

25 years of 3D Perception and Navigation

Foundations
and Future
Challenges



Prof. Dr. Andreas Nüchter

The image depicts how our robot Irma3D sees itself in a mirror. The laser looking into itself creates distortions as well as changes in intensity that give the robot a single eye, complete with iris and pupil. Thus, the image is called "Self Portrait with Duckling".

How it started

From the very beginning...

- End of 90's - Introduction of 2D laser scanners and their wide apaption in industry (2D laser scan)

- Limited use in everyday and challenging environments

(Video Crash)

(Video NoCrash)

(Video)



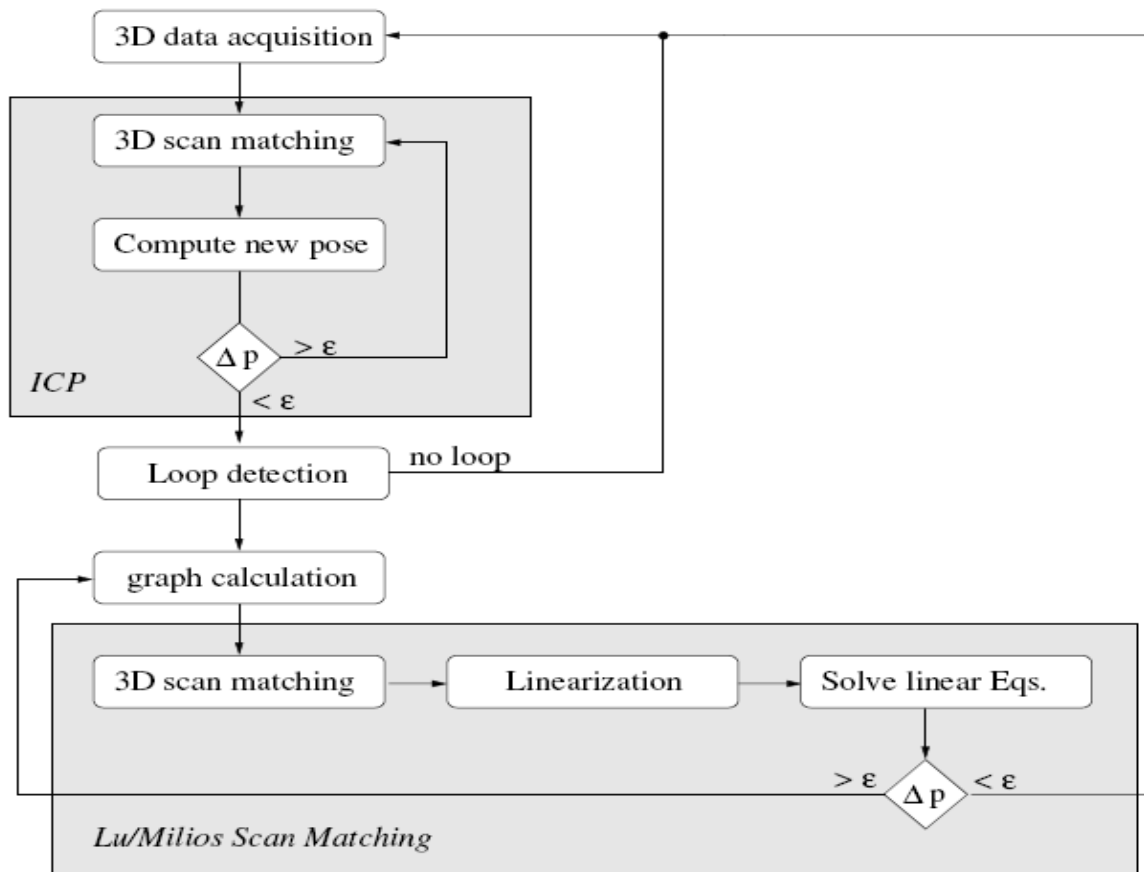
SLAM with 6DoF based on ICP

- Iterative Closest Point
- Loop Detection
- Global Relaxation based on GraphSLAM

$$E = \sum_{j \rightarrow k} \sum_i |\mathbf{R}_j \mathbf{m}_i + \mathbf{t}_j - (\mathbf{R}_k \mathbf{d}_i + \mathbf{t}_k)|^2$$

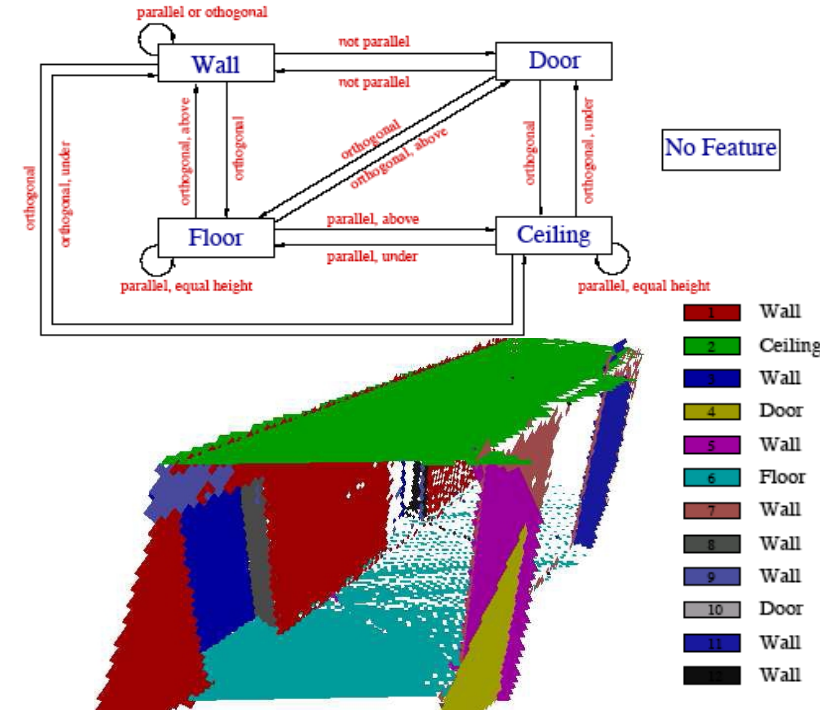
Minimize for all rotations $\mathbf{R}$ and translations $\mathbf{t}$ at the same time

(video)



6DSLAM with semantics

- Plane extraction with
 - RANSAC
 - fast, reliable 3D Hough Transform
 - Region Growing
- Object Detection with hand crafted features and SVM / AdaBoost



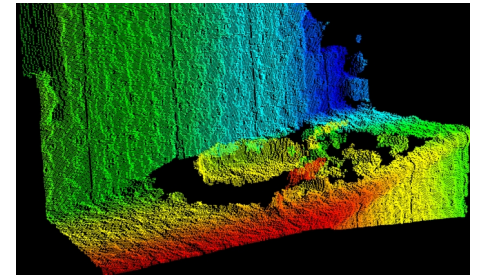
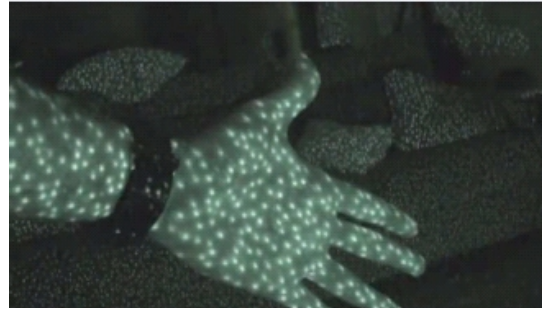
(video)

How is meaning of a symbol to be grounded in something other than just more meaningless symbols?

How it developed

Arrival of new sensors

- Microsoft's Kinect democratized 3D point clouds by turning expensive industrial depth-sensing technology into an affordable, consumer-grade device.



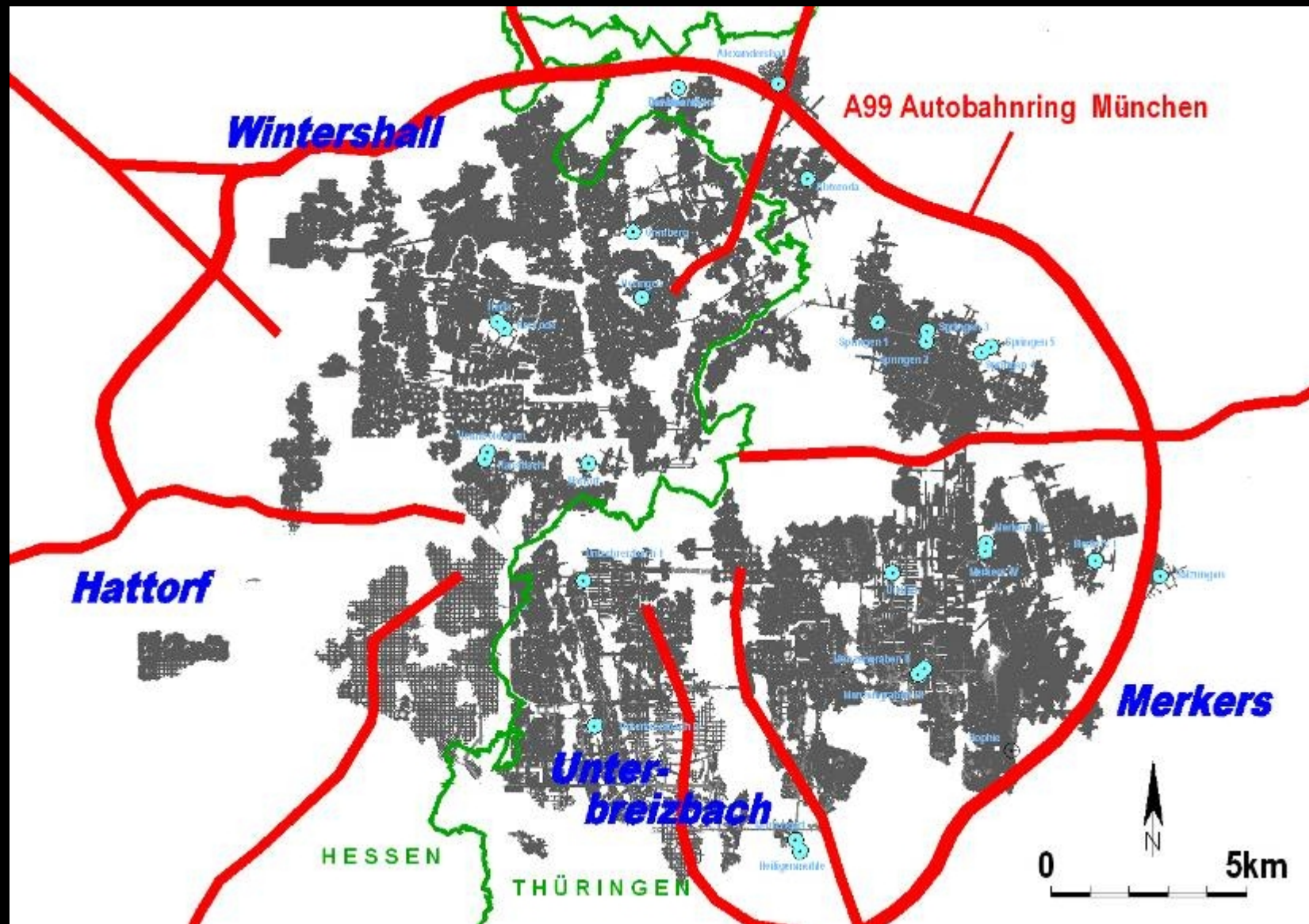
- TOF cameras appeared
- Many laser scanning manufactures entered the market

Point Clouds Everywhere

Underground



(video) 10



Underground

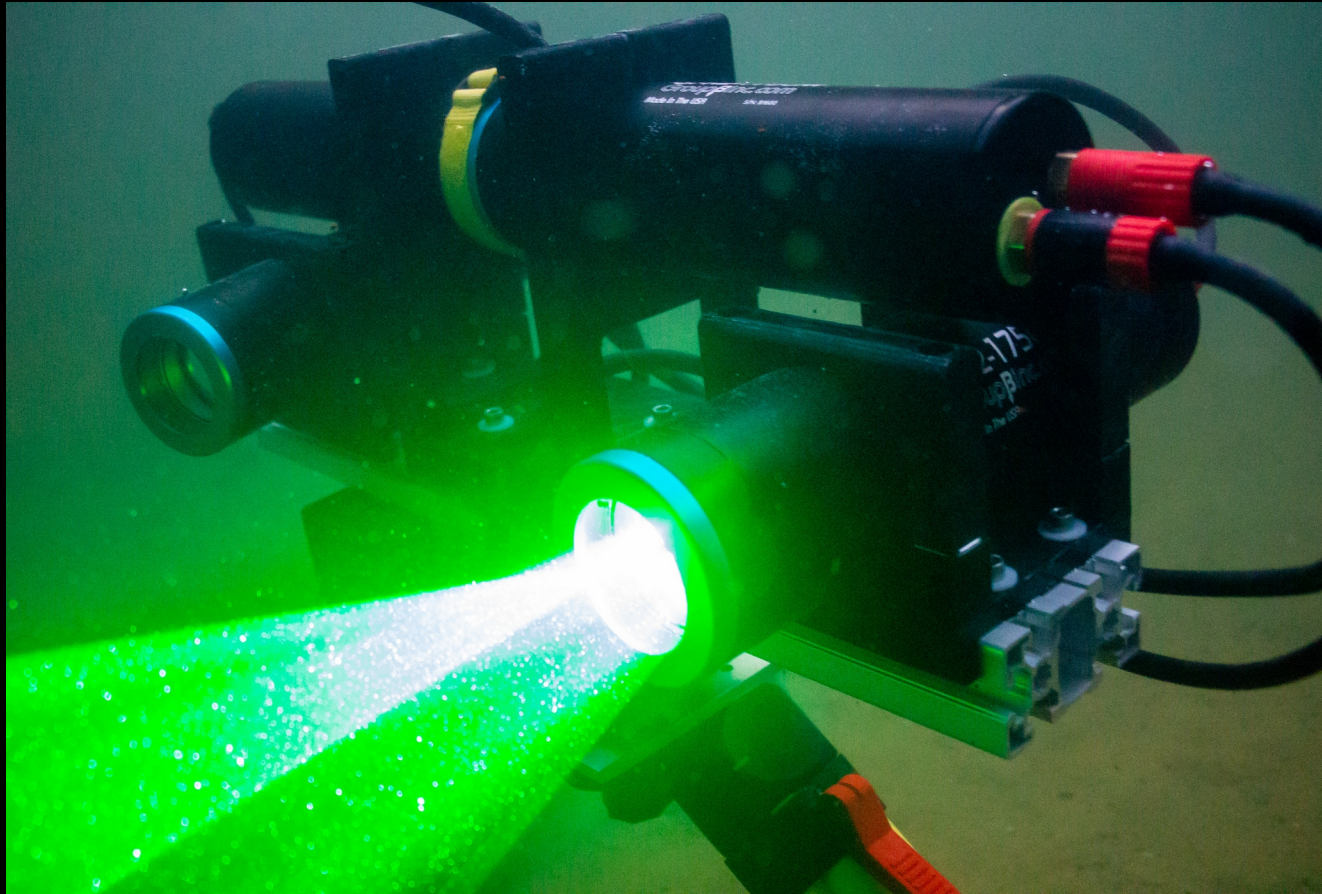
**Helge A.
Lauterbach**

**Dorit
Borrmann**

**Matthias
Maurer**



Underwater



Underwater



(video) 14

On the ground

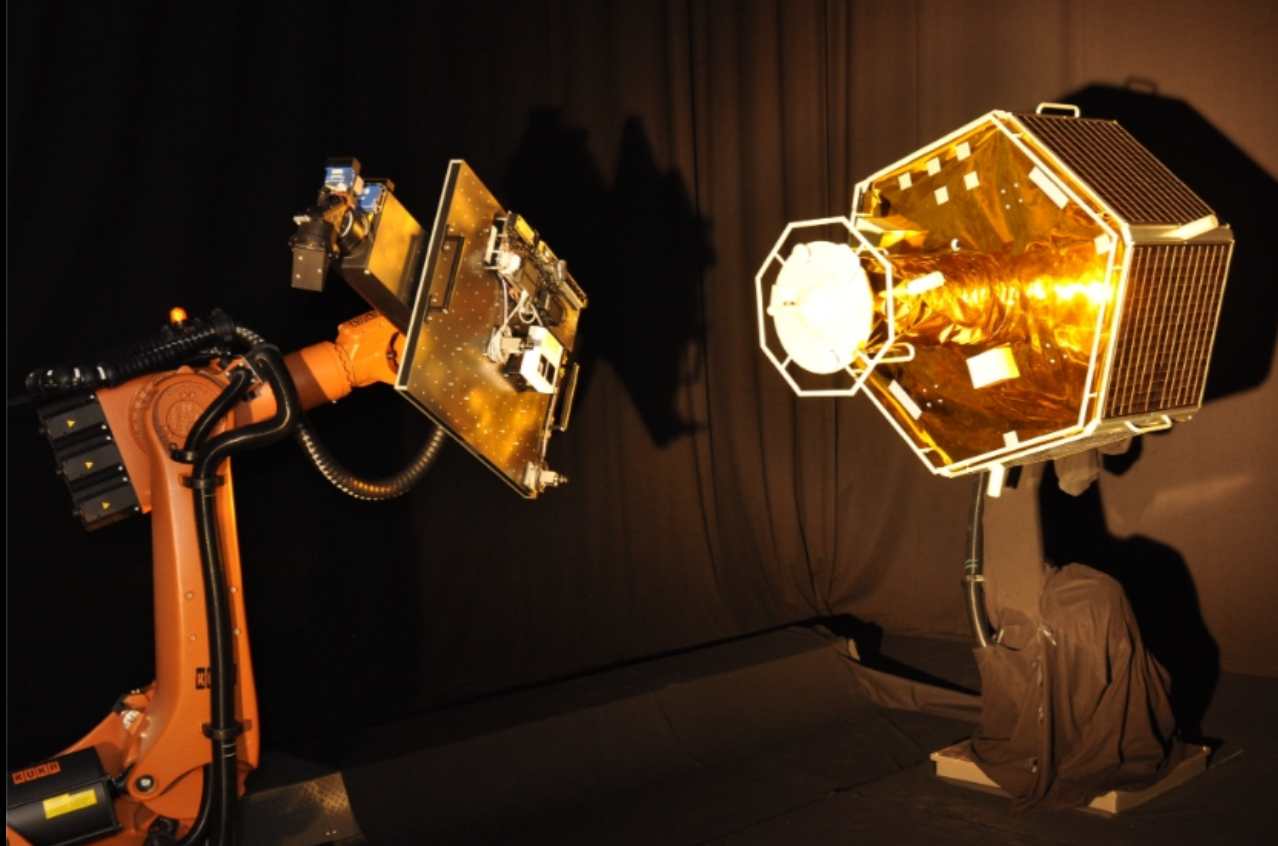


Airborne



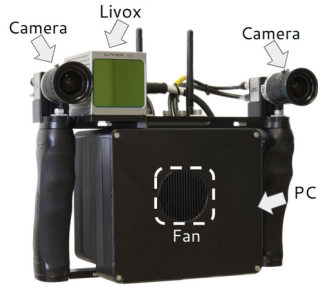
(video)

In Space

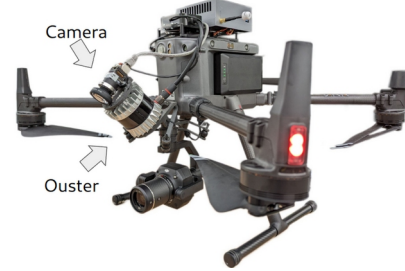


How it's going

SceneFactory – 3D mapping with various inputs



(a) Schloss (RGB-L)
Large-scale (~80x50m)



(b) Univ land (RGB-L)
Very-large-scale (~300x200m)



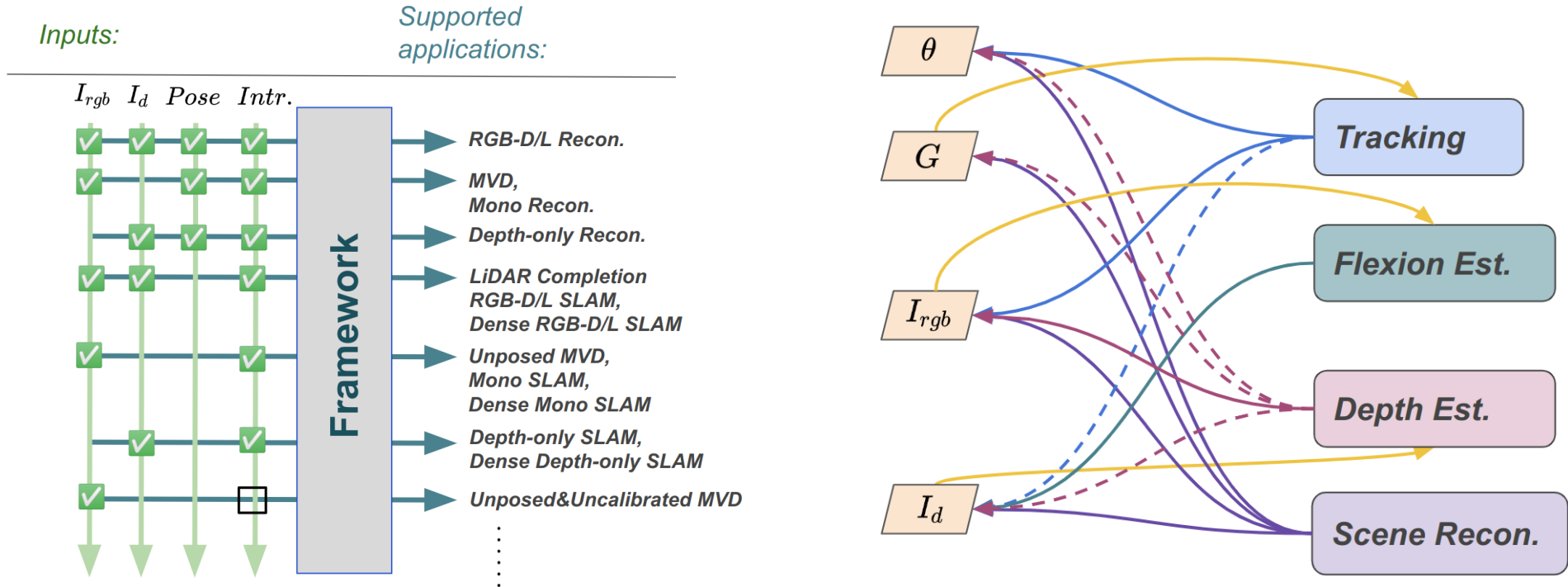
(c) Robotics hall (RGB-D)
Mid-scale (~20x10m)



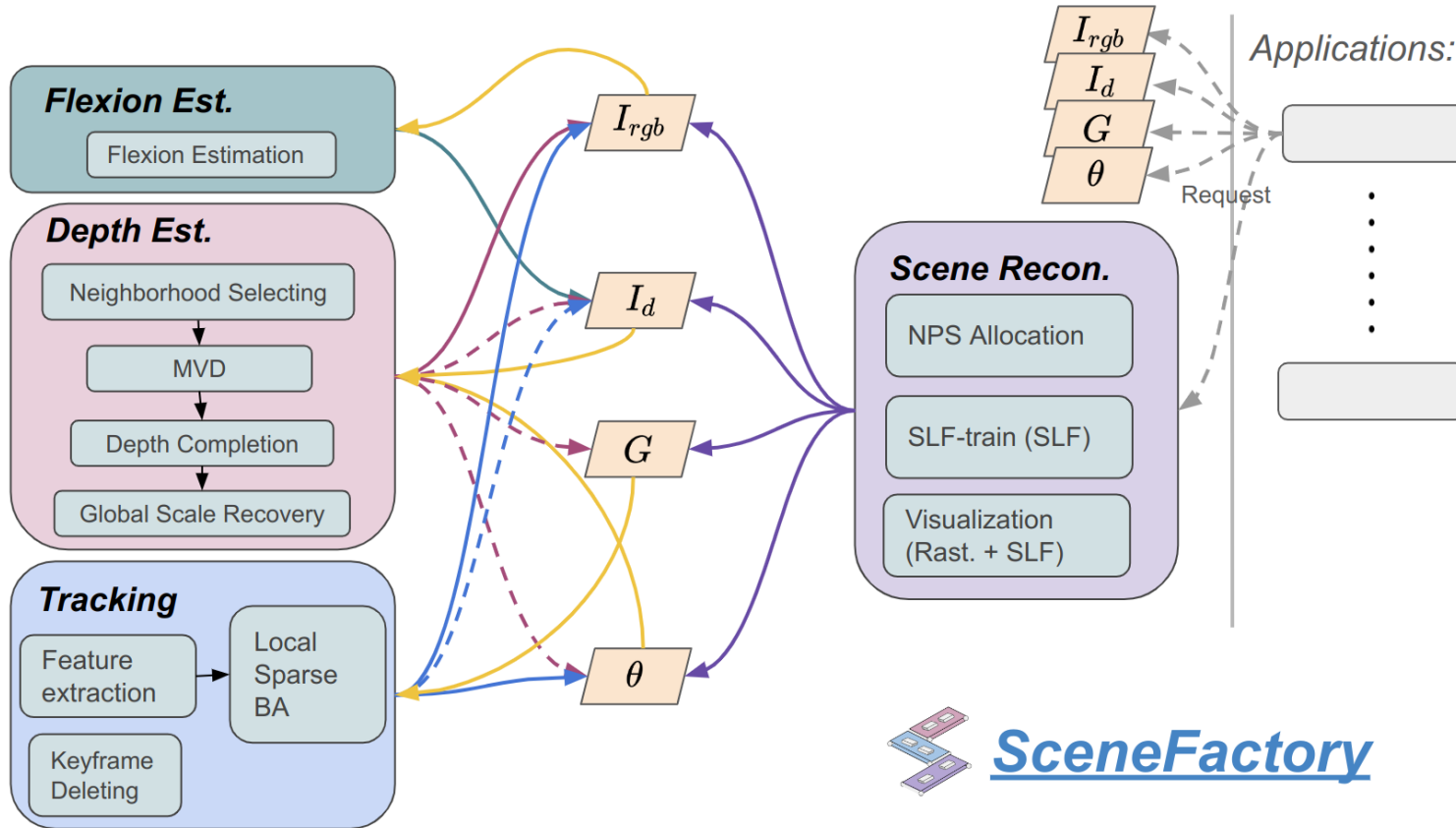
(d) Living room (RGB)
Small-scale (~5x5m)

SceneFactory

- Four production units Connected with Dependency Graph



SceneFactory – Framework

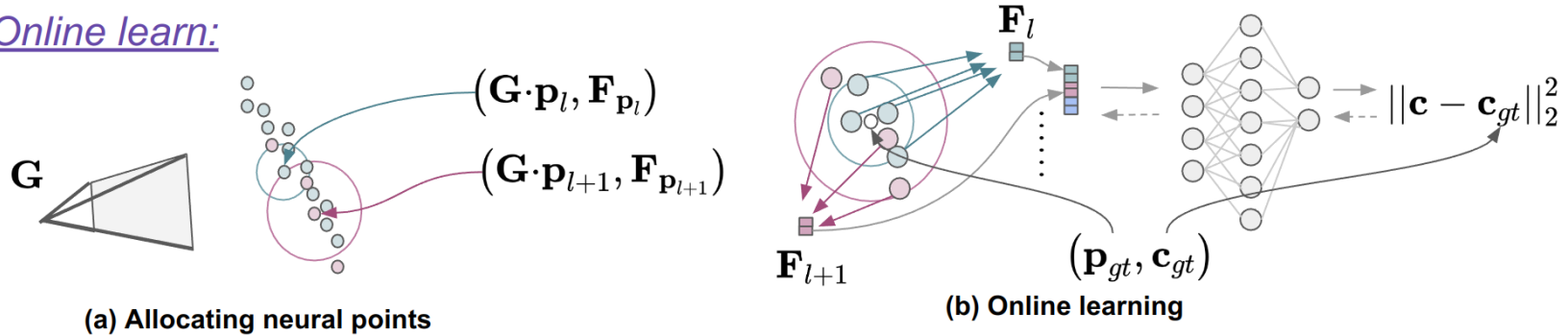


SceneFactory

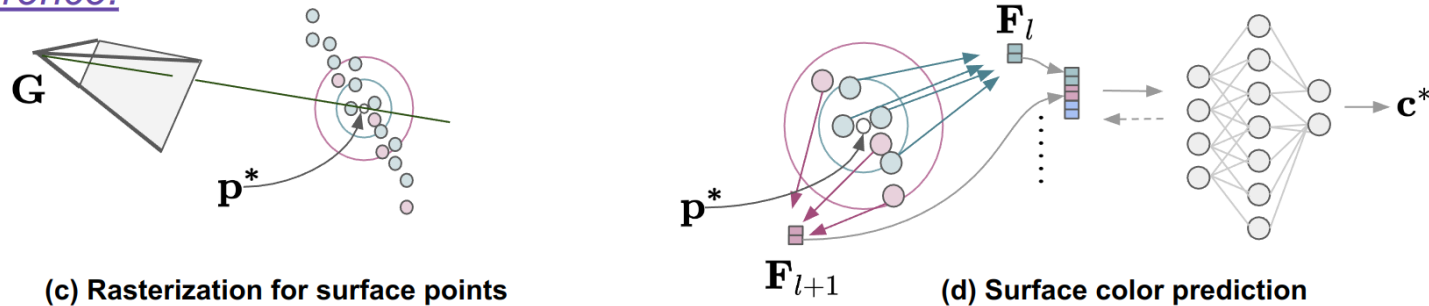
SceneFactory – Reconstruction

- Dual-purpose Multiresolutional Neural Points

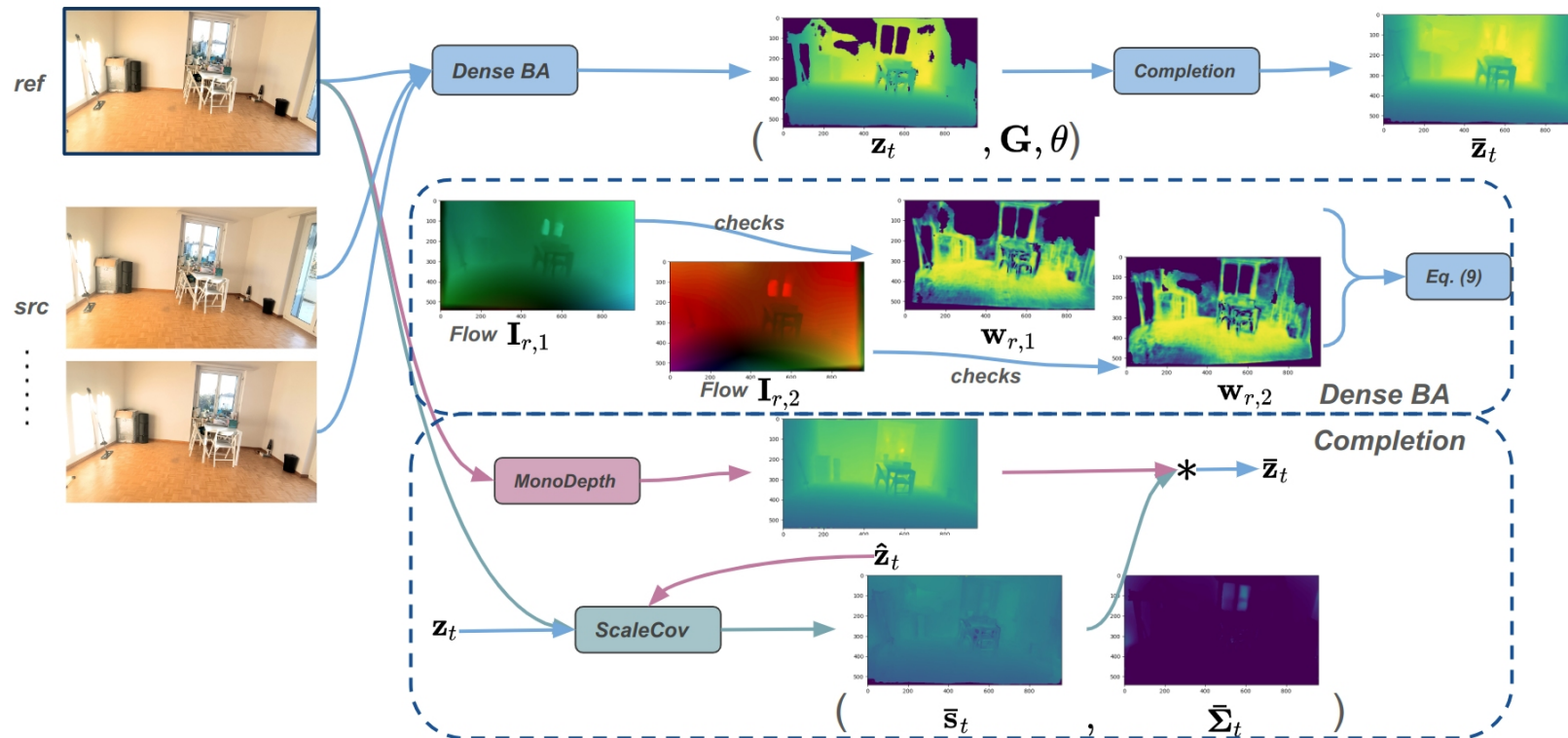
Online learn:



Inference:



SceneFactory – Example module depth estimation

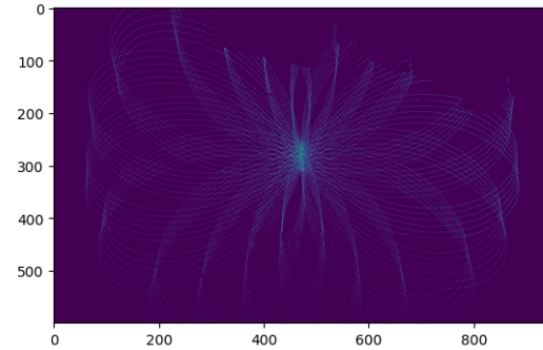


- Similarly to DepthCov [1] we utilize its deep-learned covariance function to formulate ScaleCov as Gaussian Process Regression

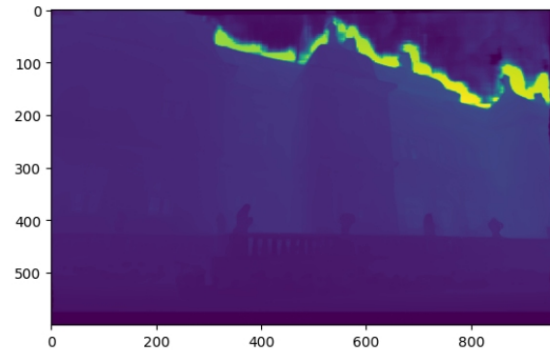
SceneFactory – ScaleCov



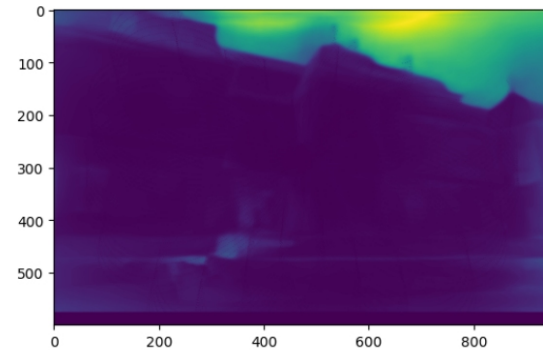
(a) RGB



(b) Livox depth



(c) Completed depth



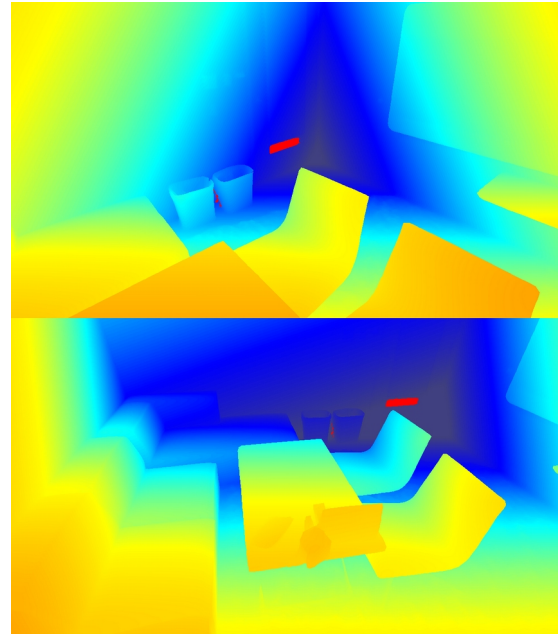
(d) Depth variance

Fig. 21. Complete LiDAR depth with ScaleCov.

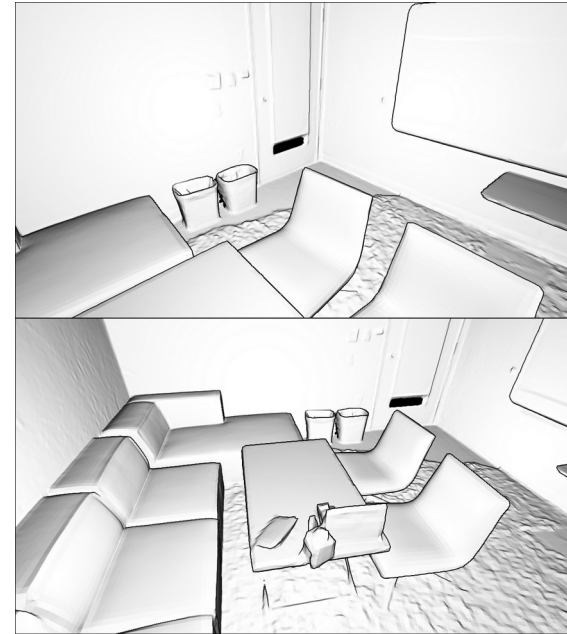
SceneFactory – Flexion

Flexion [2]

Make $SE(3)$ -invariant

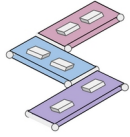


Untrackable



Trackable

SceneFactory – Results on Multiview Depth Estimation



Vision illusion
(Ames Room)

ref



src



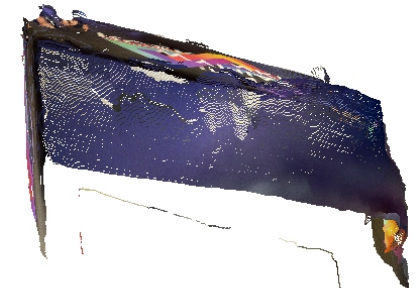
Frontview

Topview

DUST3R
[3]

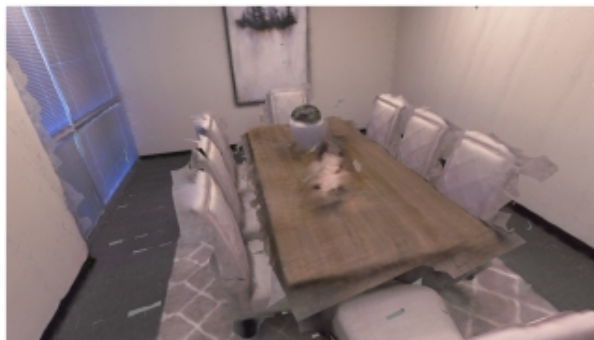


Ours



SceneFactory – Results on Surface Light Fields

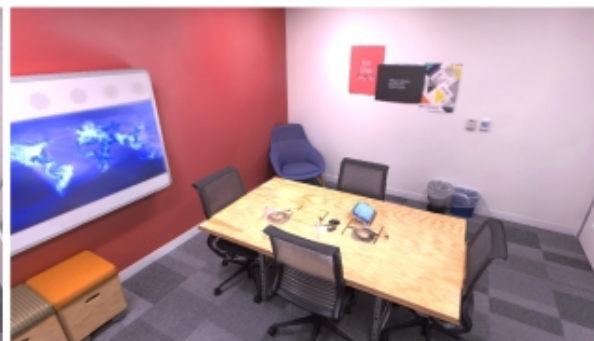
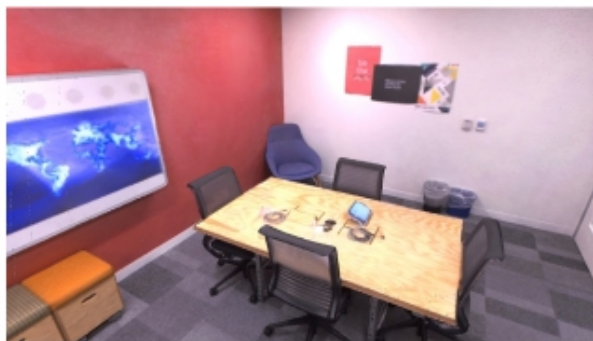
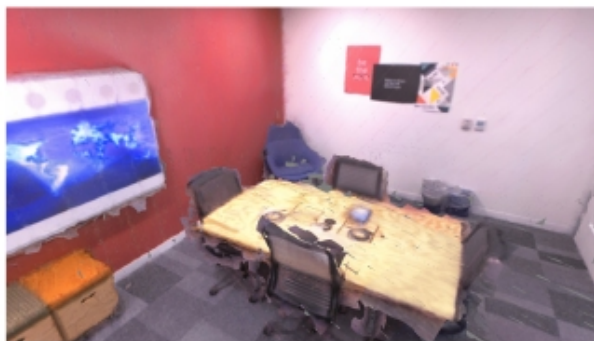
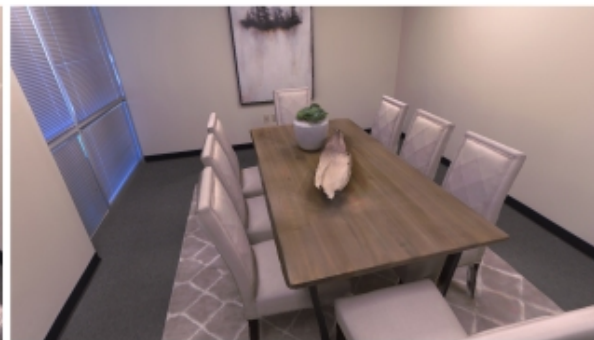
NSLF-OL



SceneFactory

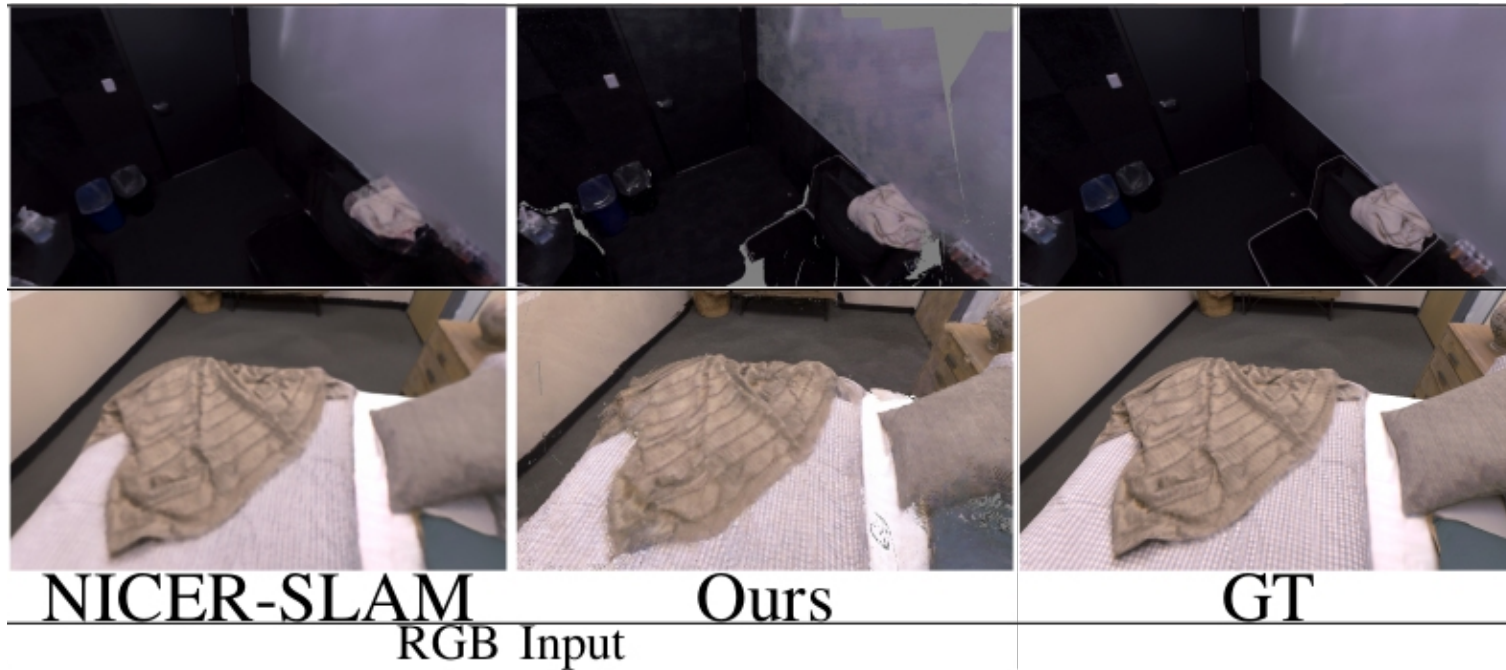


Ground Truth



SceneFactory – Results on Dense SLAM

- RGB as input



SceneFactory – Results on Dense SLAM

- RGB-D Camera as input

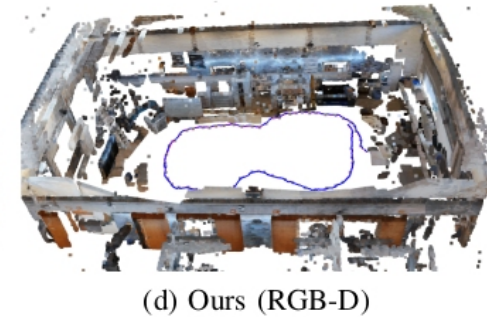
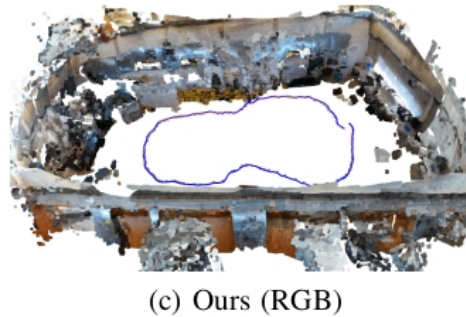
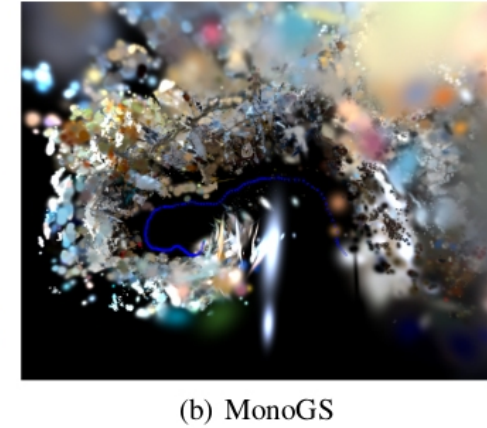
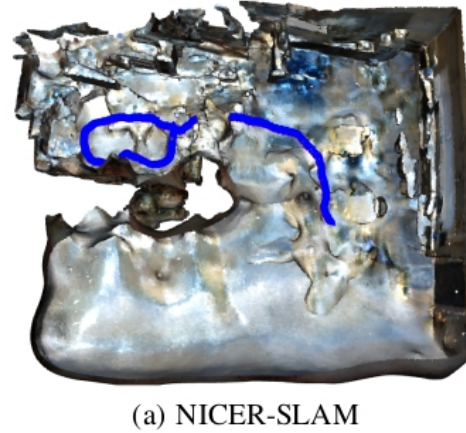
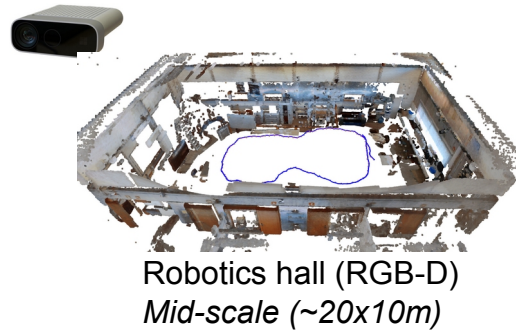


Fig. 18. Test result on our mid-range scene. Trajectories are plotted blue.

How it will end up

What will come next

- 3D Gaussian Splatting and Neural Radiance Fields (NeRFs) will complete missing information and generate **photorealistic 3D scenes**
- 3D world models are emerging
 - VideoGen (image/video-centric)
 - OccGen (occupancy-centric)
 - LiDARGen (point-cloud-centric).
- Iteratively simulate closed-loop agent-environment interactions by generating successive scene states.

Perception removes details
and adds interpretation!

Perception is controlled hallucination. Max Clowes, 1971

