Tracking and Mapping in Project Tango

Dr. Jürgen Sturm

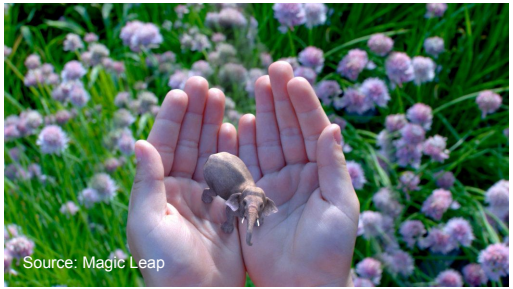
Project Tango™

Motivation

Many applications require a solid understanding of space and motion

- Personal assistants (smartphones, wearables)
- Autonomous robots, cars, drones

Navigation



AR/VR games

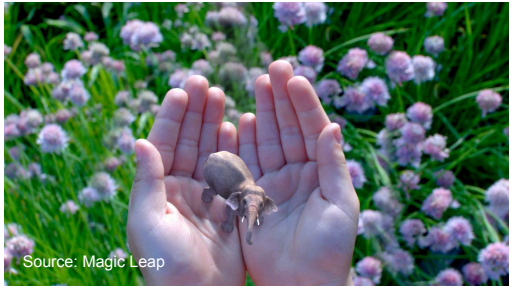
Autonomous cars

Autonomous drones

Relevant Information

- Where am I?
- How do I move?
- How does the world around me look like?
- How can I get from A to B?
- ...

Navigation



AR/VR games

Autonomous cars

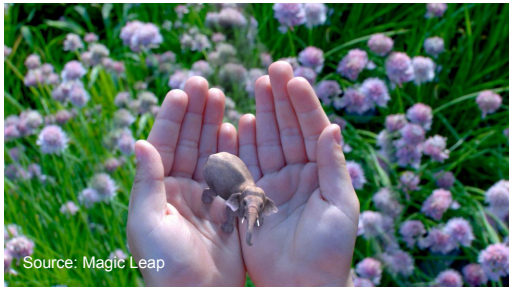
Autonomous drones

Motivating Question

How to solve this?

- Sensors
- Algorithms
- Compute

Navigation



AR/VR games

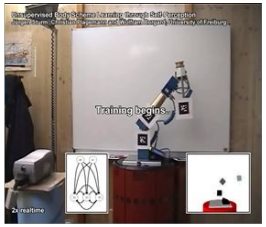
Autonomous cars

Autonomous drones

My Research Profile

- Visual Navigation for Mobile Robots

RoboCup



Kinematic Learning

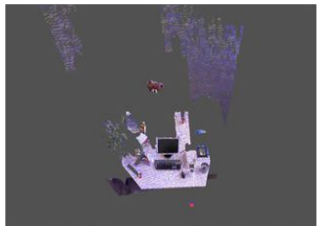
Articulated Objects

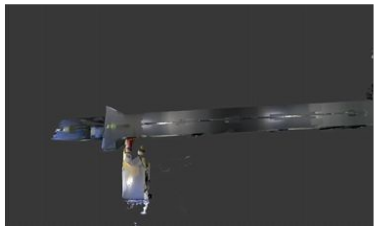

Quadcopters

MOOC Teaching

- Camera tracking, 3D reconstruction, Augmented Reality


RGB-D SLAM


Direct Methods


Large Scale Reconstruction


3D Printing

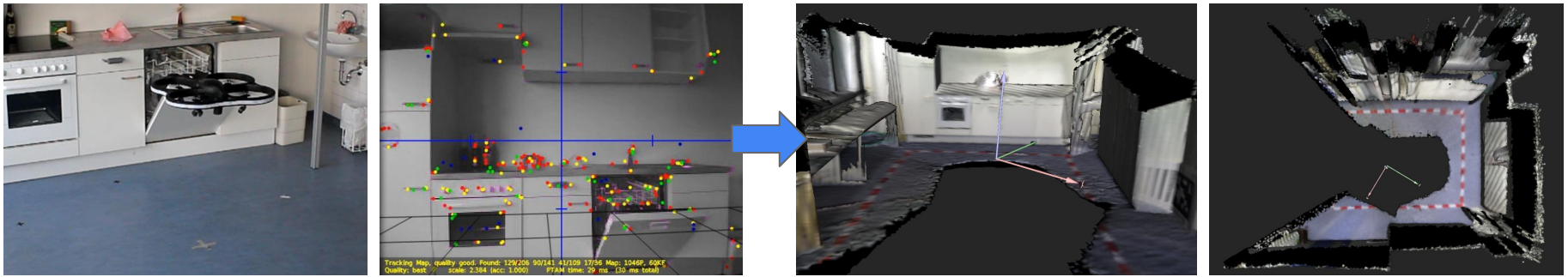

Augmented Reality

Visual Navigation with a Quadcopter

[Engel, Sturm, Cremers; IROS ‘12]

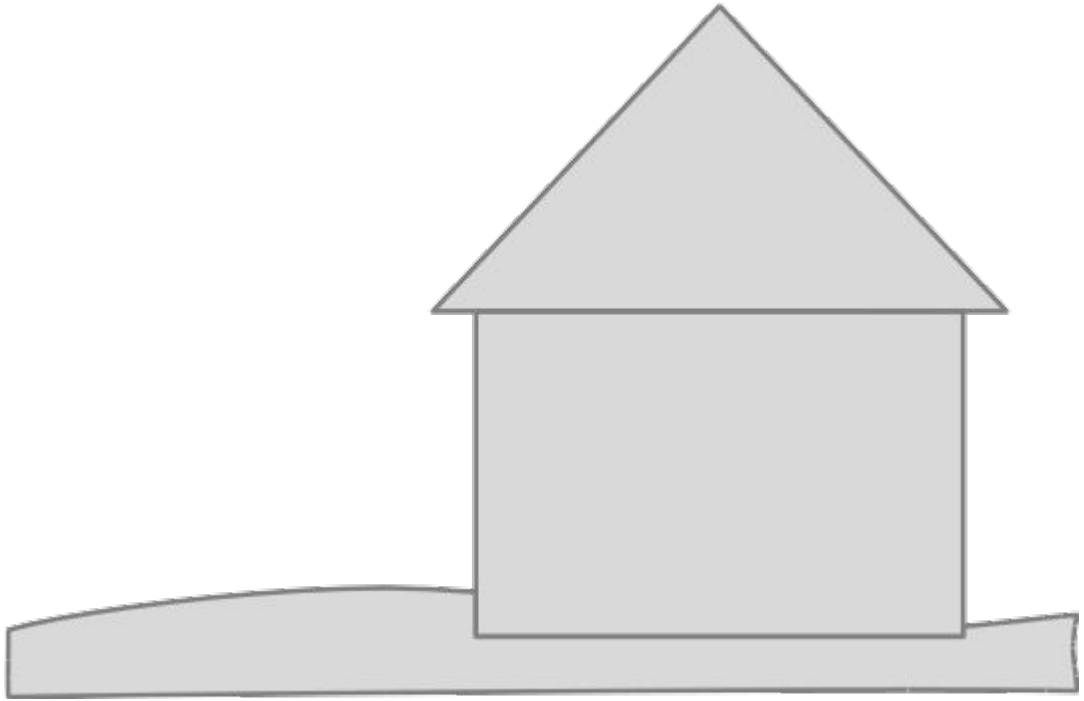
Topic of this Talk

- Sparse maps are not suitable for autonomous navigation
- **How can we generate a dense 3D model of the environment?**
- Representation, estimation, refinement



Signed Distance Function (SDF)

[Curless and Levoy; SIGGRAPH 1996] [Newcombe et al; ISMAR 2011]



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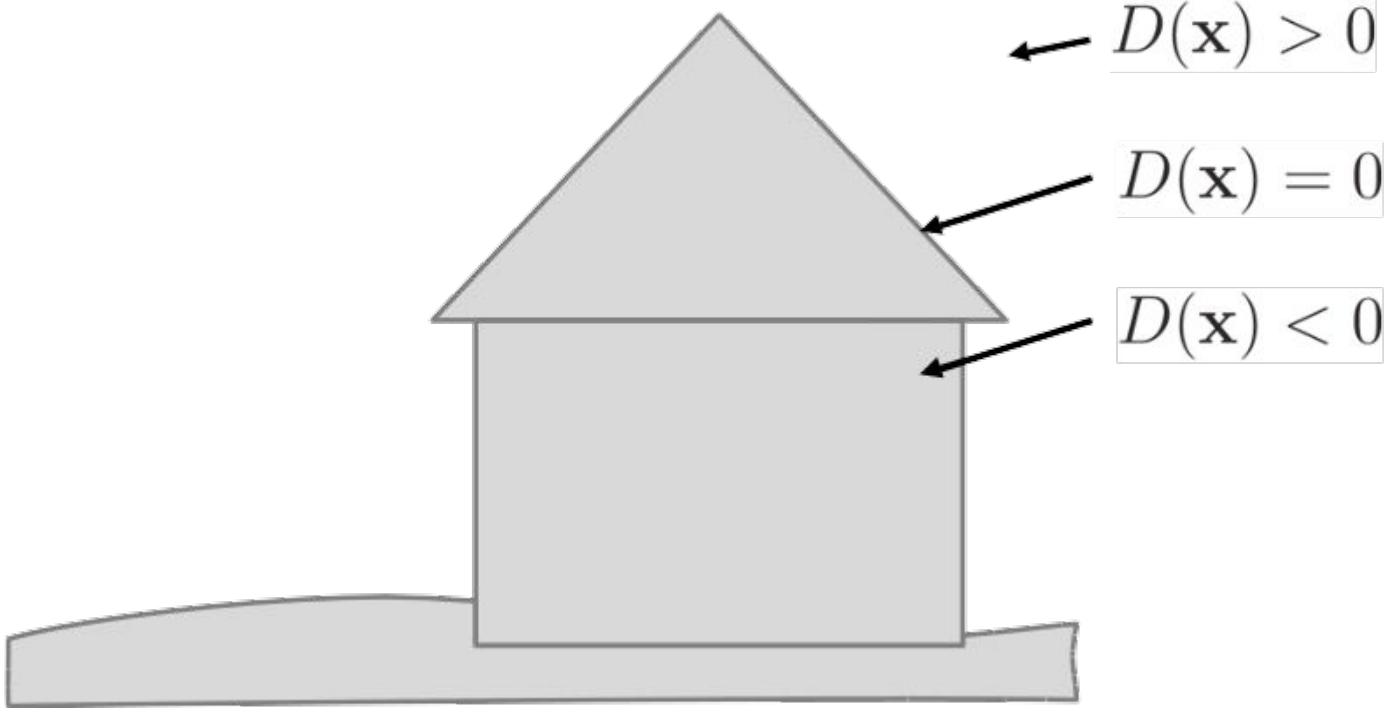

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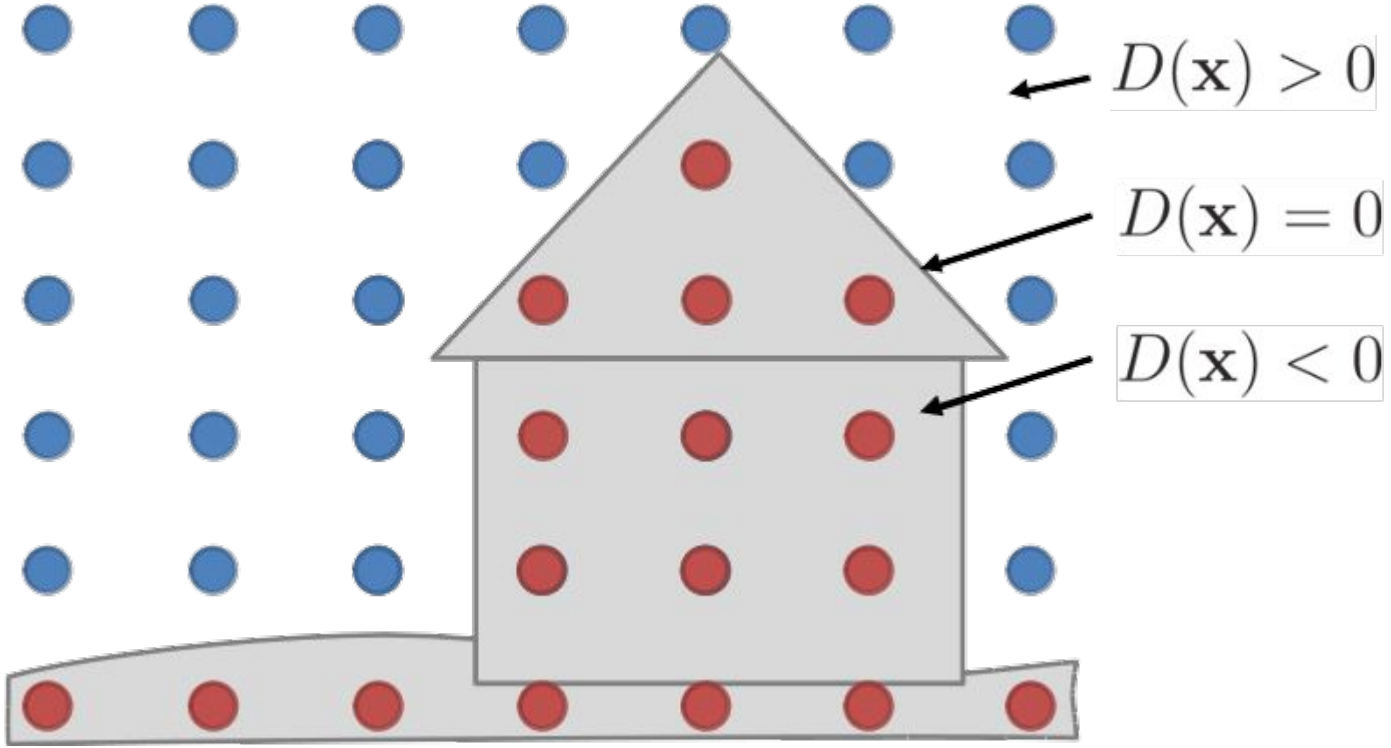
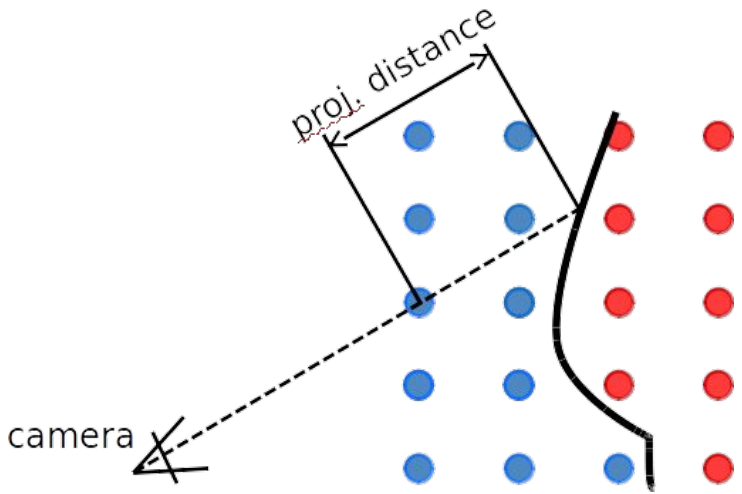


Signed Distance Function (SDF)

[Curless and Levoy; SIGGRAPH 1996] [Newcombe et al; ISMAR 2011]

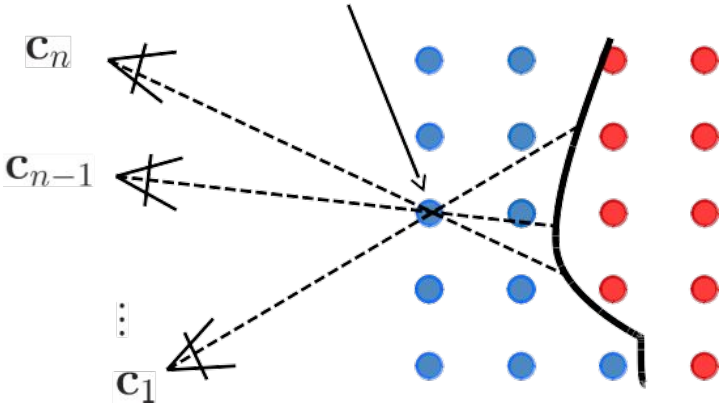
- Compute SDF from a depth image
- Measure distance of each voxel to the observed surface



Signed Distance Function (SDF)

[Curless and Levoy; SIGGRAPH 1996] [Newcombe et al; ISMAR 2011]

- Assume known camera poses (for now)
- Calculate weighted average over all measurements



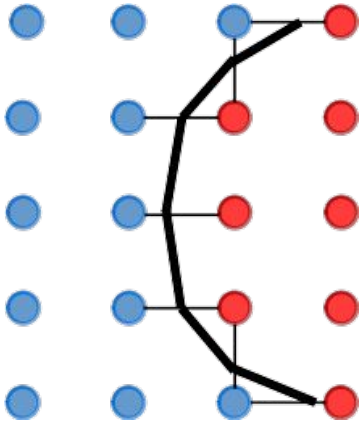
$$D \leftarrow \frac{WD + wd}{W + w}$$

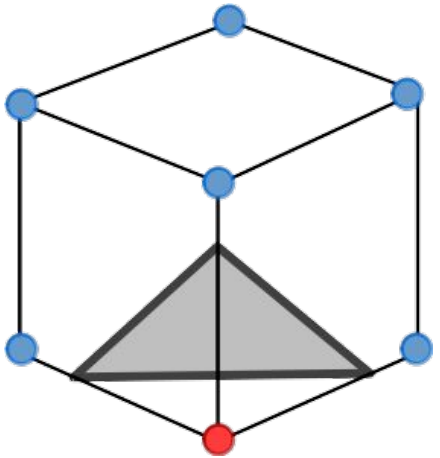
$$C \leftarrow \frac{WC + wc}{W + w}$$

$$W \leftarrow W + w$$

Mesh Extraction with Marching Cubes

Find zero-crossings in the signed distance function by interpolation

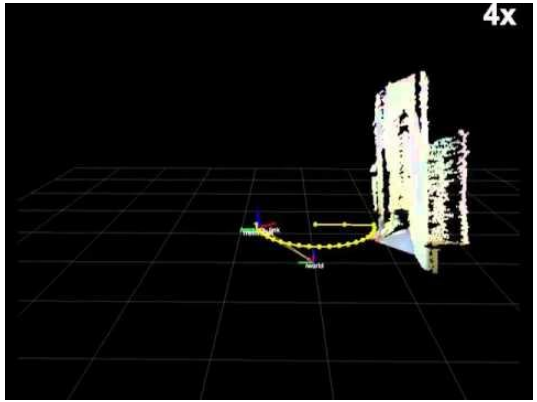


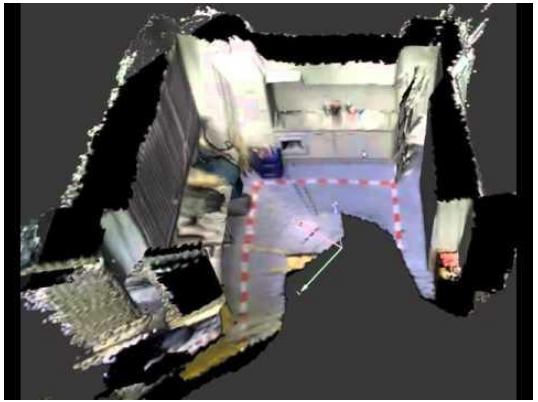


3D Room Scanning with a Quadcopter

[Bylow, Sturm, Kahl, Cremers; RSS ’13] [Sturm, Bylow, Kahl, Cremers; UAV-g ’13]

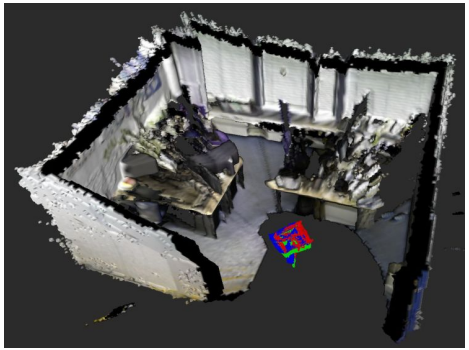
- AscTec Pelican quadrocopter
- Real-time 3D reconstruction, position tracking and control (off-board, needs GPU)





More Examples

[Bylow, Sturm, Kahl, Cremers; RSS ’13] [Sturm, Bylow, Kahl, Cremers; UAV-g ’13]



Nice 3D models, but resolution could be higher.

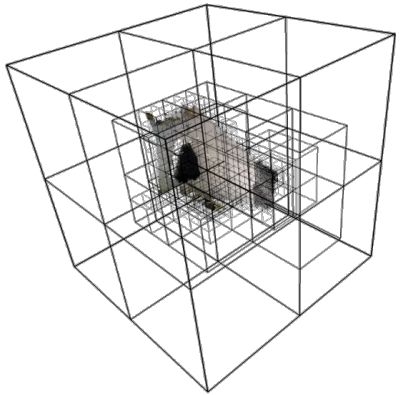
Problem: Memory consumption grows cubically!

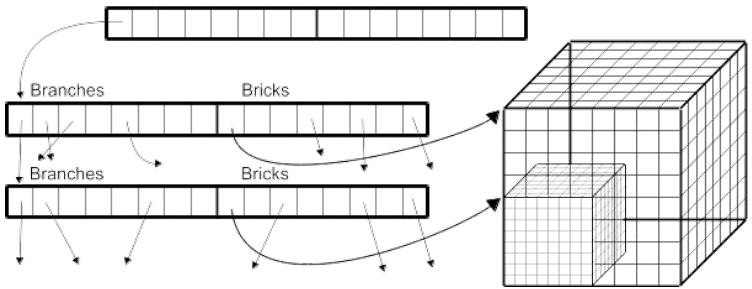
- 512^3 voxels, 24 byte per voxel → 3.2 GB
- 1024^3 voxels, 24 byte per voxel → 24 GB
- …

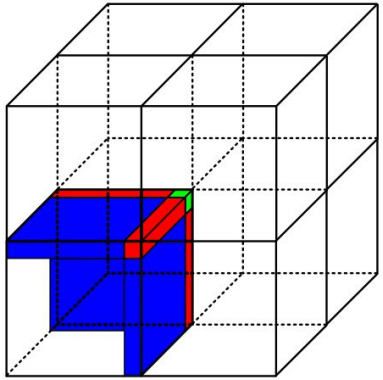
High-Resolution 3D Reconstruction

[Steinbrücker, Kerl, Sturm, Cremers; ICCV 2013] [Steinbrücker, Sturm, Cremers; ICRA 2014]

- Save data in multi-level oct-tree data structure
- Bricks (8^3 volumes) are only allocated when needed
- Store geometry at multiple resolutions
- Tree grows dynamically (no fixed size/origin)



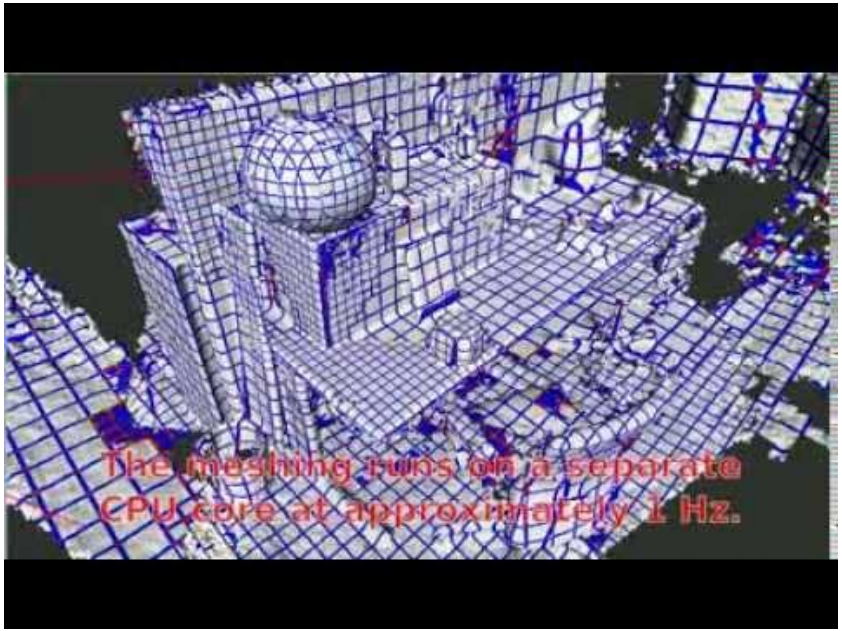




High-Resolution 3D Reconstruction

[Steinbrücker, Kerl, Sturm, Cremers; ICCV 2013] [Steinbrücker, Sturm, Cremers; ICRA 2014]

- Multi-level oct-tree implementation, open-source!
- Runs at 45fps (640x480, 0.5cm grid resolution, 3GB)



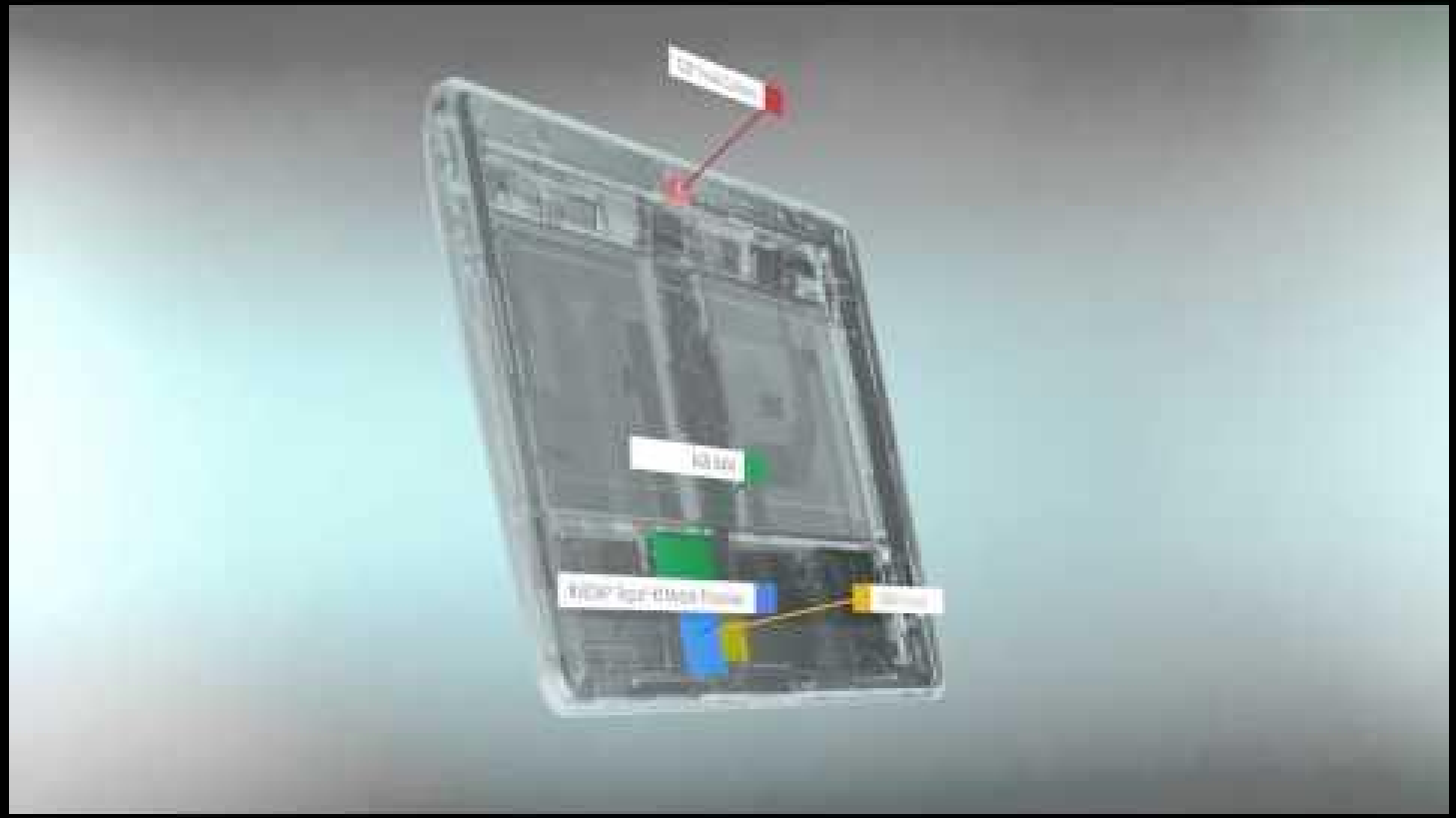
Project Tango

Liked what you saw so far?

What if there was a device that can do (most of this) out-of-the-box?

Would this save you or your PhD students time?

What applications could you build on top of it?

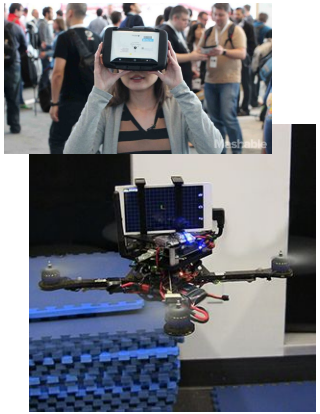


Project Tango

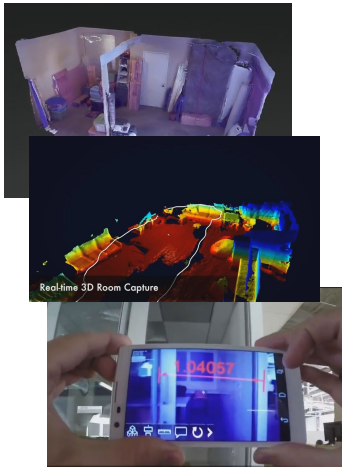
Integrated hard- and software stack that provides:

- Low latency 6-DOF pose
- Map optimization and bundle adjustment
- Global re-localization
- Meshing
- C++/Java/Unity API

Use Cases

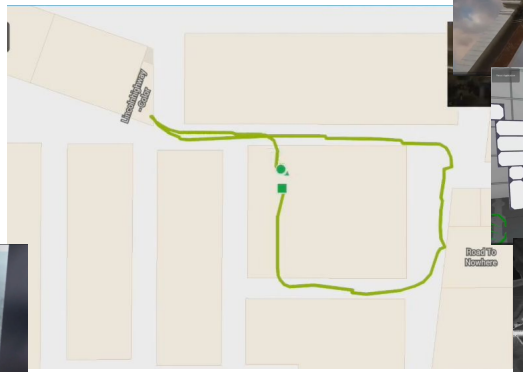


Emerging:
Virtual Reality
Robotics

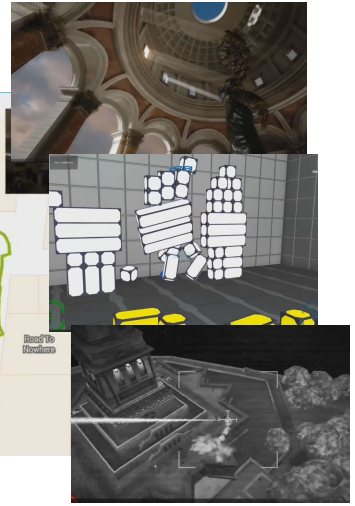


Professional:
Building-scale
3D scanning &
measurement

Prosumer:
Virtual Showroom
Shopping
Remodeling



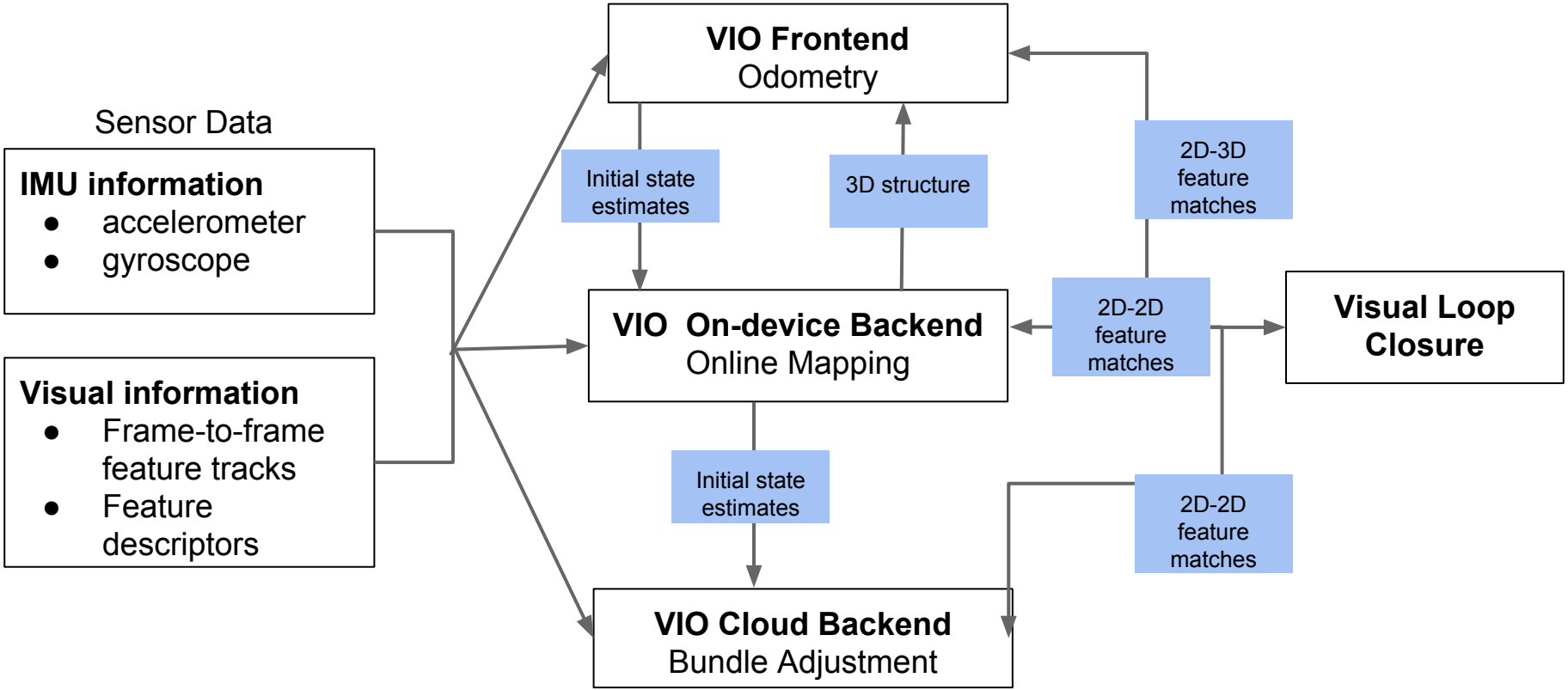
Consumer:
Centimeter-scale Indoor
Navigation (no
GPS/Wifi/Bluetooth)



Entertainment:
Motion Gaming
Geo-Social Activities

Tango: Visual-Inertial Odometry (VIO)

[Hesch, Kottas, Bowman, Roumeliotis; T-RO '09] [Nerurkar, Wu, Roumeliotis; RSS '13]
[Lynen, Sattler, Bosse, Hesch, Pollefeys, Siegwart; RSS '15]



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- Frontend: Sliding-Window Filter
  - Real-time w/ low computational complexity (10 Hz vision + 100 Hz IMU)
  - Accumulates drift over large distances (< 1% of distance travelled)

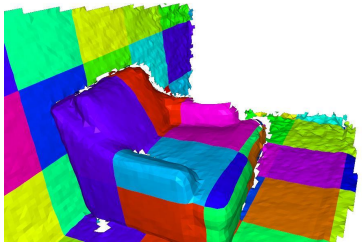
- On-device Backend: Online Bundle Adjustment with vision-based loop closure
  - Flexible raw + marginalized VI constraints
  - Real-time w/ < 5 cm RMSE on VICON

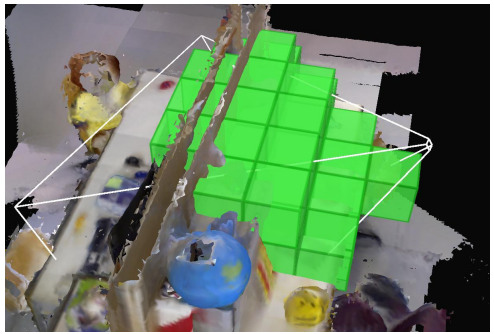
- Cloud Backend
  - MAP estimates with high accuracy (< 2 cm RMSE on VICON)
  - Offline w/ high computational complexity

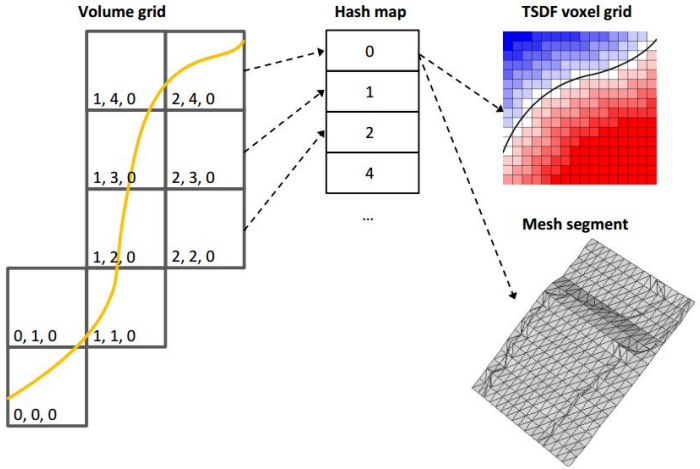
Tango: 3D Reconstruction

[Klingensmith, Dryanovski, Srinivisa, Xiao; RSS ’15]

- Camera poses from online VIO or offline BA
- Fixed-resolution chunks of 16x16x16 voxels
- Spatial hashing





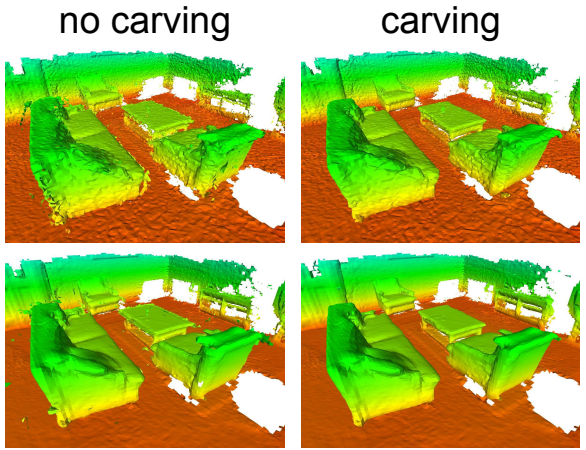


Tango: 3D Reconstruction

[Klingensmith, Dryanovski, Srinivisa, Xiao; RSS ’15]

- Timings on device:
  - Voxel updates: 128ms
  - Meshing: 102ms

- Default settings:
  - 3cm resolution
  - Raycasting
  - Carving




Tracking In Difficult Environments

Conclusion

- Tango provides 6-DOF tracking and 3D reconstruction out-of-the-box
- Lightweight, small form factor, highly integrated
- Tango API for C++/Java/Unity
- Would this be useful for you or your PhD students in any of your projects?
- Free devices available, contact me after the talk
- Next steps: Improve 3D reconstruction, object detection & scene understanding

We are looking for academic partners and new colleagues!

Interns, Post-Docs, Visiting Faculty are very welcome.

Opportunities for funded research that help advance the platform.

Project Tango is located in Google offices in Mountain View, Zurich and Munich.

Contact us at: *jsturm@google.com*

Project Tango™

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