UTN

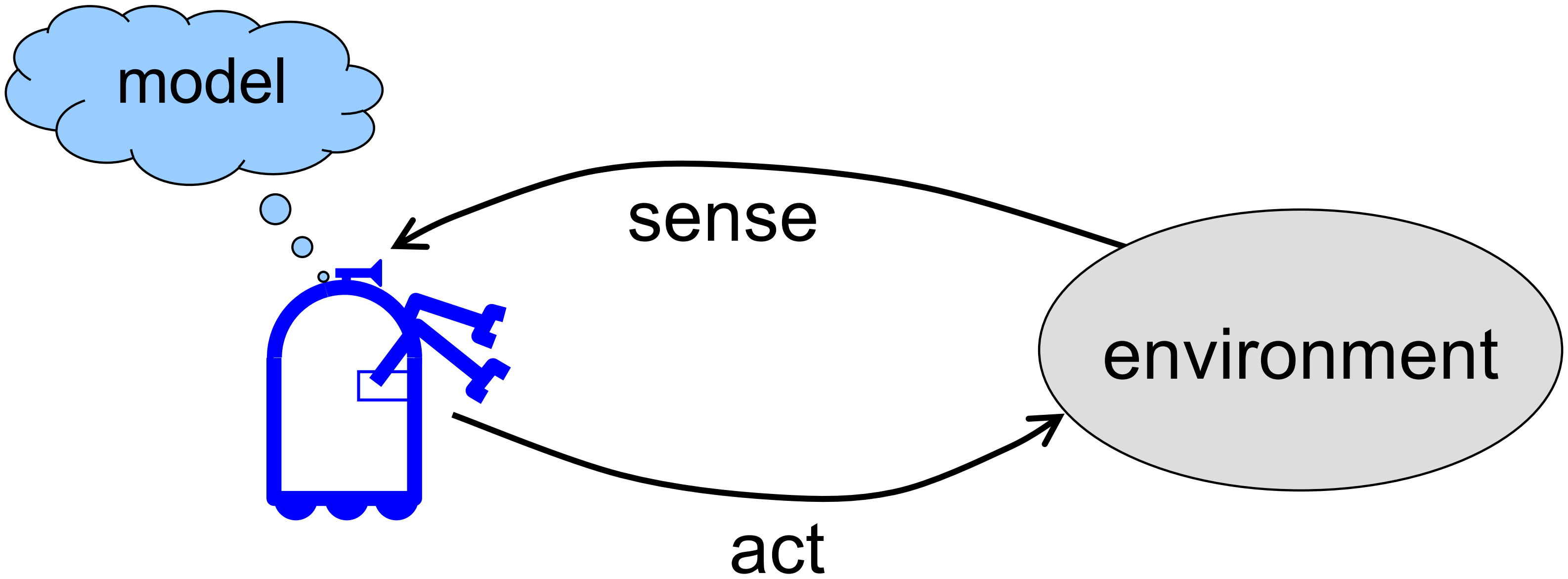
University of Technology Nuremberg

Probabilistic and Deep Learning Techniques for Autonomous Navigation and Automated Driving

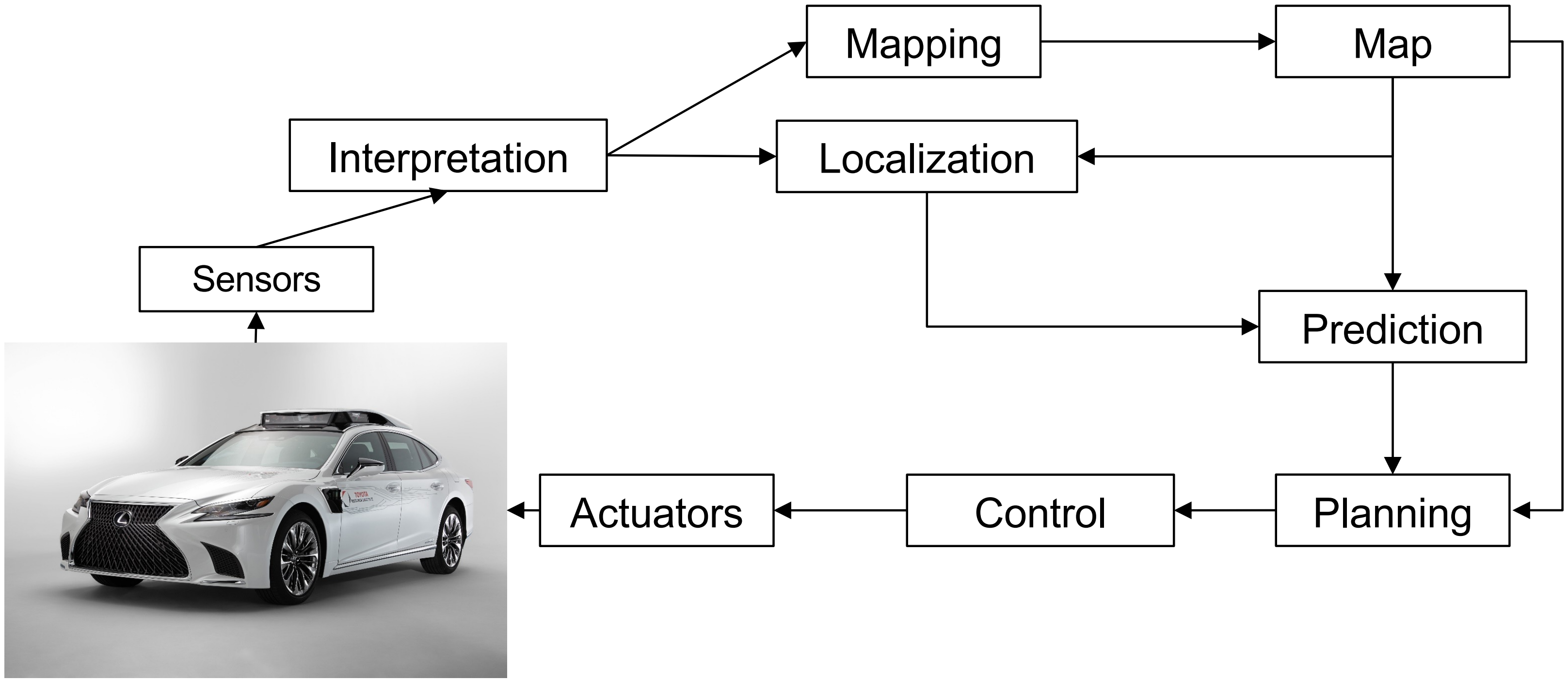
Wolfram Burgard

Autonomous Robots

- Perceive their environment with their sensors,
- build a model/representation, and use it to
- generate their actions



Major Components of the Software-Stack of a Self-Driving Car



Probabilistic Robotics

Explicit representation and utilization of uncertainty

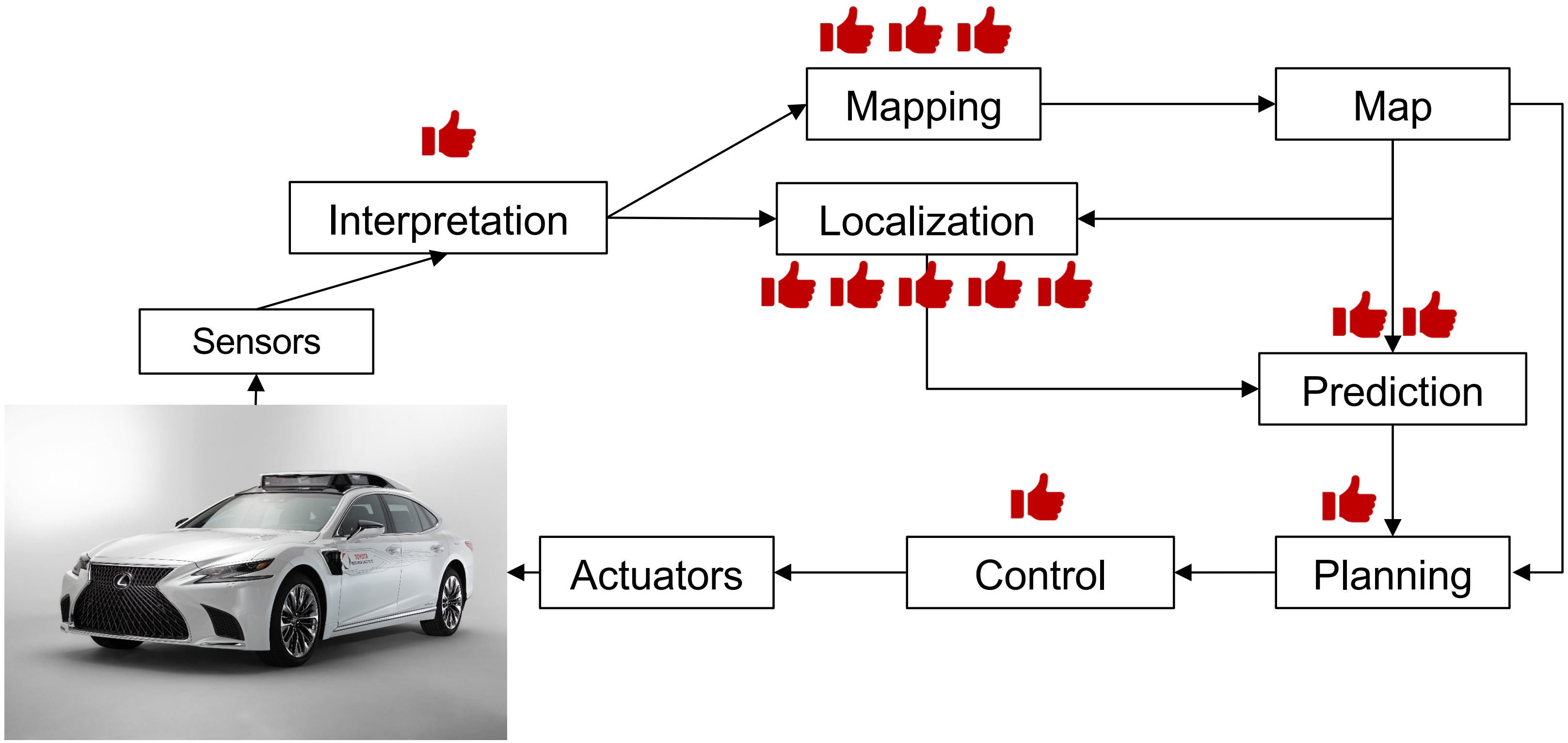
- Perception = state estimation

$$Bel(x \mid z, u) = \alpha\, p(z \mid x) \int_{x'} p(x \mid u, x')\; Bel(x')dx'$$

- Action = utility optimization

$$\pi^*(x) = \operatorname*{argmax}_u \sum_{x'} p(x' \mid u, x) V^*(x')$$

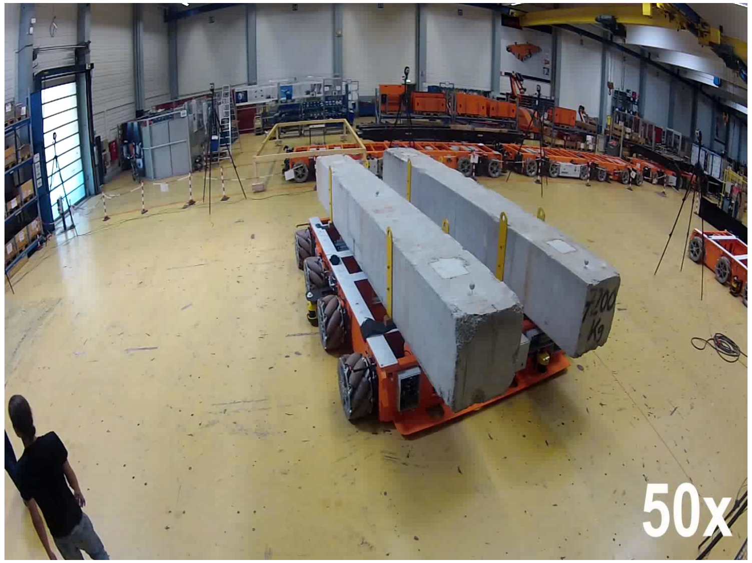
Probabilistic-Robotics-Based…

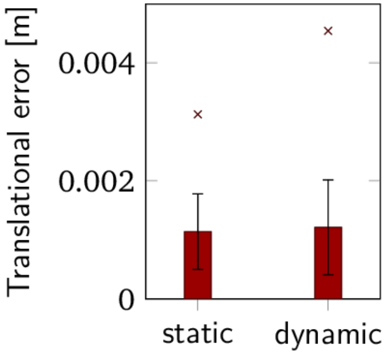


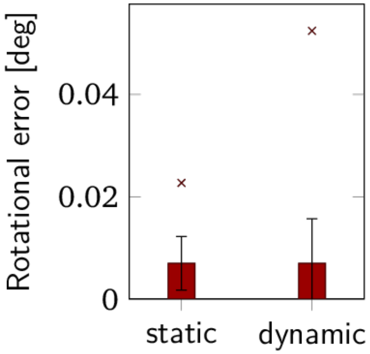
Precise Localization and Positioning for Mobile Robots

Accurate Localization in Dynamic Environments

- KUKA omniMove (11t)
- Safety scanners
- Error in the area of millimeters
- Even in dynamic environments

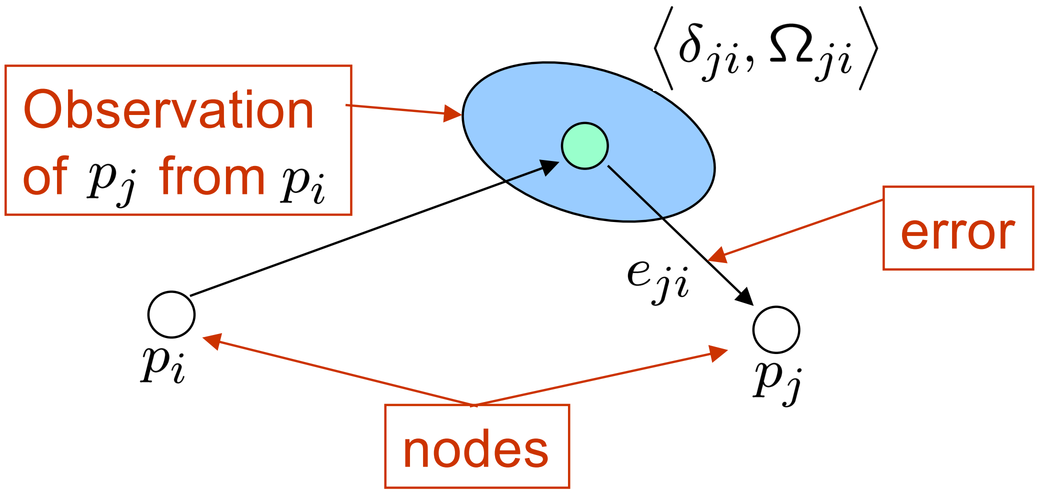






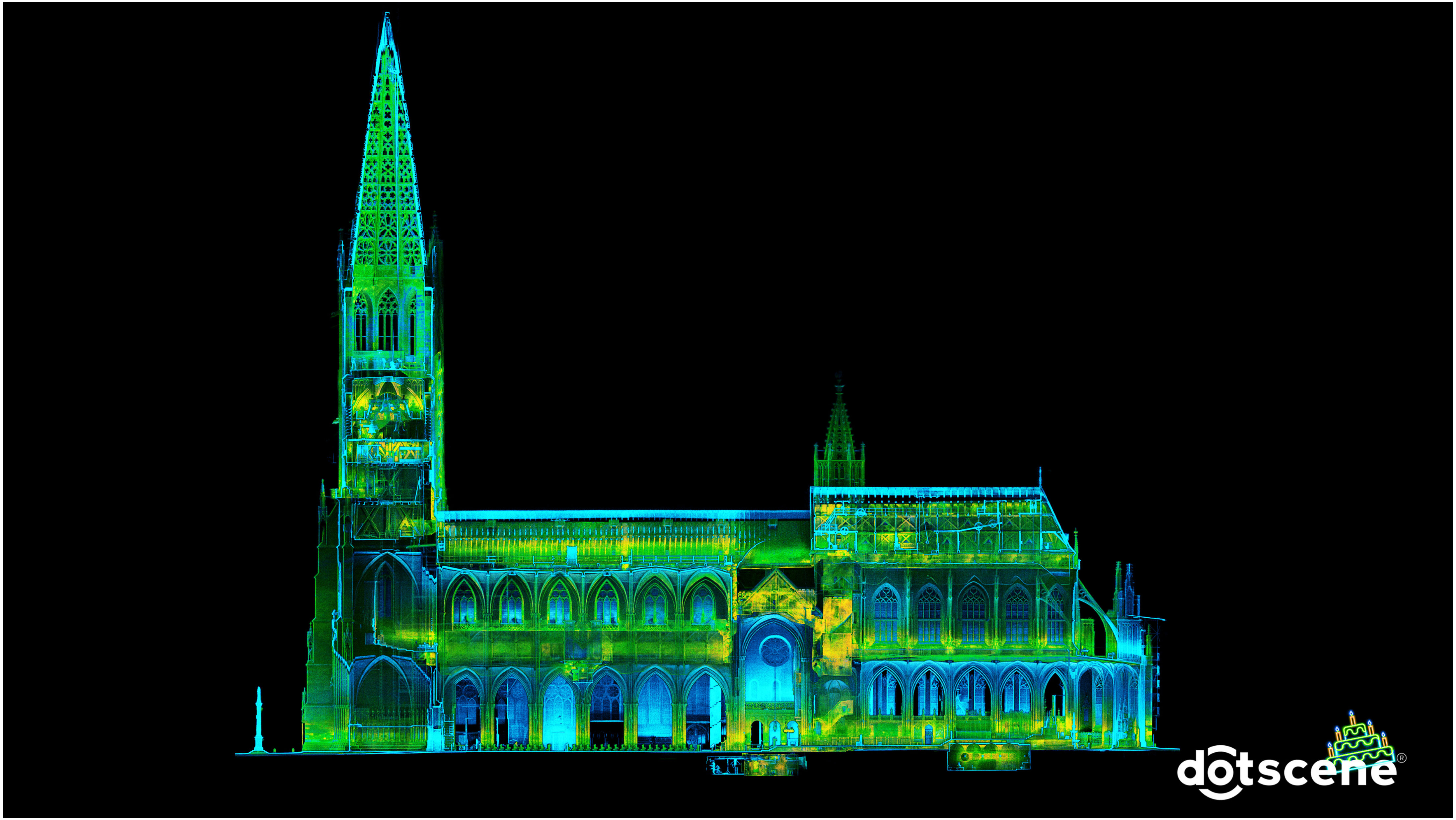
Pose-Graph-SLAM

Goal: Find the poses of the nodes minimizes the negative log likelihood of the observations



$$\mathbf{p}^* = \underset{\mathbf{p}}{\operatorname{argmin}} \sum_{ji} e_{ji}^T \Omega_{ji} e_{ji}$$

dotscene®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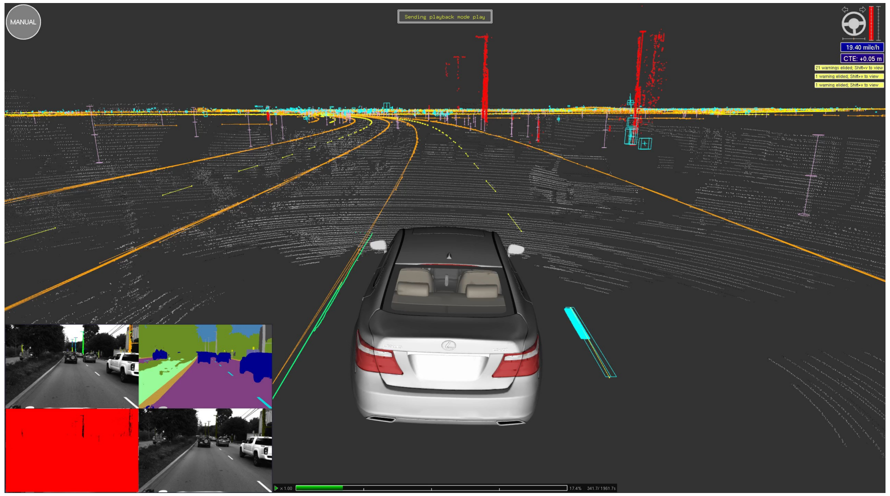
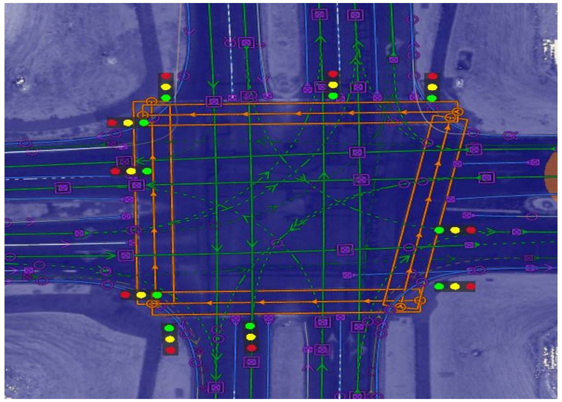
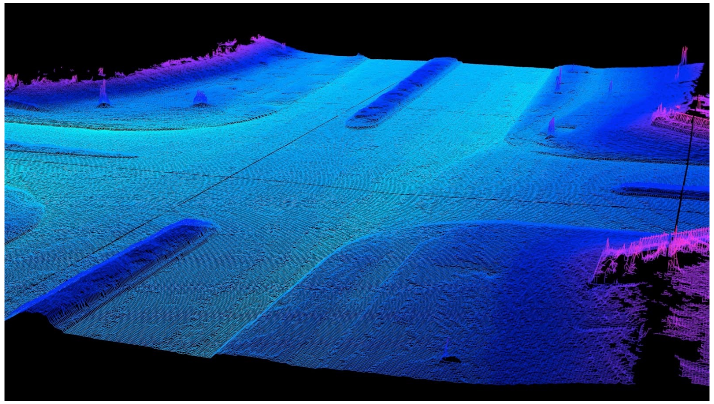
Maps in Automated Driving

Useful for

- Perception
- Tracking
- Localization
- Prediction
- Planning
- Control
- …

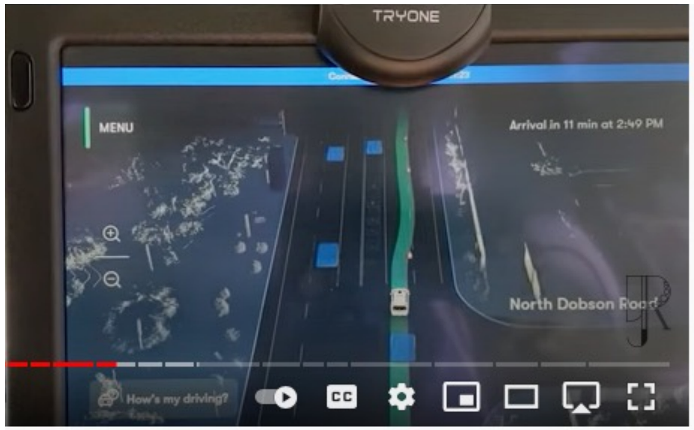




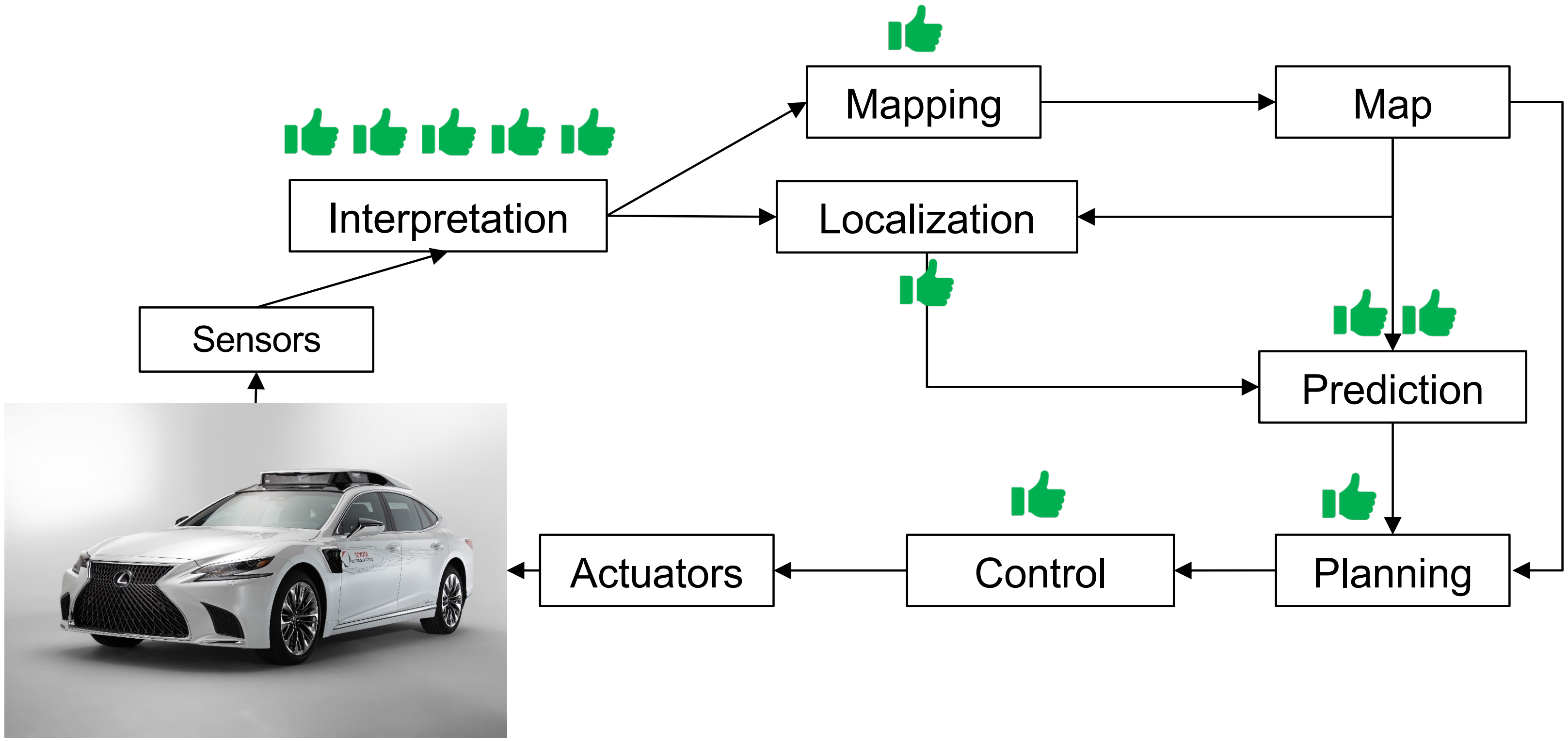


Challenges for HD Maps

- Expensive to acquire
- Assumptions about availability of features
- Change detection
- Domain adaptation
- Expensive to update
- …
- L5 barrier

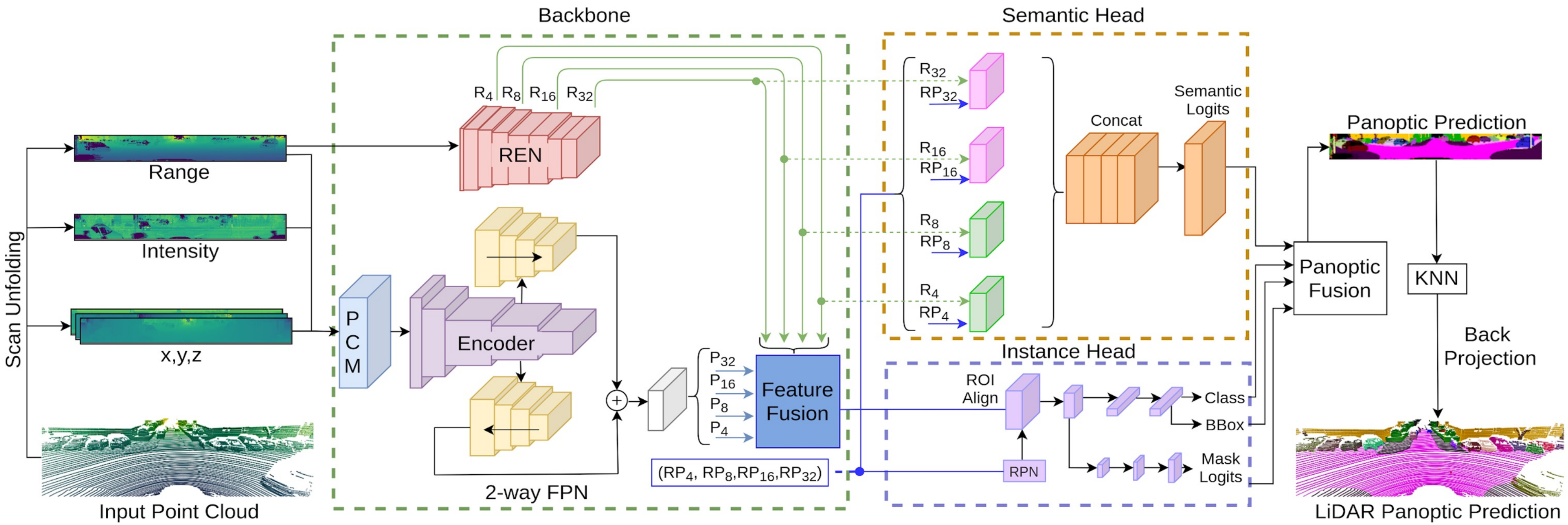


Deep-Learning-Based…



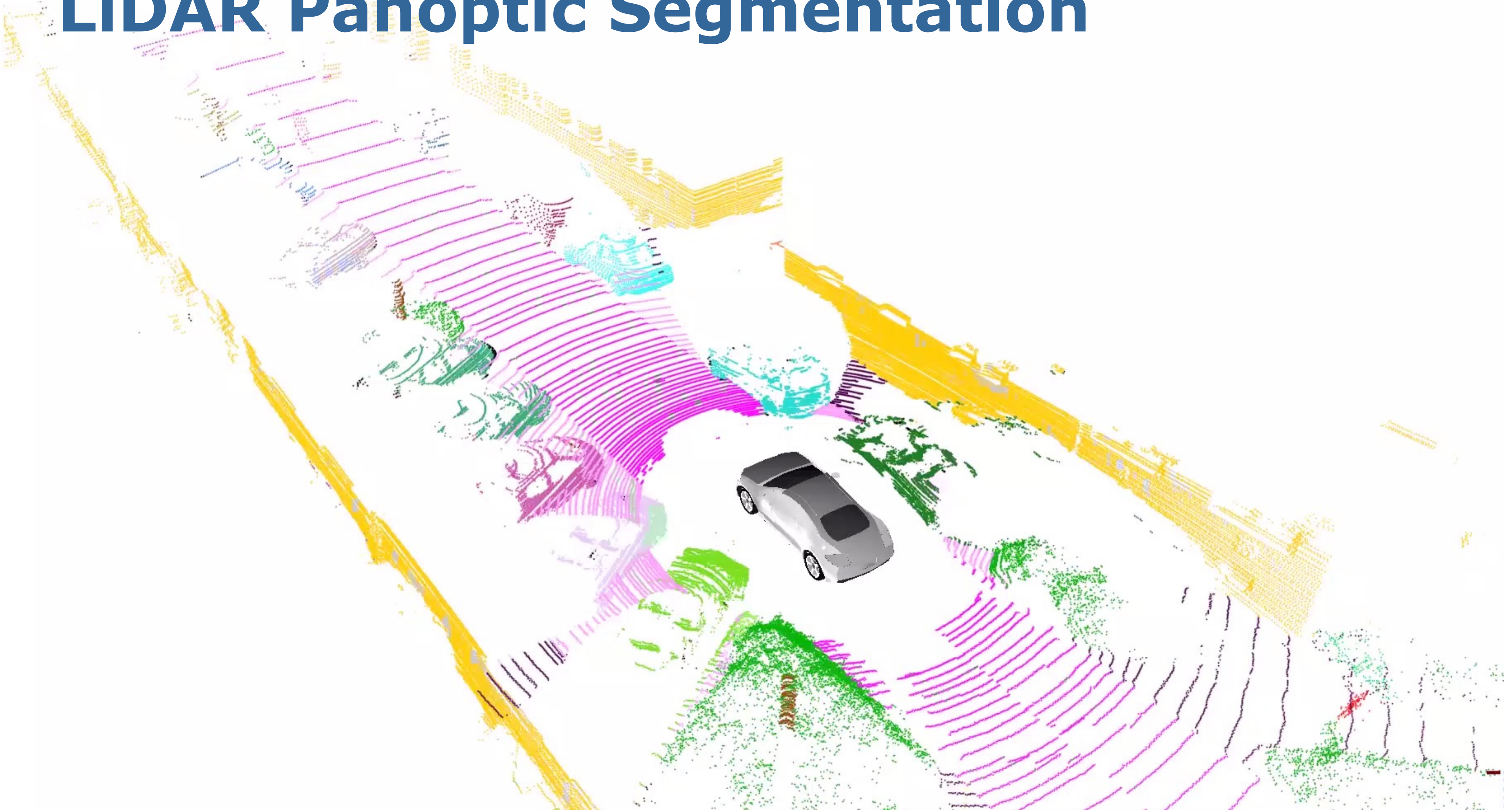
Example: Semantic Segmentation and Panoptic Tracking

EfficientLPS Architecture



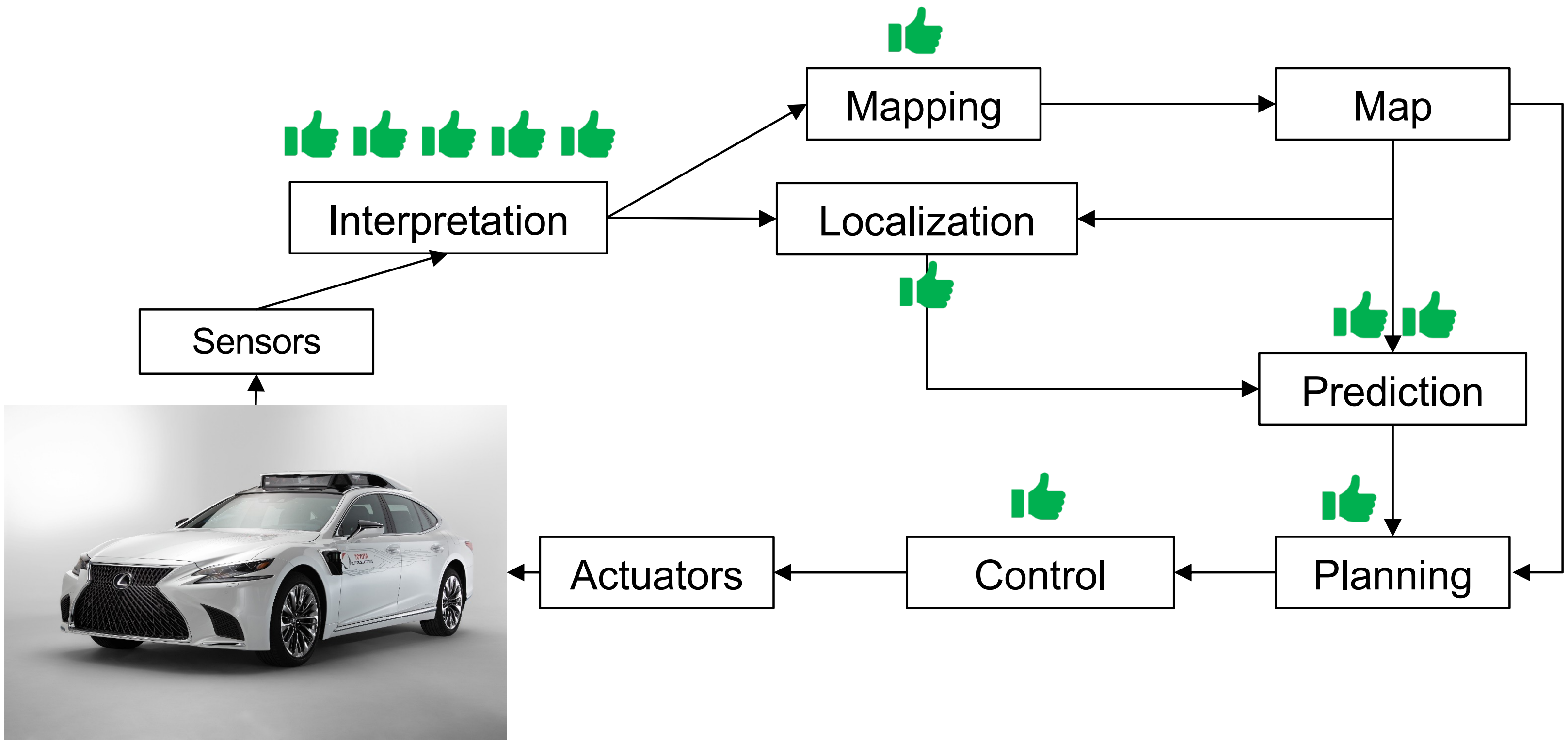
- Scan unfolding projection
- Backbone: PCM + Encoder + REN + 2-way FPN
- Semantic Head, Instance Head, Panoptic Fusion Module
- Reprojection into 3D using kNNs

LiDAR Panoptic Segmentation

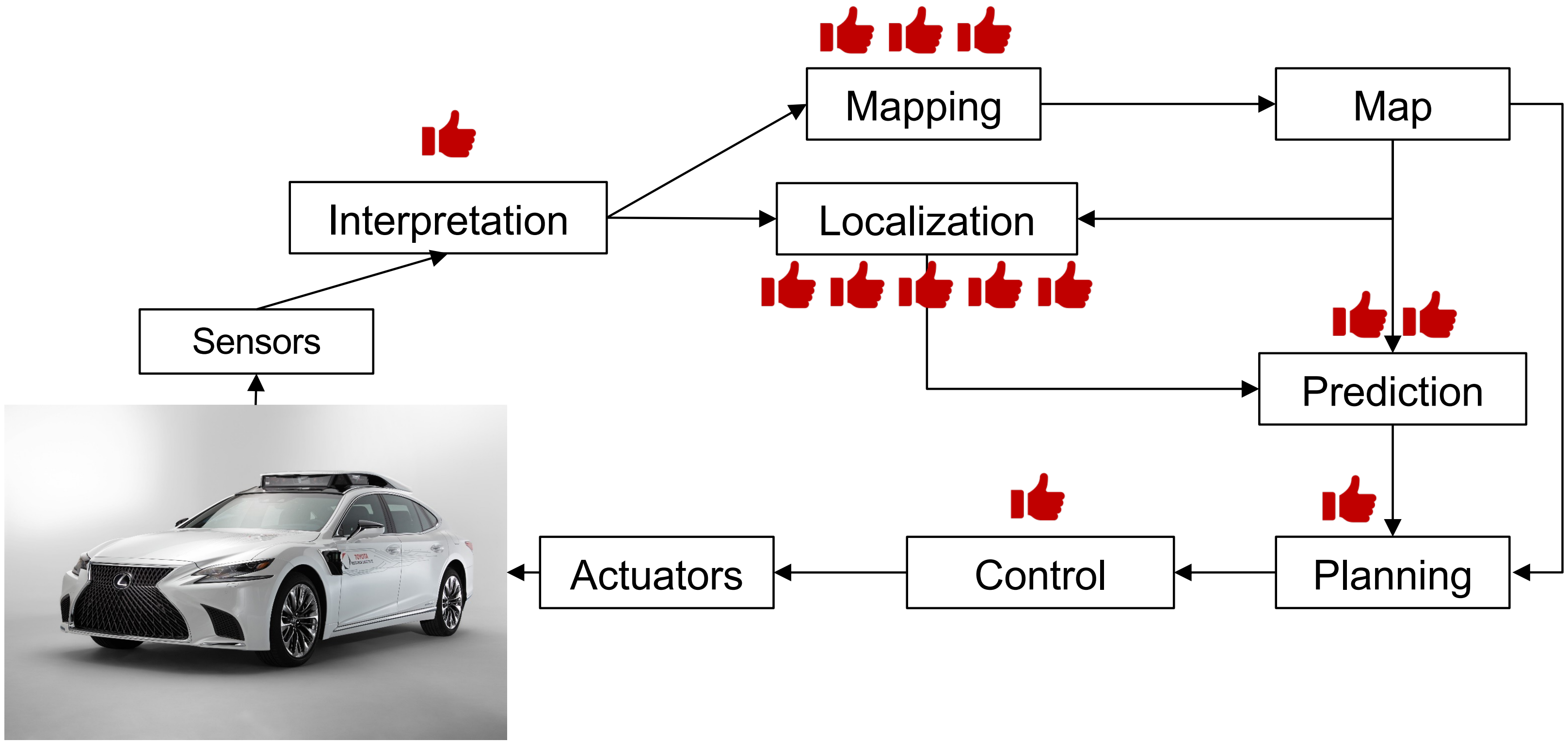


Vision-Based MOPT

Deep-Learning-Based…

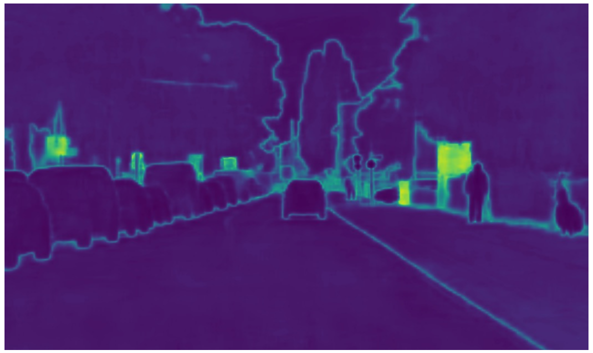


Probabilistic-Robotics-Based…



Example: Uncertainty-Aware Panoptic Segmentation

Semantic segmentation

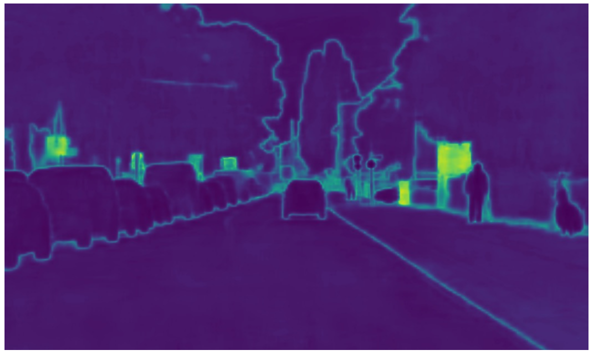


Semantic uncertainties

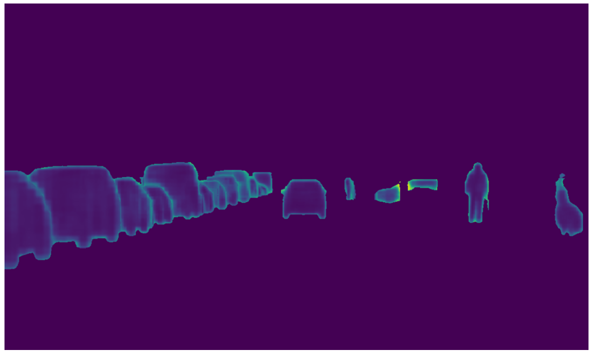
Example: Uncertainty-aware Panoptic Segmentation

Semantic segmentation

Instance segmentation



Semantic uncertainties



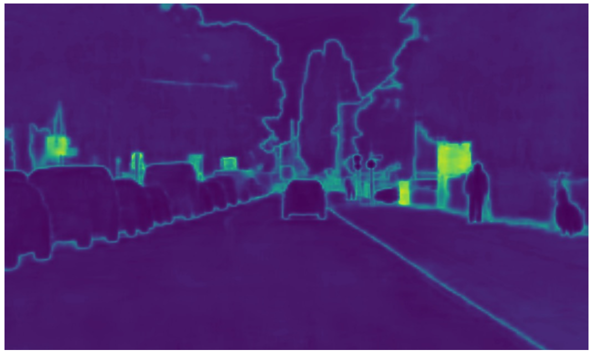
Instance uncertainties

Example: Uncertainty-aware Panoptic Segmentation

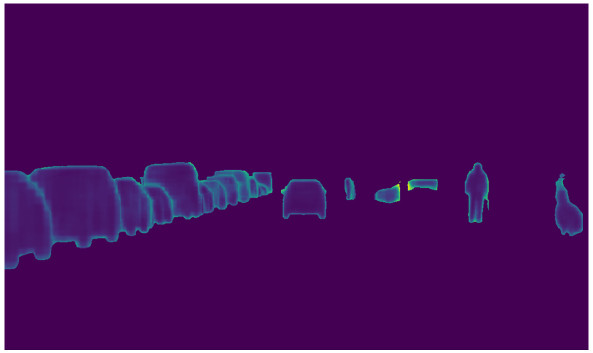
Semantic segmentation

Instance segmentation

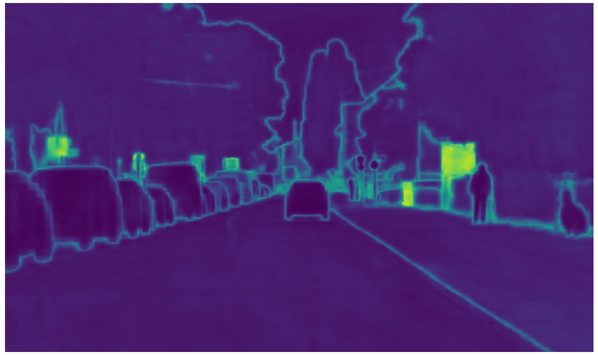
Panoptic segmentation



Semantic uncertainties

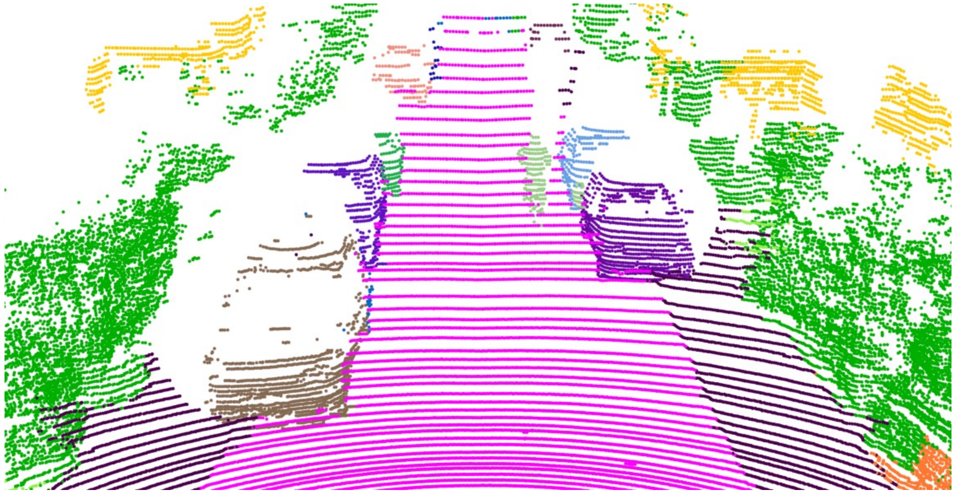


Instance uncertainties

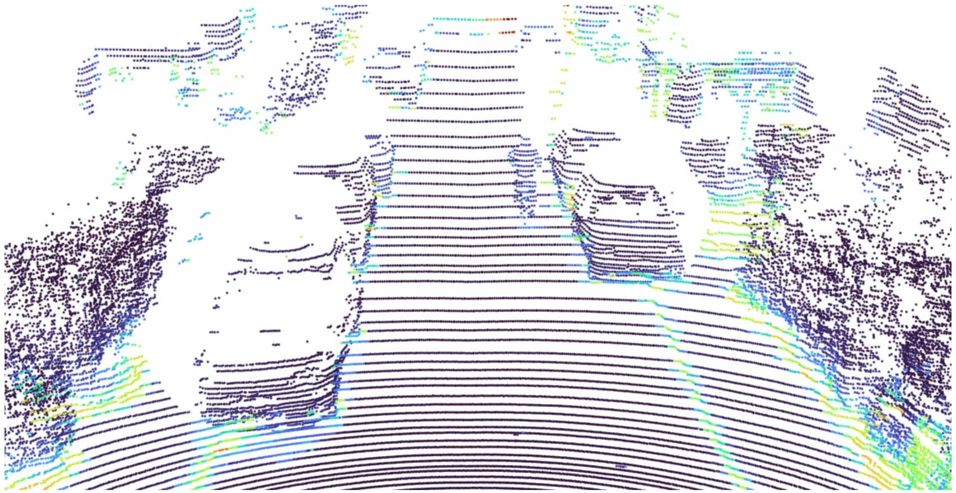


Panoptic uncertainties

Uncertainty-aware LiDAR Panoptic Segmentation

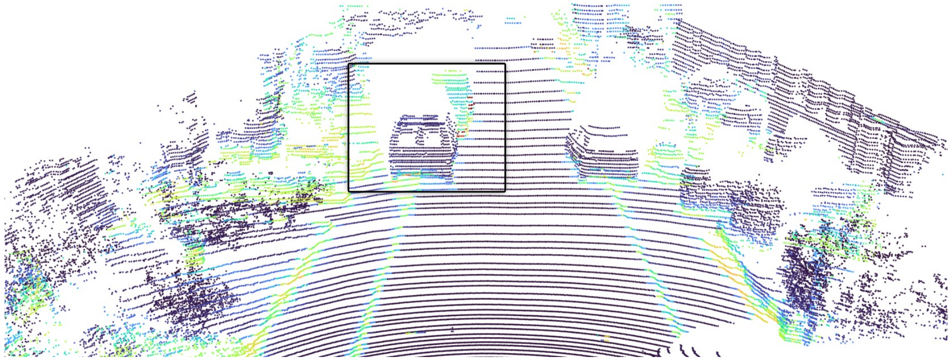


Panoptic segmentation

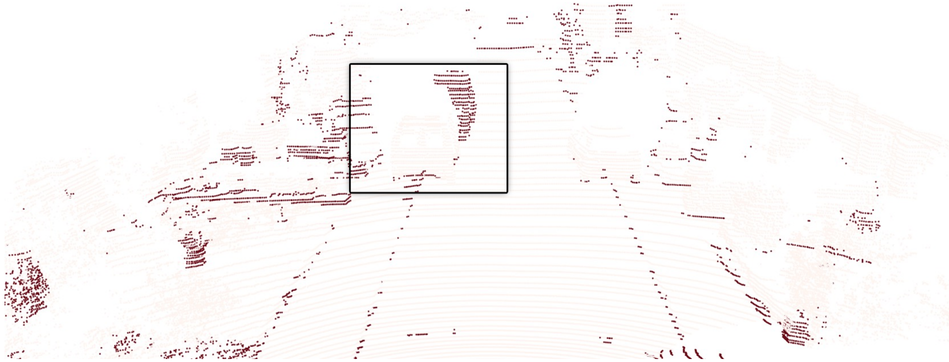


Panoptic uncertainties

Qualitative Results: Uncertainty vs Error

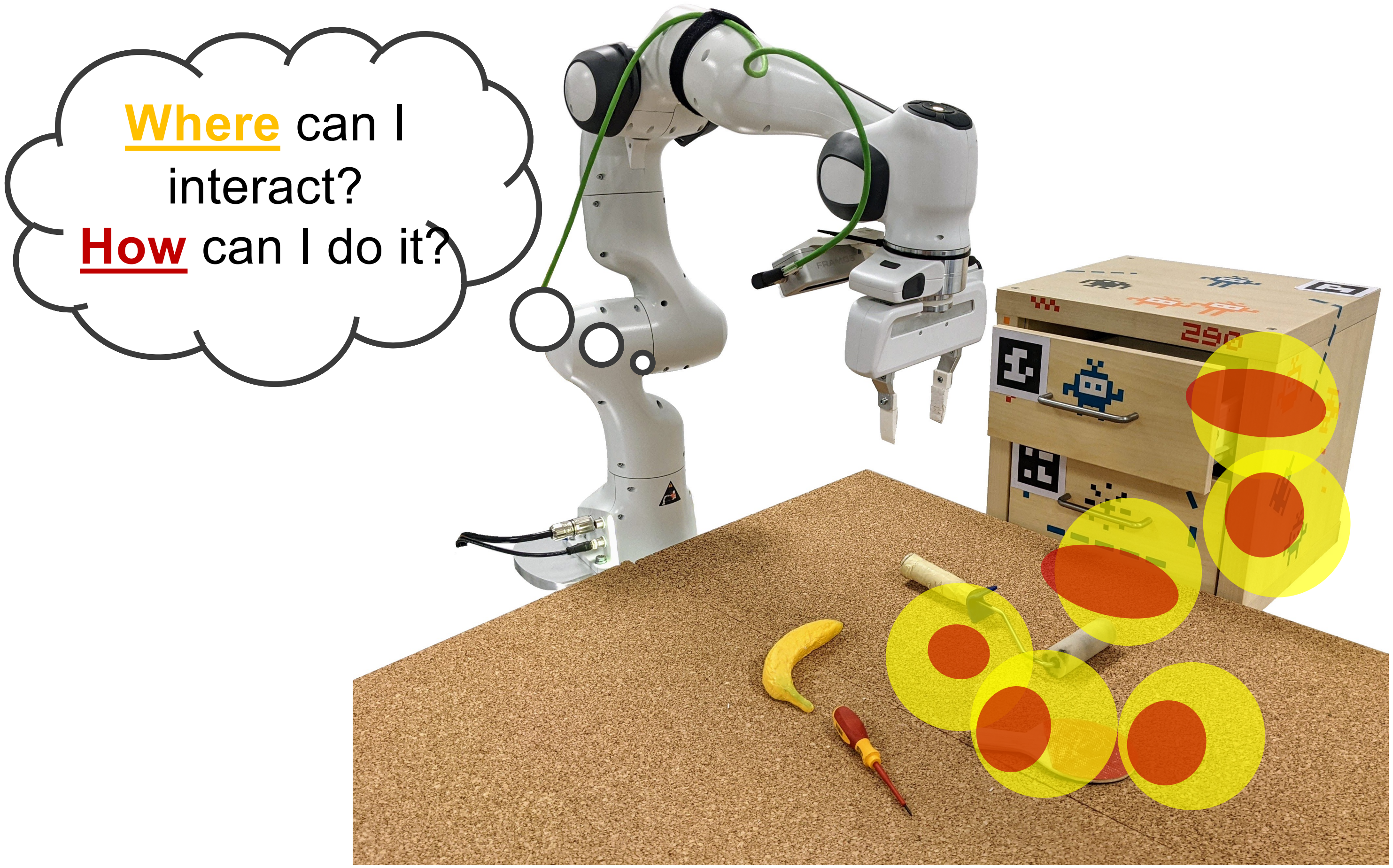


Panoptic uncertainties



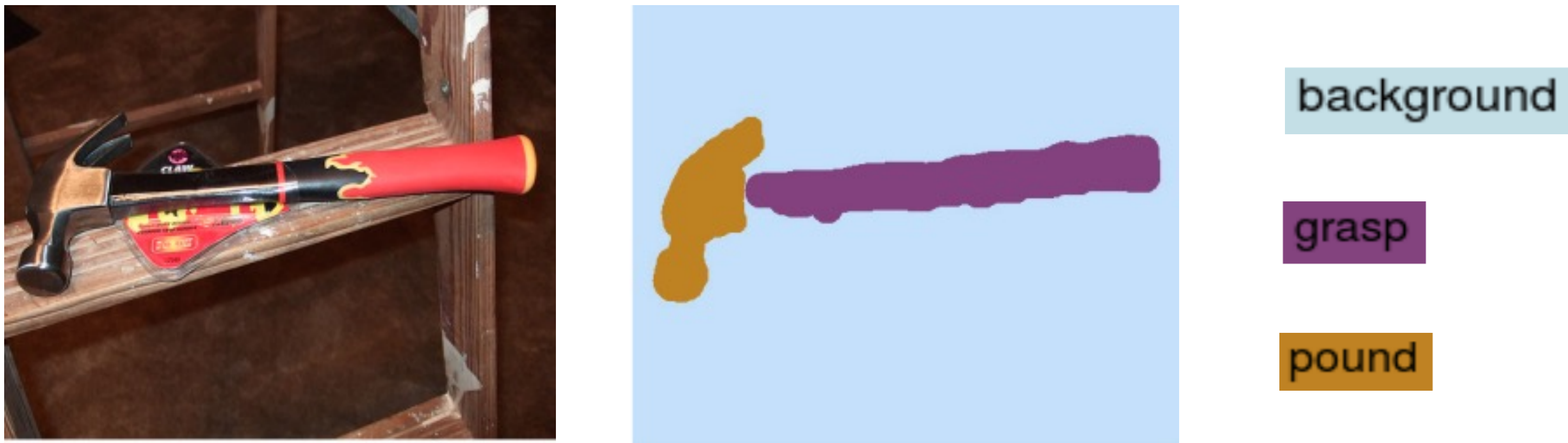
Error map

Learning Manipulation Tasks



Current Affordance Learning Methods

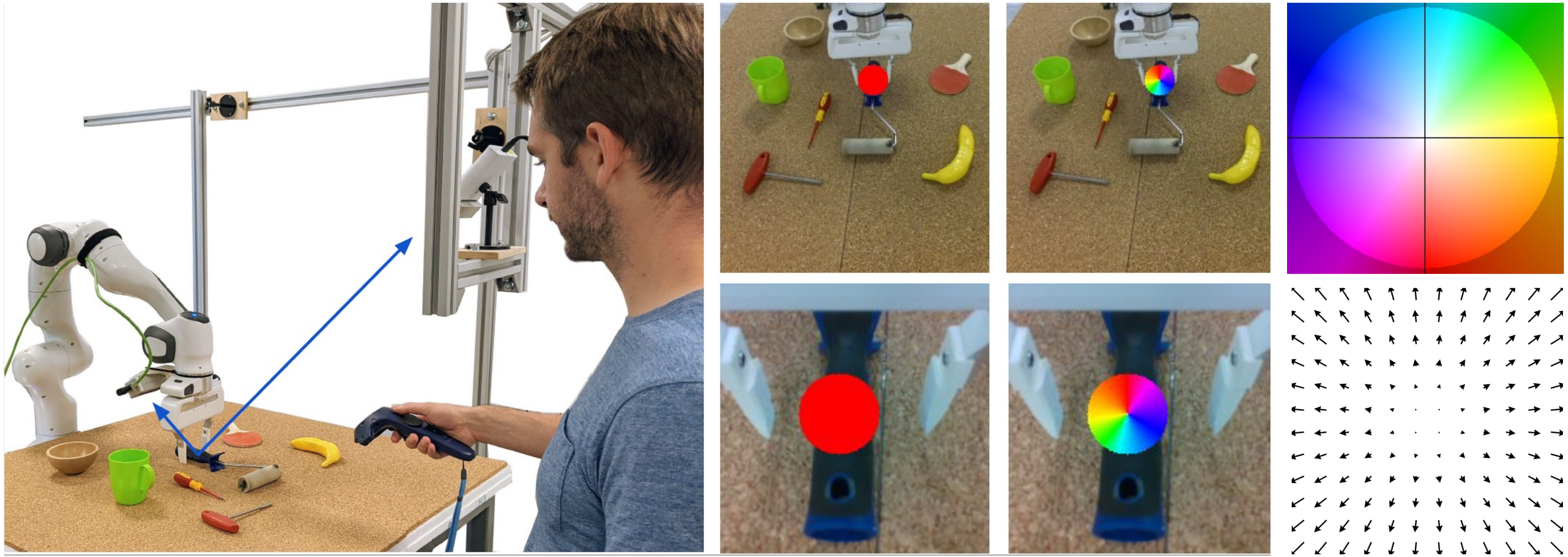
- Require heavy supervision
- Limited in the complexity of the actions they model



[Nguyen et al. 2017]

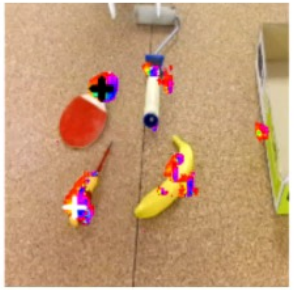
Learning Affordances from Play data

- Play data is structured by human knowledge of object affordances
- Implicitly contain human affordances

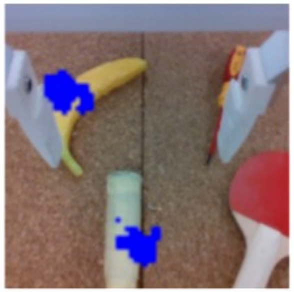


Real-world Experiments

Selected affordance region

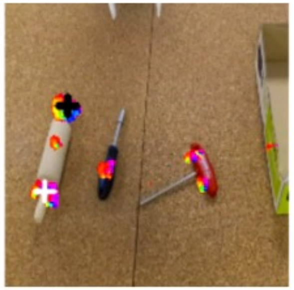


Detected affordance region center

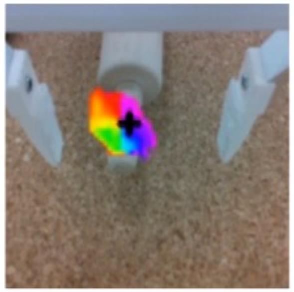


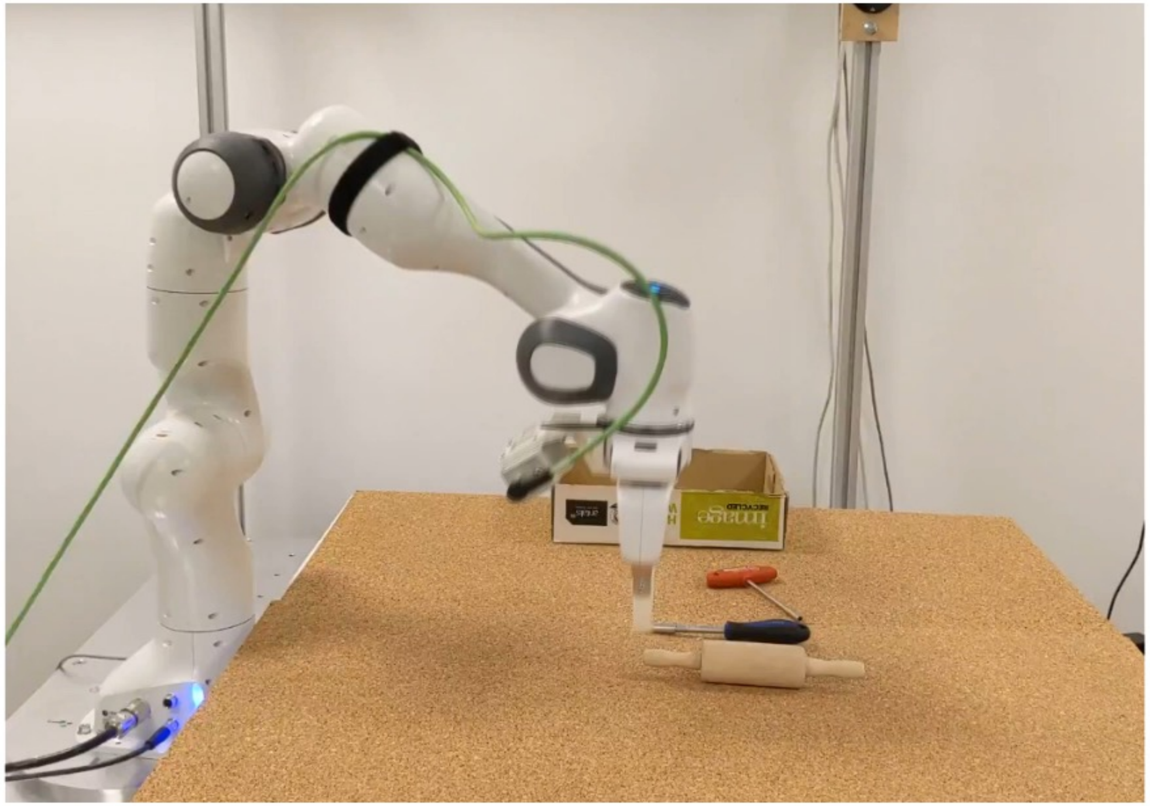
Real-world: Generalization

Selected affordance region



Detected affordance region center





Visual Language Maps for Robot Navigation

Chenguang Huang[1], Oier Mees[1], Andy Zeng[2], Wolfram Burgard[3]

[1]Freiburg University, [2]Google Research, [3]University of Technology Nuremberg

Visual Language Models for SLAM

CLIP

Sorting of objects:

„Photo of a …“

GPT3

Generating potential room types:

„I think I see a ( ), ( ) and ( ) in here. Therefore, this place is most probably a …“

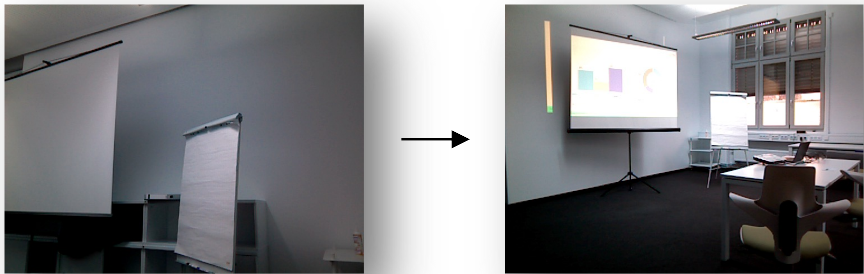
CLIP

Sorting of room types:

„Photo of a …“

Similarity measure:

- Stationary objects
- Room types
- Movable objects

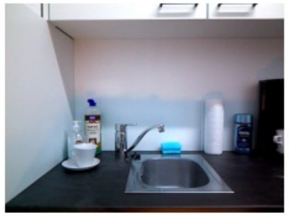


First Results

kitchen

query image:

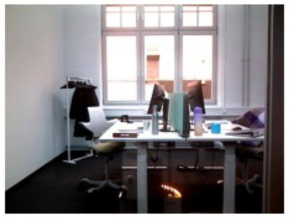
reference image:

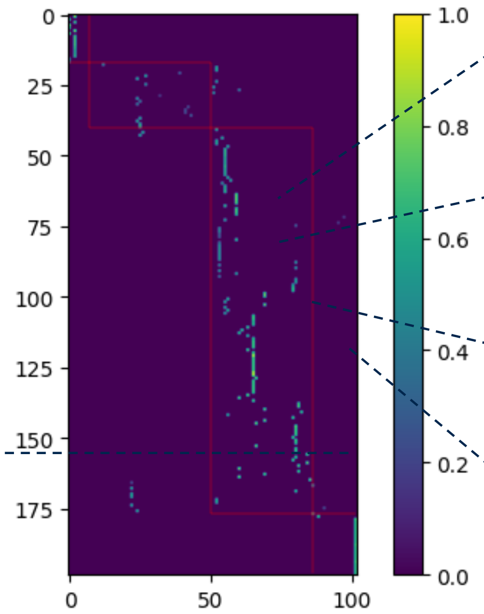


office

query image:

reference image:

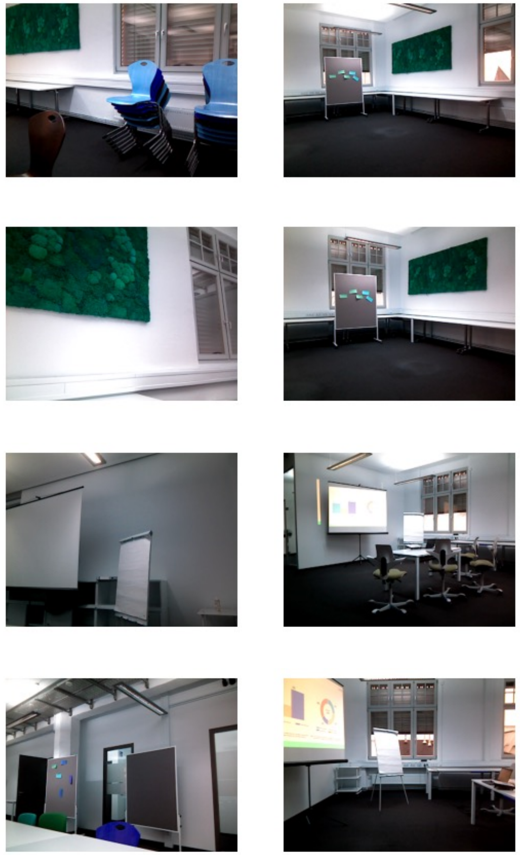




meeting room

query image:

reference image:



Summary

- **Deep Learning is taking over** more and more tasks
- **Probabilistic state estimation** still plays an **important role**
- To integrate both, we need **deep learning approaches** with **properly calibrated likelihoods**
- We lack good **solutions without "argmax"** operations anywehere in the stack
- Language models open a new direction in navigation
- **Decision making under uncertainty is key!**

Thank You!