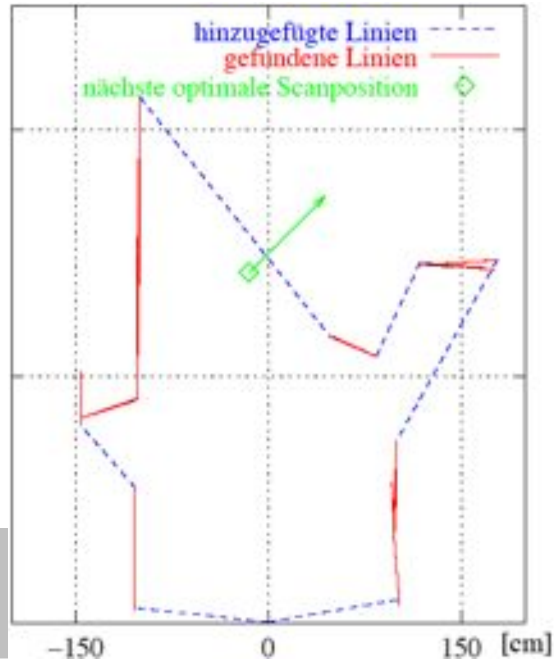
3D-SPLAM (4/5)

Rate scan pose candidates $\mathbf{x}$

- $IG(\mathbf{x})$ (*information gain*): # virtual laser beams that cut across any artificial lines (the more, the better!)
- $||\mathbf{x}_{\text{Start}} - \mathbf{x}||$: Distance to $\mathbf{x}$ from current robot position $\mathbf{x}_{\text{Start}}$ (the smaller, the better!)
- $||\theta_{\text{Start}} - \theta(\mathbf{x})||$: Angular difference between the current robot orientation θ_{Start} and the orientation $\theta(\mathbf{x})$ of pose $\mathbf{x}$ (the smaller, the better!)

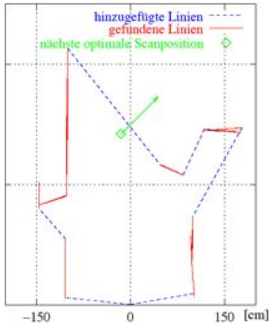


Optimal scan pose

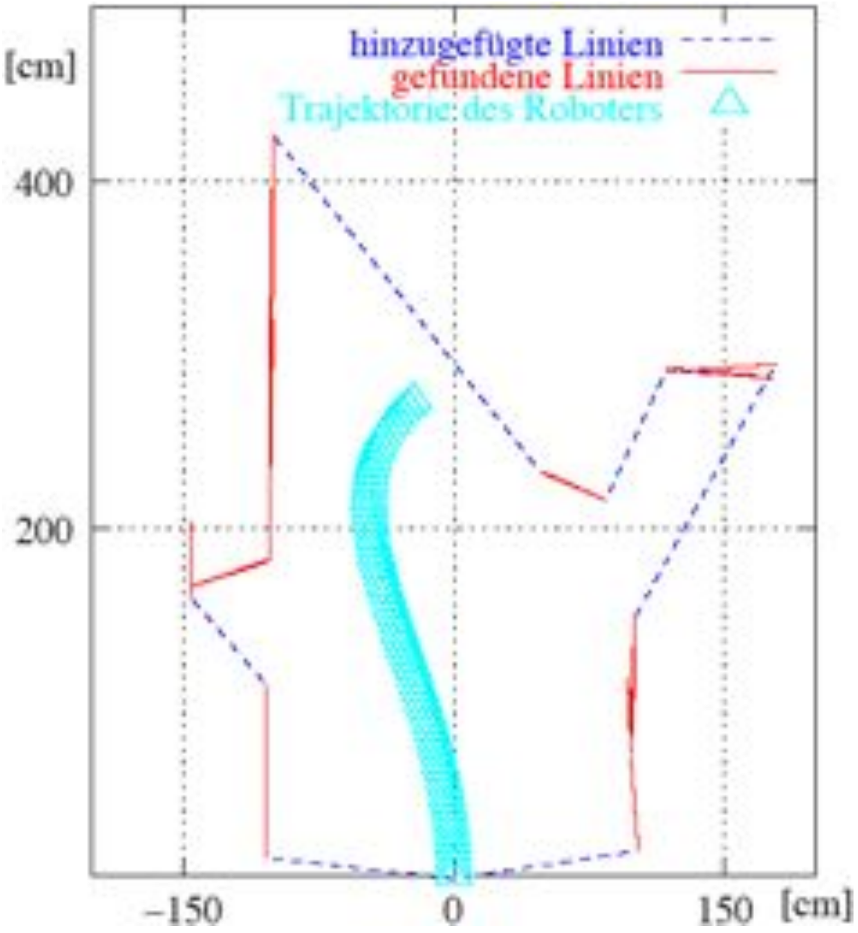


e.g.

$$\mathbf{x}_{\text{Ziel}} = \underset{\mathbf{x}}{\operatorname{argmax}} \left[w_1 IG(\mathbf{x}) + w_2 \left\| \mathbf{x}_{\text{Start}} - \mathbf{x} \right\| + w_3 \left\| \theta_{\text{Start}} - \theta(\mathbf{x}) \right\| \right]$$



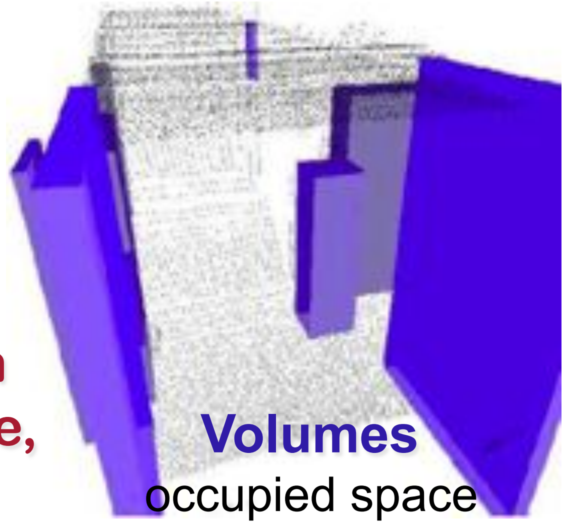
3D-SPLAM (5/5)



Plan trajectory

- Either in closed-form continuous solution (elegant, somewhat brittle)
- Or with „discrete“ approach:
  - turn to goal point;
  - drive there straight;
  - turn into goal orientation
- Both maybe with intermediate targets
- Then check in 3D model, whether trajectory free!
  - If not, take next pose

Physical ride with obstacle avoidance, of course!



Volumes
occupied space

Cousins from Computational Geometry I

Art Gallery Problem

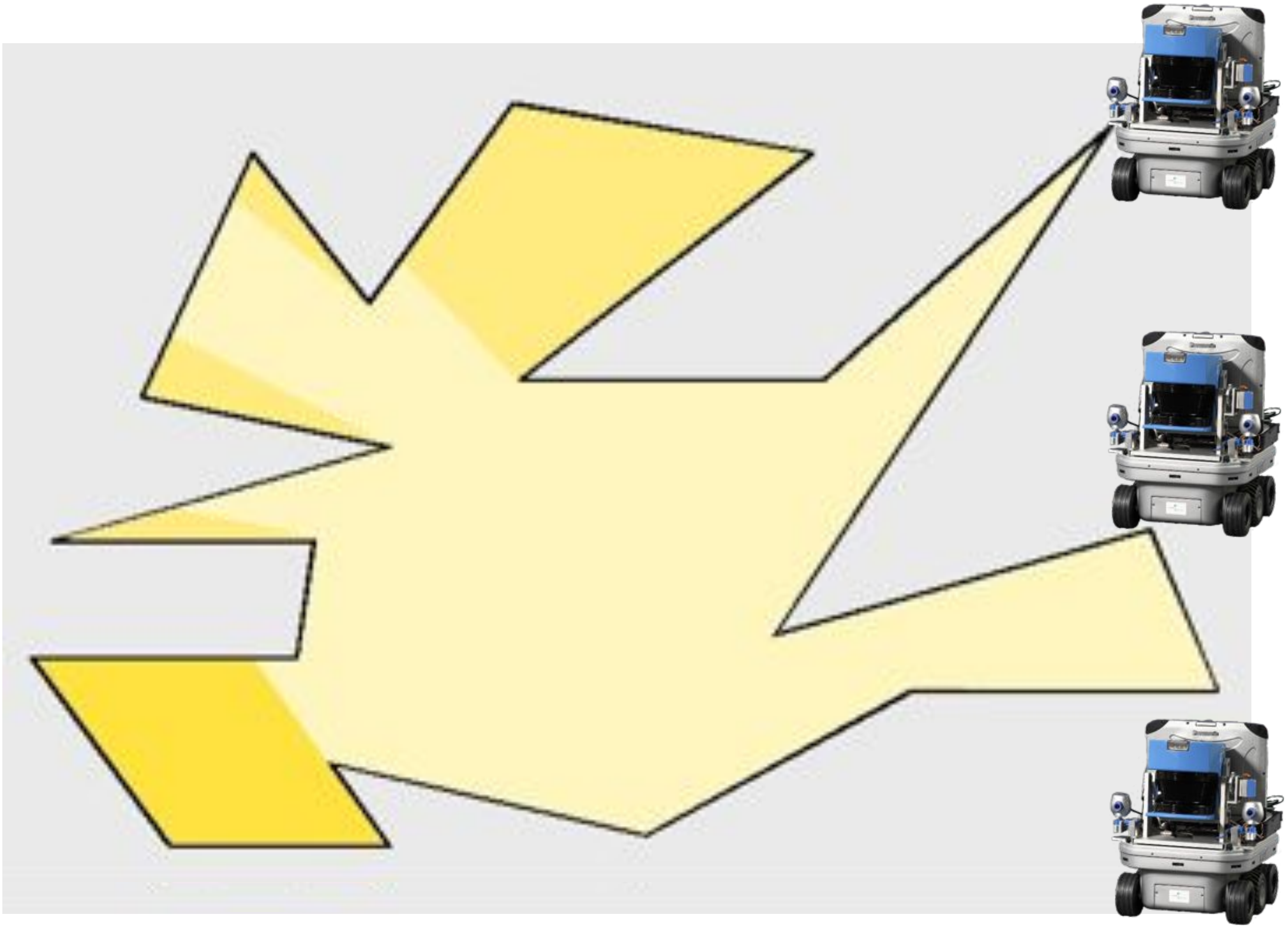
Where put N guards, so that they can see all points of the inside area of a polygon (without holes)?

Theorem
For Polygon of P vertices ex. solution for $N=\lfloor P/3 \rfloor$

Is it simple to find good solutions?

Theorem
The Art Gallery Problem is NP-hard

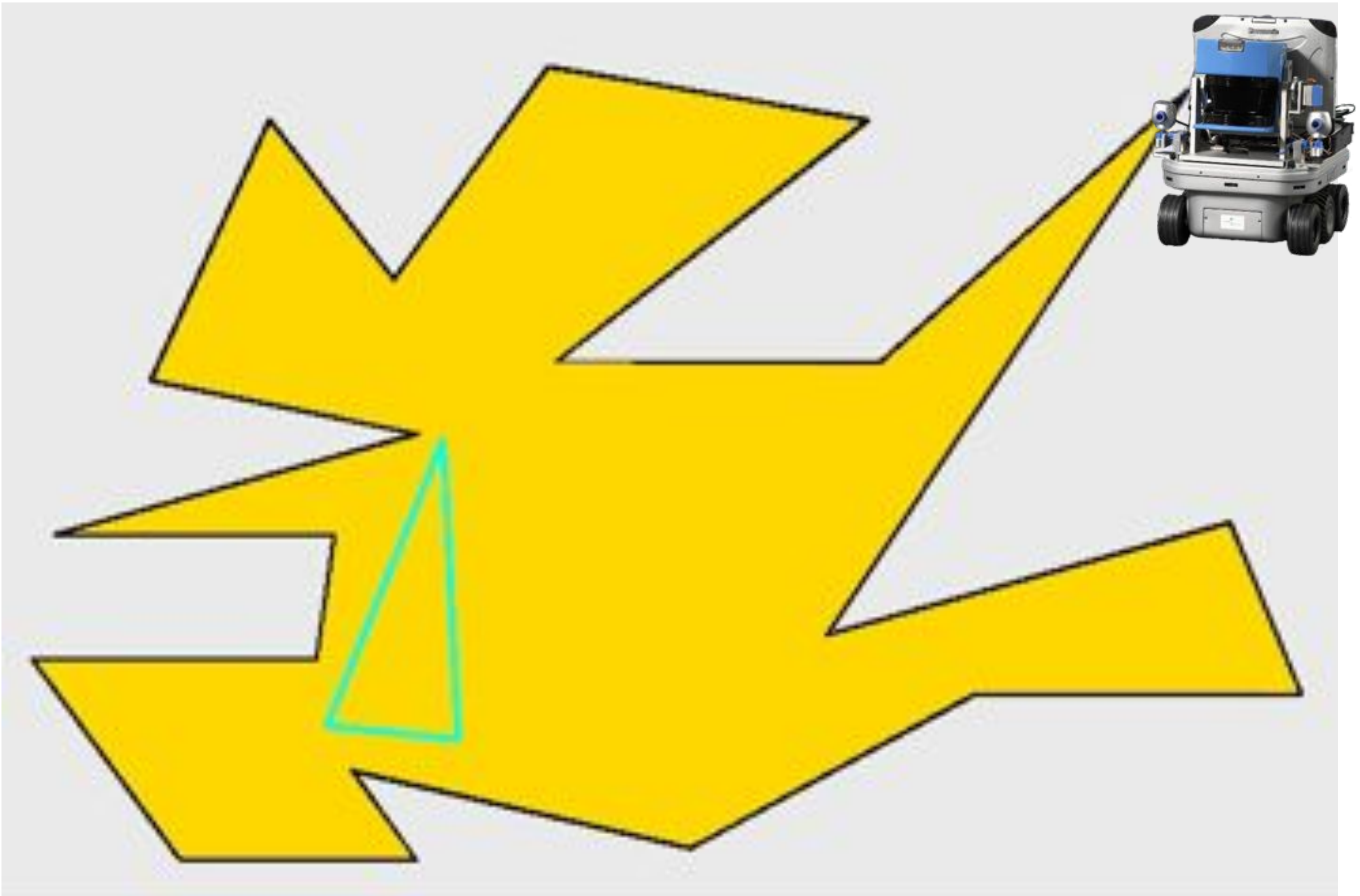
But we want only 1 robot!



Cousins from Computational Geometry II

Watchman Problem Find a (minimal) path for one watchman, that allows him to oversee the inside area of the polygon completely!

Theorem
The Watchman Problem is NP-hard
(because the Art Gallery Problem is)

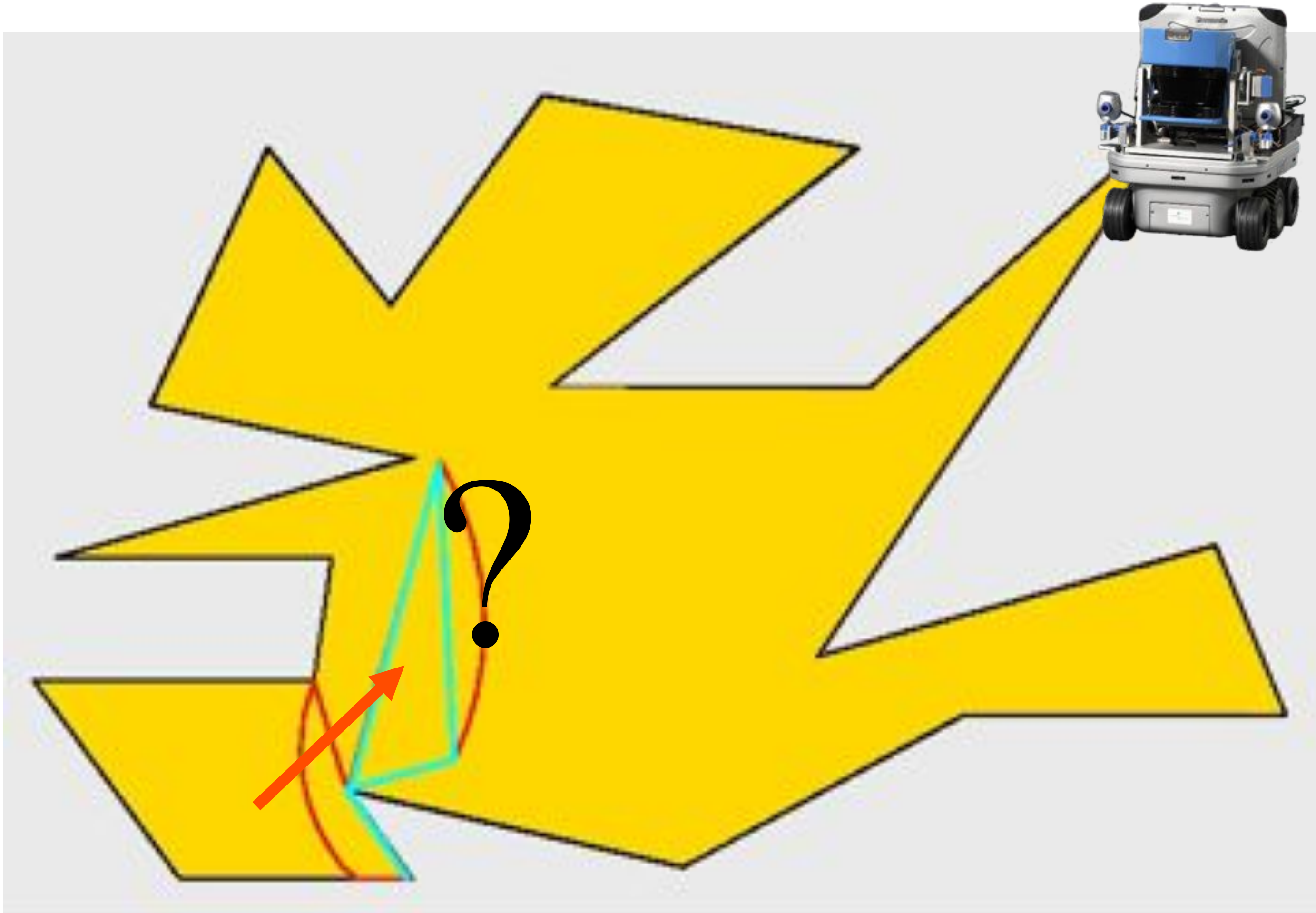


But we watch in static poses only!

...and we do not have the map!

The Problem of Optimal Exploration

What is, dependent on start information and real environment geometry, a drivable (kinematic, collision), expectedly shortest path between scan poses, at the end of which the polygon's inside area is completely mapped?



Solution currently unknown!

More Reasons for a Robot for Particular Target Points

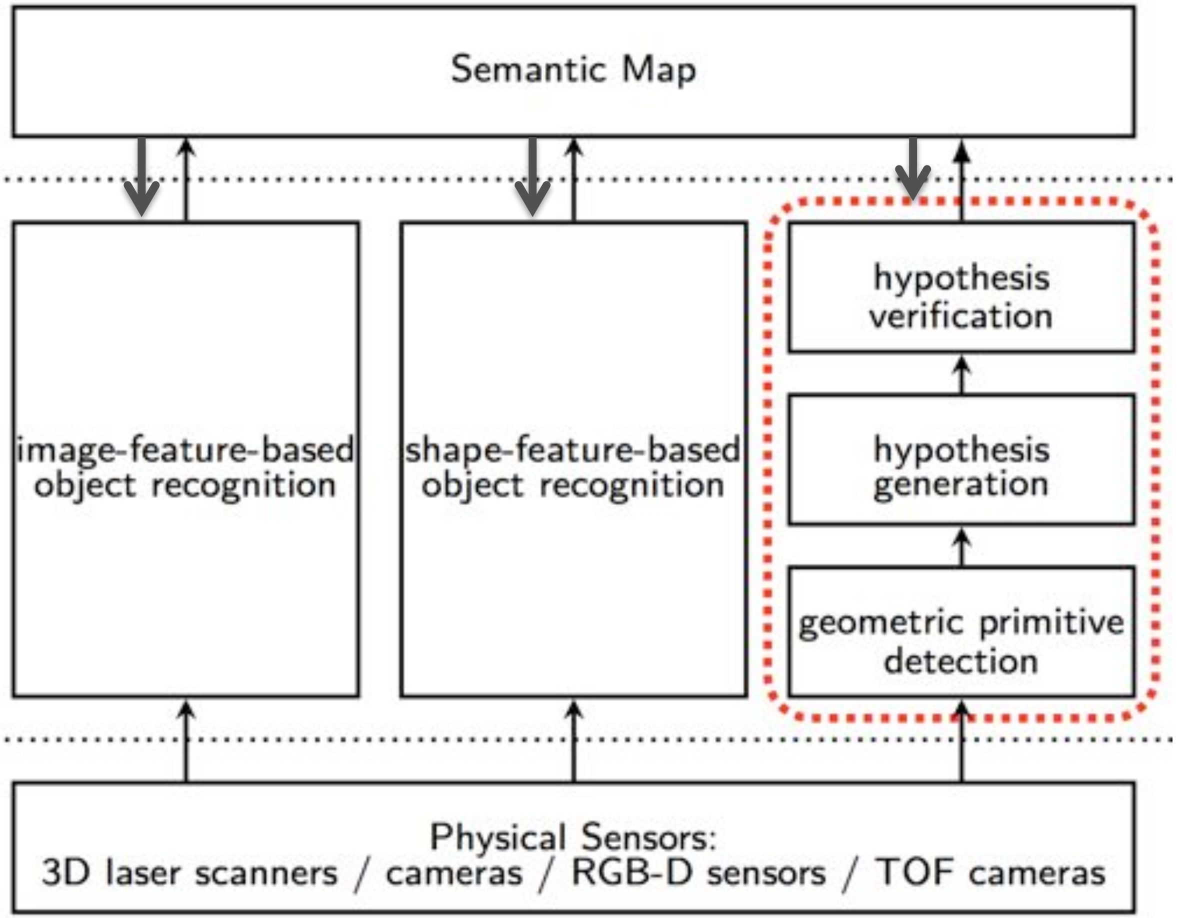
- Self organization
  - e.g., “Go to charging station!”
- Pose disambiguation
  - e.g., if entropy in probabilistic localization too high (“Go to landmark!”)
  - or planned right away as intermediate targets to avoid losing the pose estimation in the first place (“**coastal navigation**”)
- “Transit poses”
  - e.g. door passing: Pass through pose on the door normal to avoid crossing through the door in an angle
- Poses to manipulate individual objects
  - e.g. clear table: Drive to pose allowing to reach as many clearable items as possible

Overview

1. Pose Planning in Autonomous (Semantic) Mapping
2. **Some More on CAD Model Matching**
3. Open Issues

Reminder: Architecture Context

Other object recognition methods may/should co-exist!



Model-based object recognition

Practical Issues in 3D Semantic Mapping

- Practically, Semantic Mapping is based on single scans/ frames, rather than fully registered scene models
- In particular RGB-D cameras have small opening angle: only partial object views per frame, blurred by sensor noise
- Surfaces in real-world scenes are frequently cluttered
- Shiny and transparent objects exist
- A great many object models are available for matching

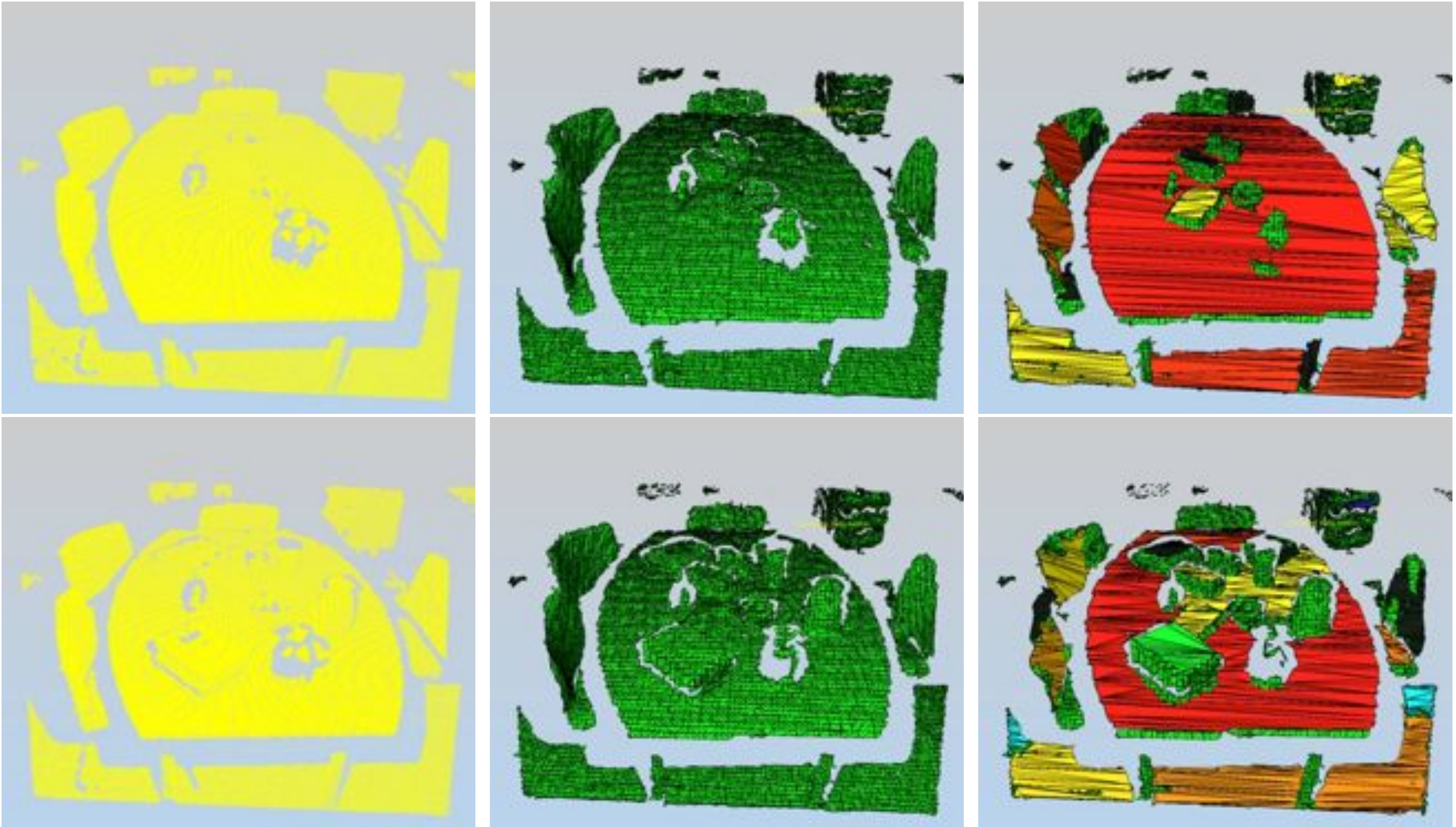
☛ Care about robustness

- against occlusion
- of CAD matching

Robustness Against Occlusion

- When does object detection break in face of clutter?
- When does plane detection break?
- Table experiment

Point Cloud, Mesh and Segmentation



Result in Summary

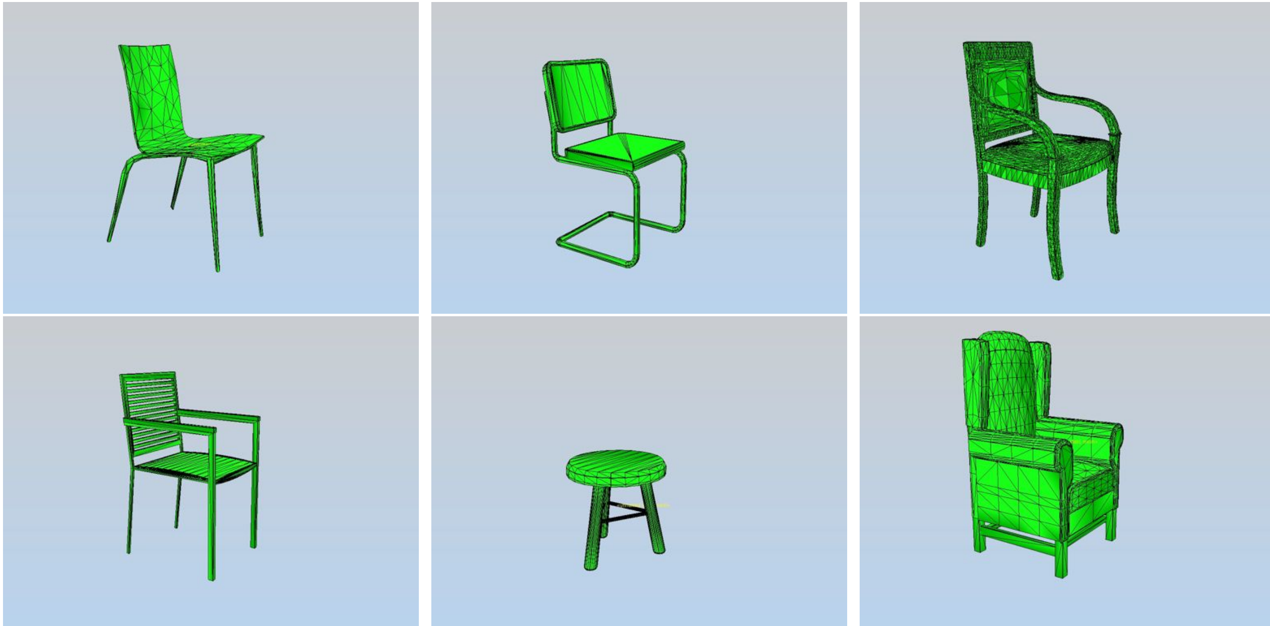
	0 obj.	2 obj.	3 obj.	4 obj.	5 obj.	6 obj.	7 obj.	12 obj.
Region Growing	1.50 93%	1.47 92%	1.47 92%	1.40 87%	1.35 84%	1.26 79%	1.17 73%	0.95 59%
Contour Triangulation	1.50 93%	1.50 93%	1.49 93%	1.52 95%	1.52 95%	1.52 95%	1.50 93%	1.20 75%

- Table top area in m^2 and as percentage of ground truth
- Region growing starts breaking for moderate clutter
- Contour triangulation stabilizes matters, unless the contour is occluded, too
- Need help, e.g., of texture

Robustness of CAD Object Matching

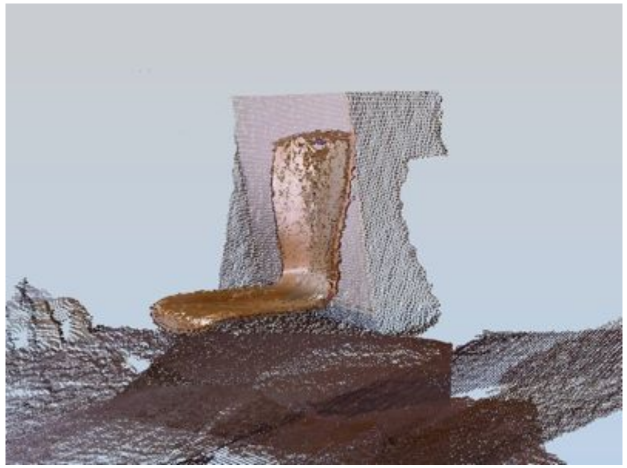
Chairs are different

CAD models of different chair types applied for matching against sensed chairs



Sensed chairs even more

Chair model registered from 3 Kinect frames



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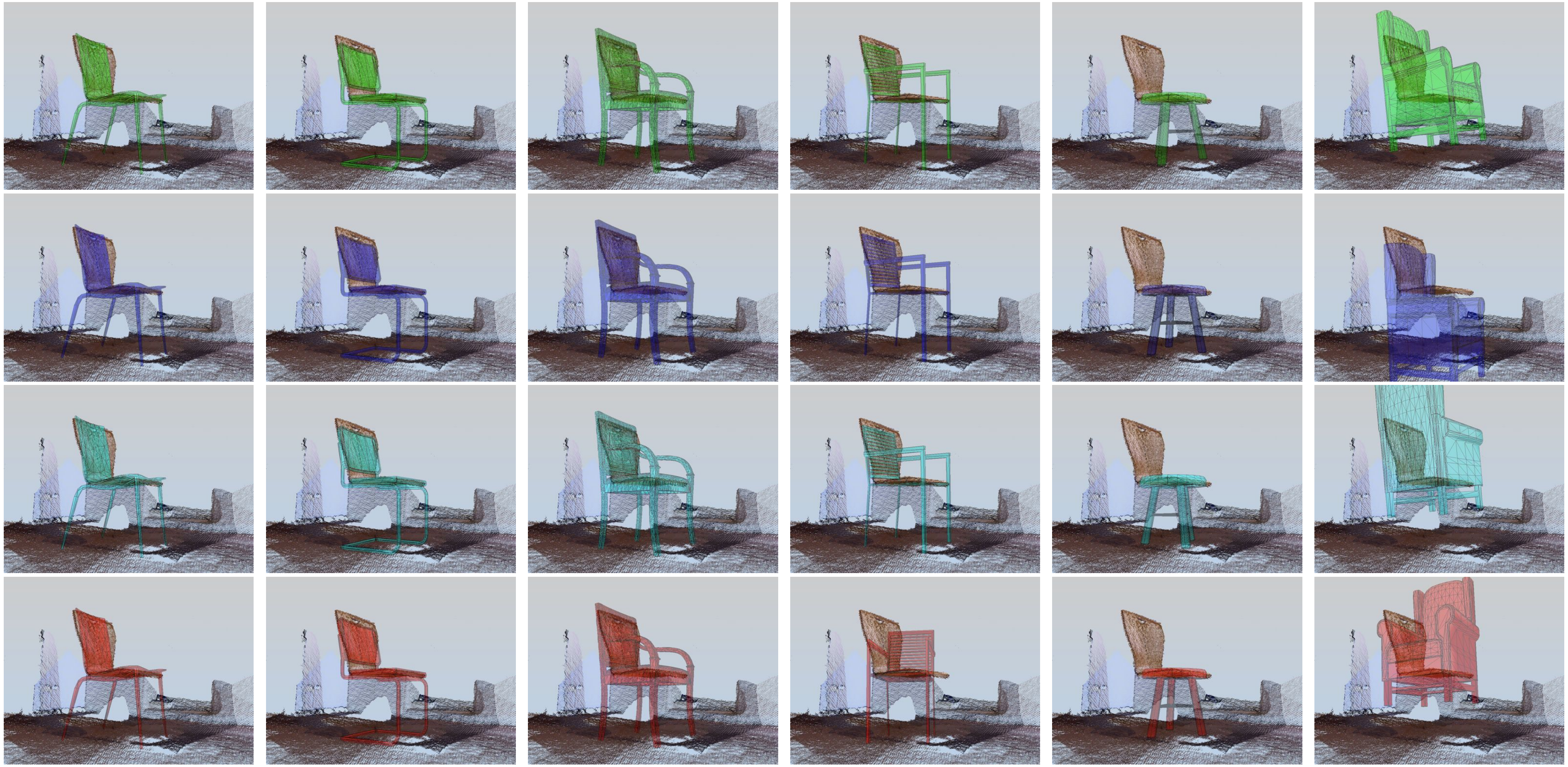
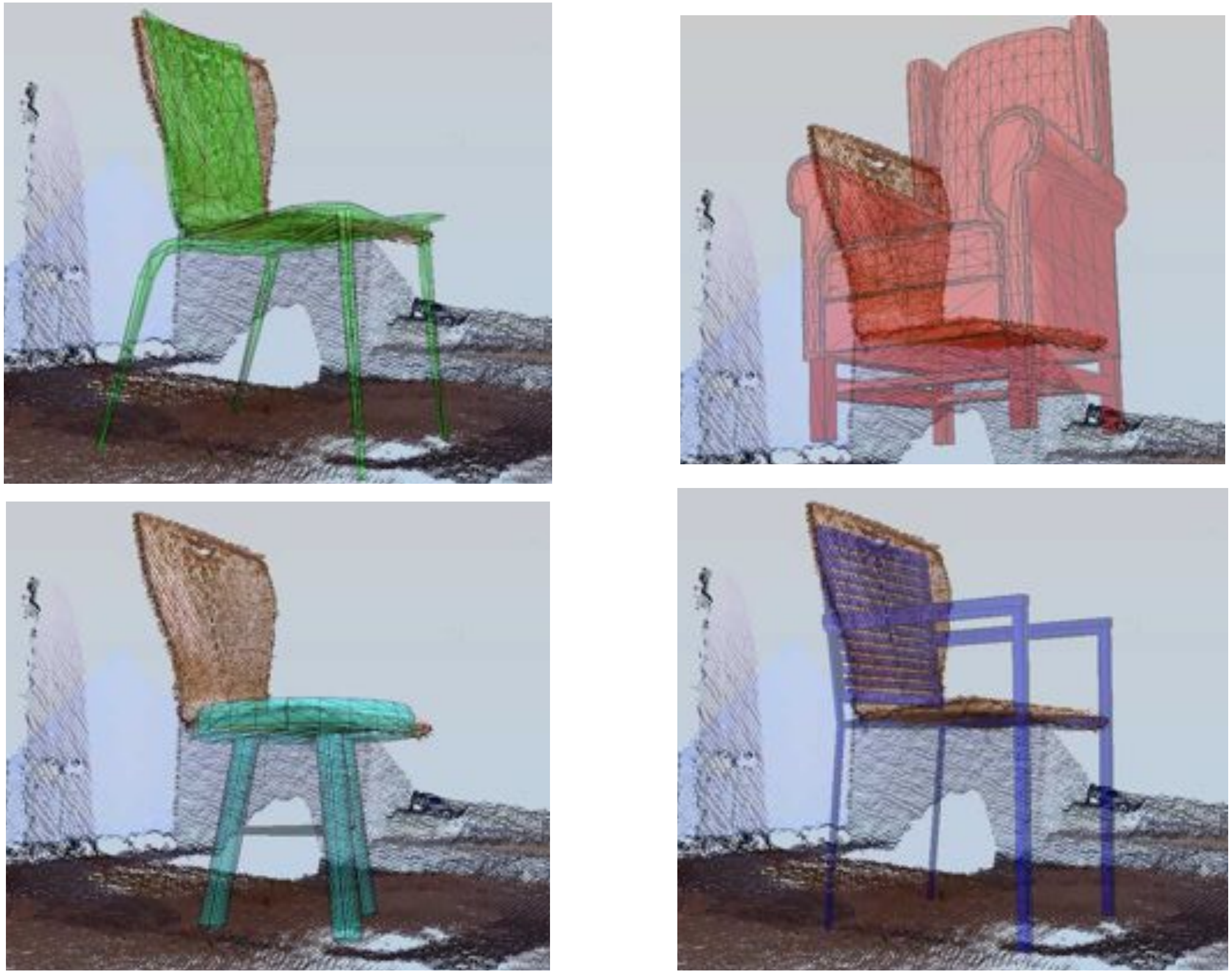
Best Matches depend on …

- … good pose guess and good type guess
- A best match does always exist!



Some Details



Quantitative Results

	final pose error					
	pose 1		pose 2		pose 3	
	$e_{\text{translation}}$	e_{rotation}	$e_{\text{translation}}$	e_{rotation}	$e_{\text{translation}}$	e_{rotation}
chair 1	0.5 cm	0.47°	0.5 cm	0.48°	0.5 cm	0.0°
chair 2	0.0 cm	0.1°	0.1 cm	0.11°	0.0 cm	0.0°
chair 3	0.0 cm	0.04°	0.0 cm	0.04°	0.0 cm	0.01°
chair 4	0.1 cm	0.04°	0.1 cm	0.05°	1.9 cm	34.07°
chair 5 †	3.1 cm	12.22°	2.2 cm	22.55°	3.0 cm	12.77°
chair 6	29.5 cm	3.56°	11.1 cm	42.81°	10.9 cm	42.85°

- Insignificant differences among “plausible” chair models
- Stool and wingchair stick out

† Stool is largely rotation symmetric, don’t regard rotation error!

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Open Issues/Work in Progress

- Care about transparent and shiny objects
- Find criteria for “good enough” match
- Really do multi-modal semantic mapping
- Really do active semantic mapping (to resolve ambiguity, move sensors & manipulate environment)
- Use GIS technology for storing semantic maps (space-related part) compactly and help optimize (some) queries
  - “Give me the list of green tables with at least 1 muffin on”

Thank you for your time!