Map Representations

Instructor: Chris Mavrogiannis

TAs: Kay Ke, Gilwoo Lee, Matt Schmittle

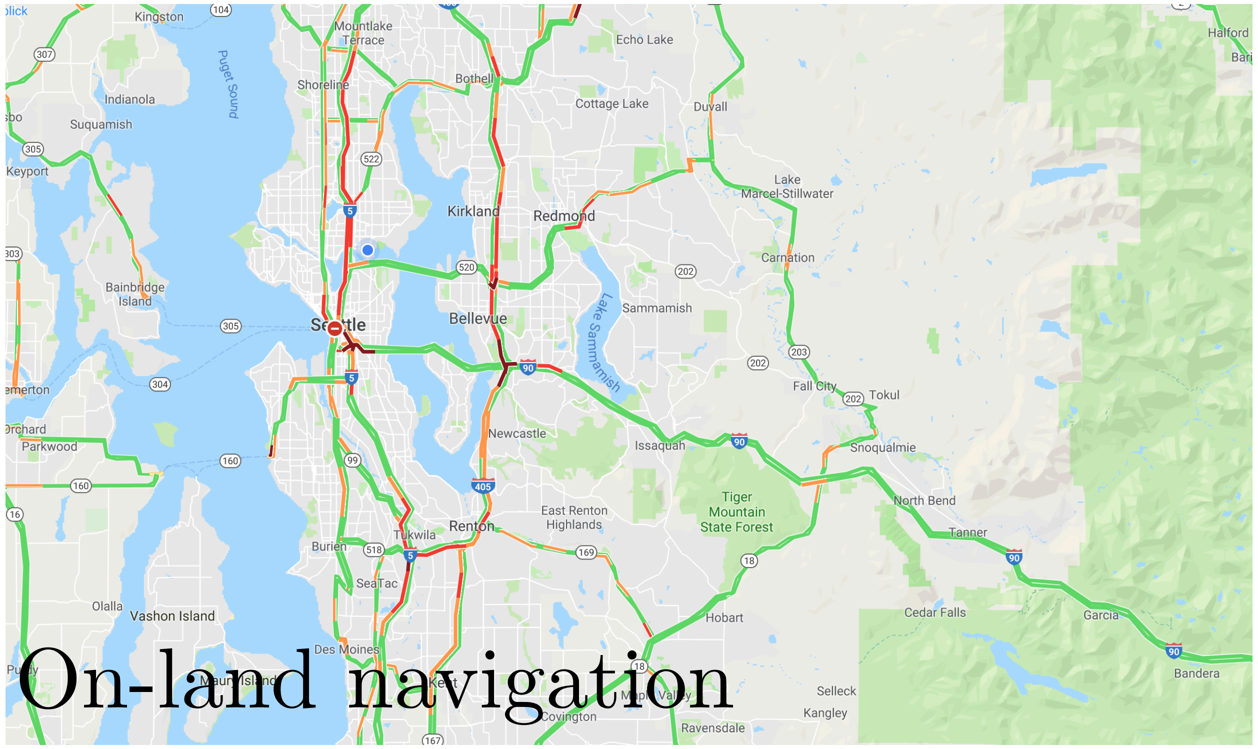
*Slides based on or adapted from Sanjiban Choudhury, Cyrill Stachniss, Michael Kaess, S.Scherer

Announcements

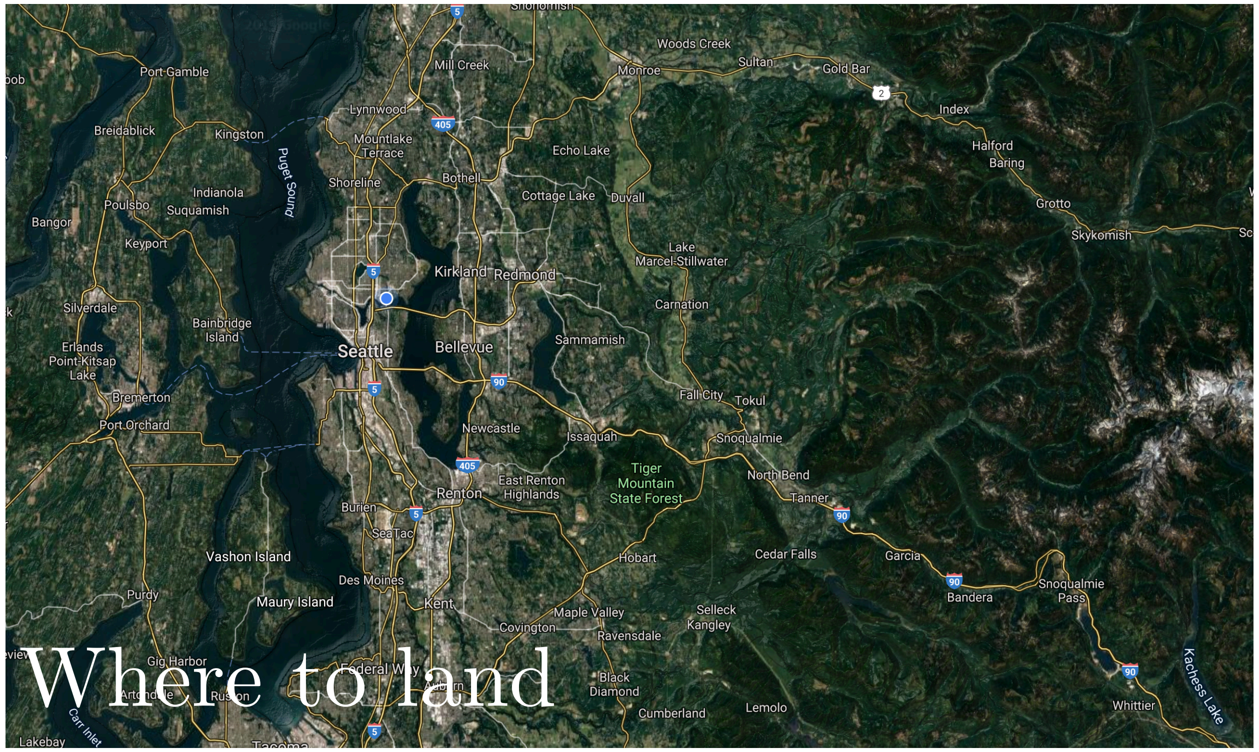
- Deadline for lab1 coming up: Friday 1/31 at 11:59 p.m
- This is the due date for the writeup
- Lab evaluation (demo) now pushed to Thursday Feb 6. Times to be announced by end of week.

What is a map?

Do all maps convey the same information?


On-land navigation


During flight


Where to land

Maps are a summary of information about the world

What sort of information? Depends on the task

Task also determines how we query, update, store maps

Today's objective

1. Framework / taxonomy to think about maps

2. Look at various maps and the underlying tasks they serve

3. Distance map

What do we want from maps?

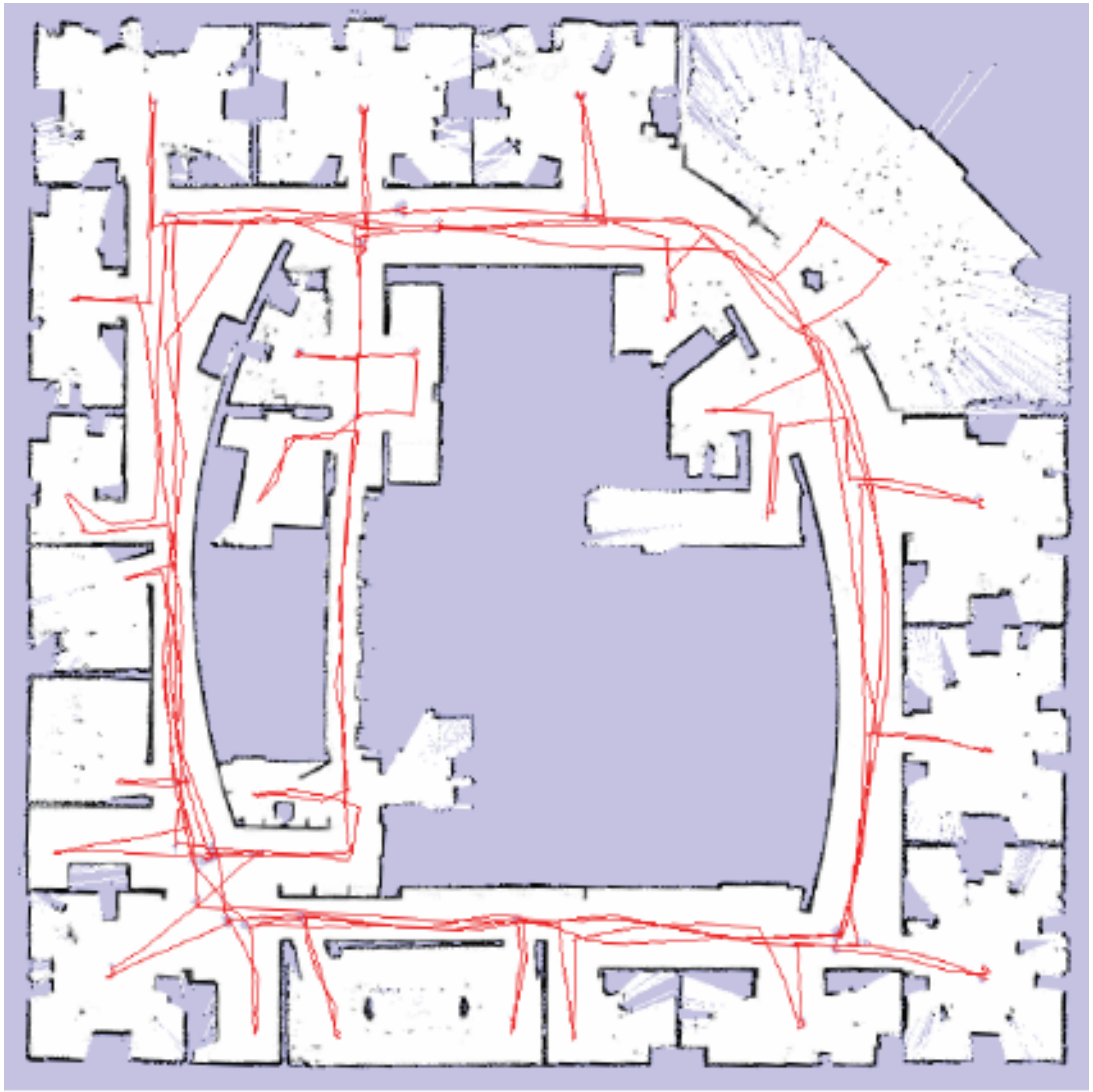
1. Information - What task does it help me solve? (Help me localize, help me navigate, help humans navigate / plan their lives etc)

2. Query - Can we query it online? How often?

3. Updatable - Can we update it online? Can it deal with noisy measurements?

4. Memory - How much storage does it need? Is it transportable? How does it scale with time? Scale with amount of stuff we see ?

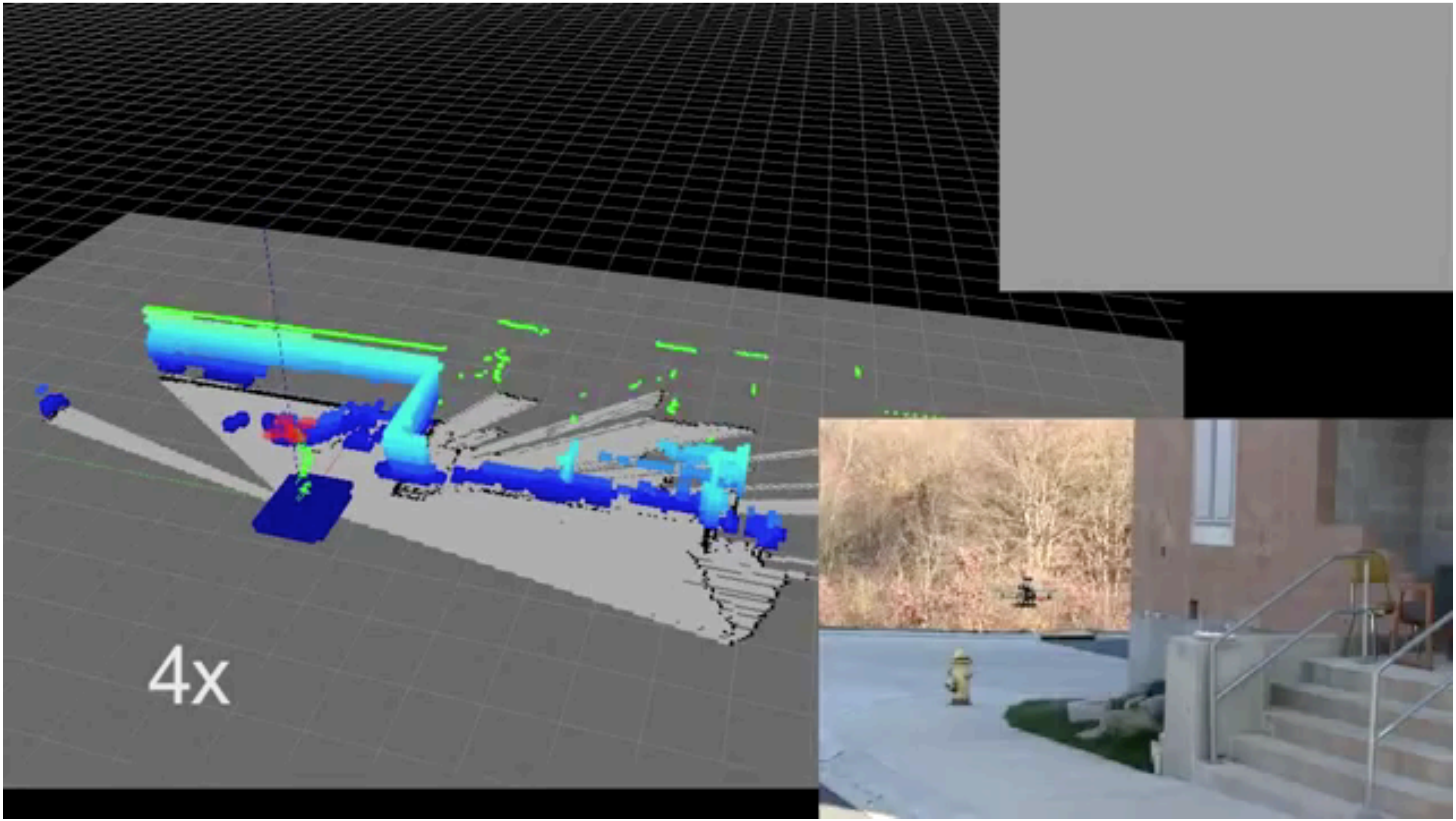
Example 1: Occupancy grids



Example 1: Occupancy grids

Category	Details
Information	
Query	
Update	
Memory	

Occupancy grids in action



"Autonomous Multi-Floor Indoor Navigation with a Computationally Constrained MAV", S. Shen, N. Michael, V.Kumar, 2010

Example 1: Occupancy grids

Category	Details
Information	
Query	
Update	
Memory	

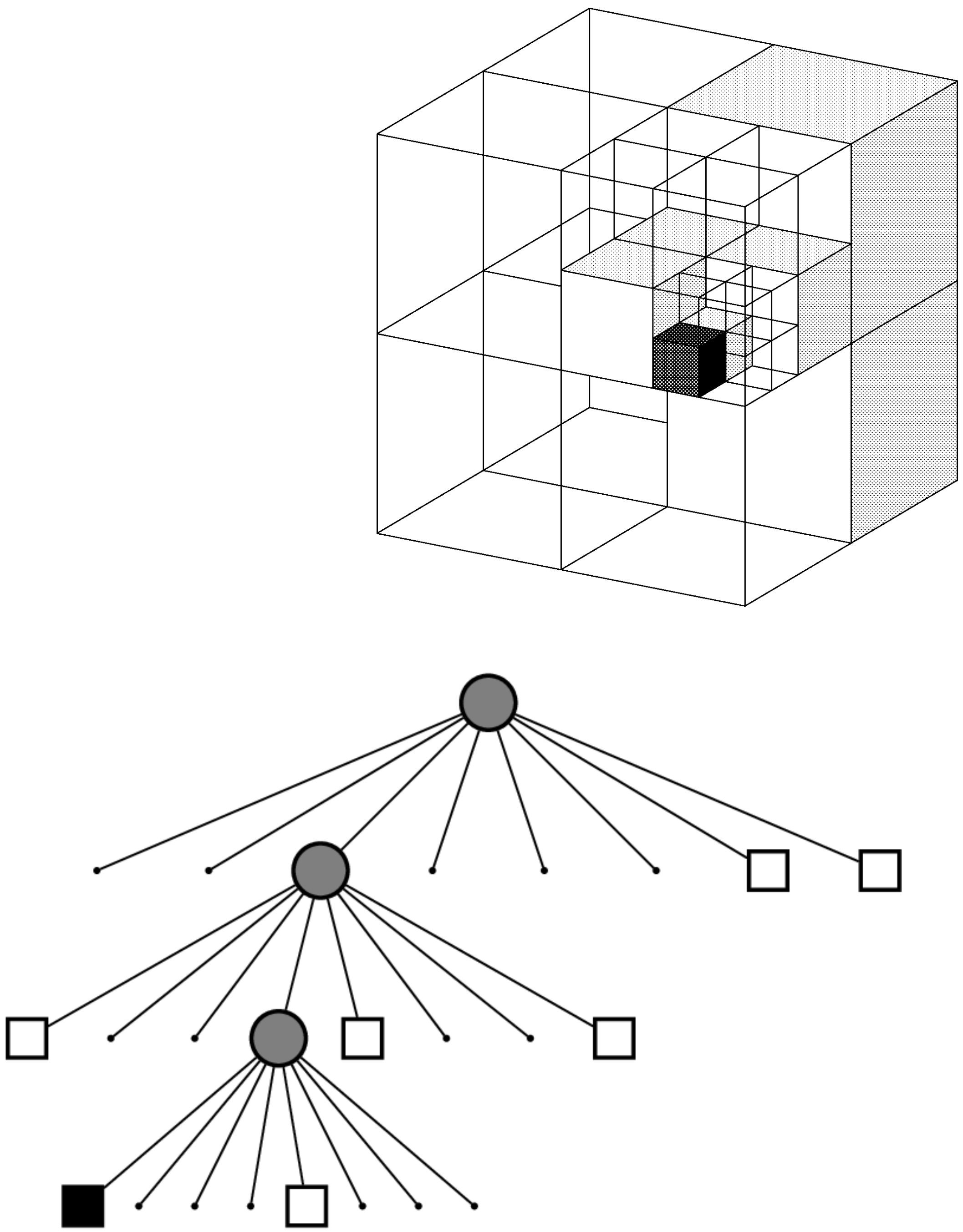
Problems with occupancy grids

1. Memory scales with distance travelled in any one direction

2. Do I need high resolution information everywhere?

Example 2: Occupancy Trees (OctoMap)

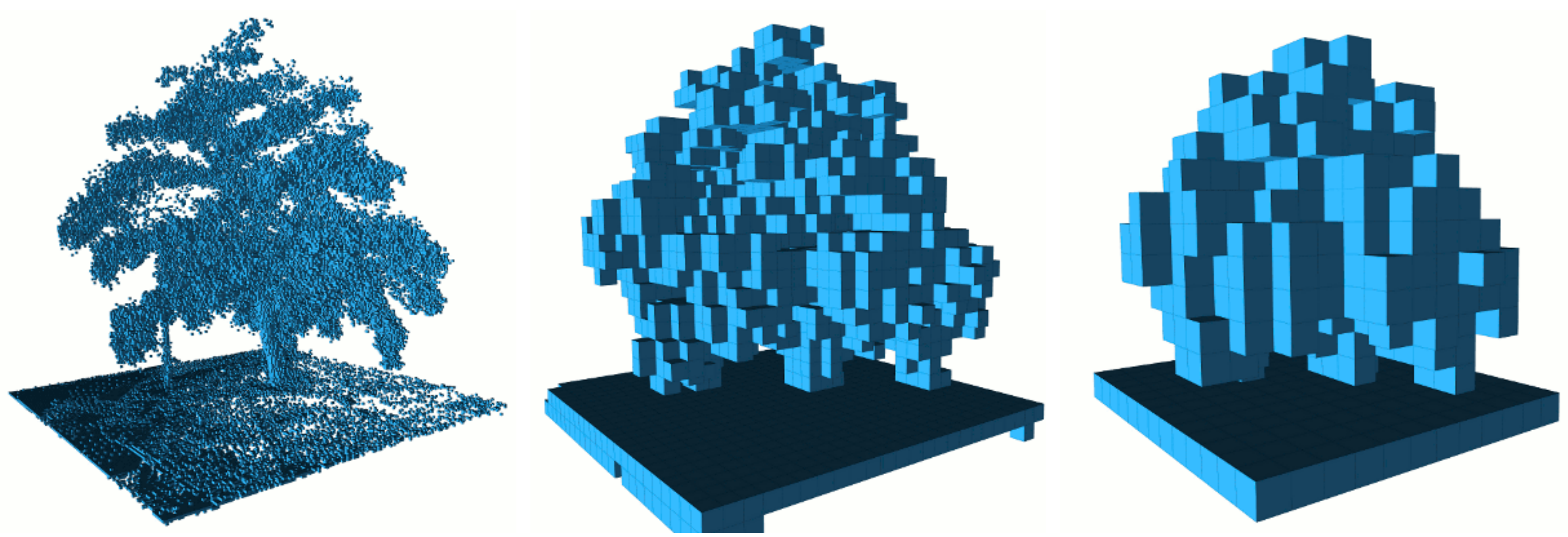
Hornung et al. 2013



Tree-based data structure

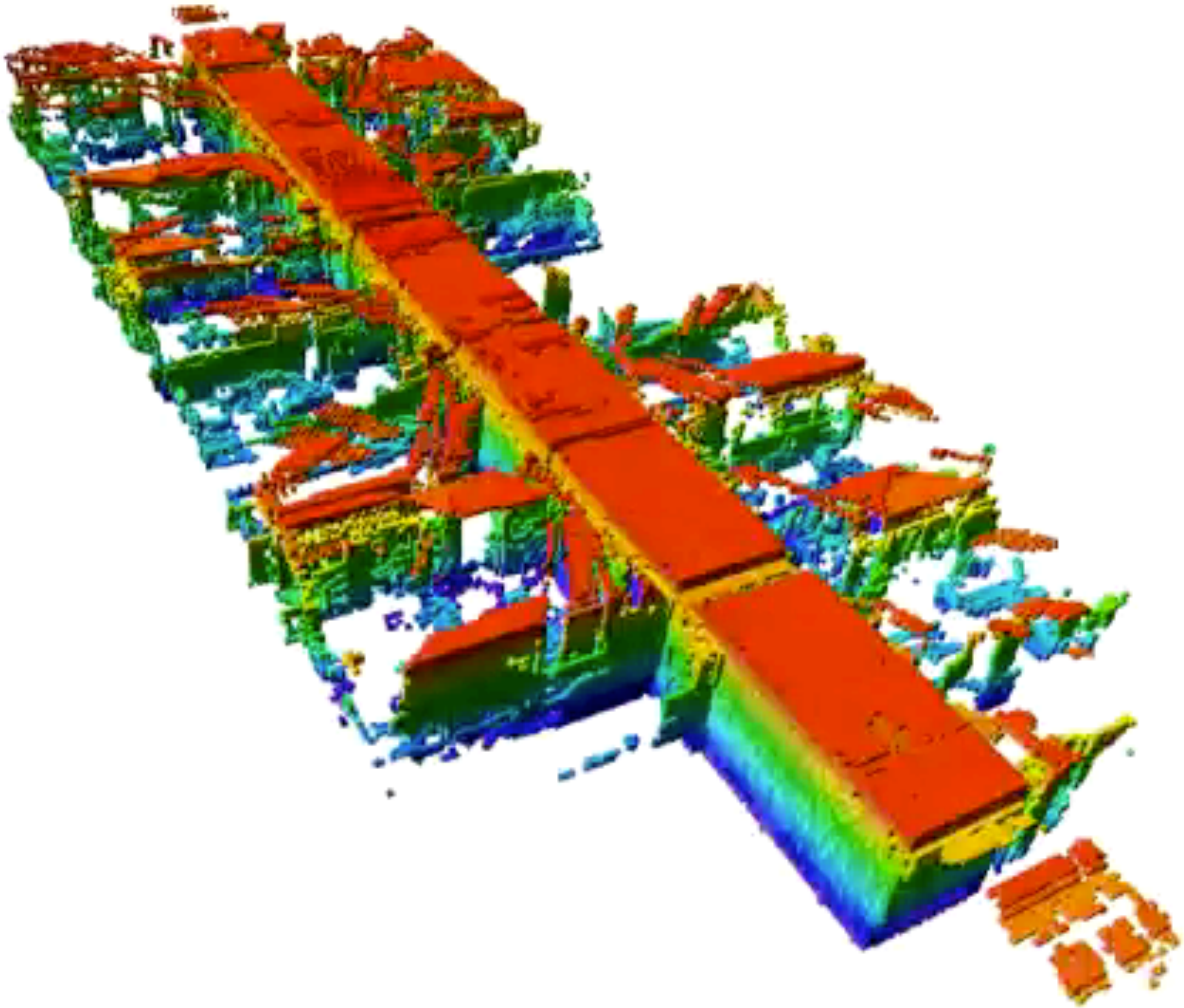
Recursive sub-division of space

Query maps at multiple-resolutions!



https://octomap.github.io/

Example 2: OctoMap



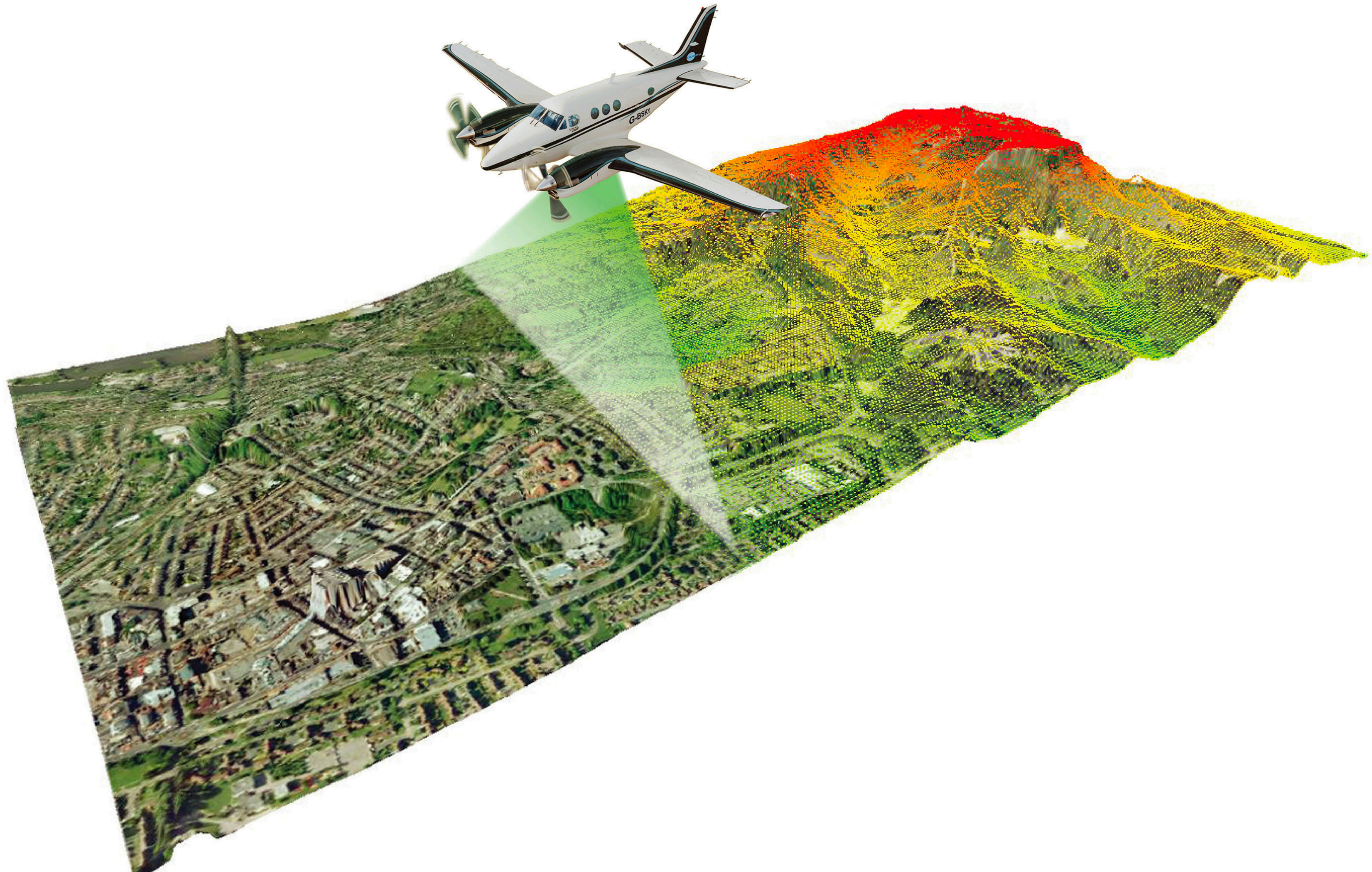
Example 2: OctoMap

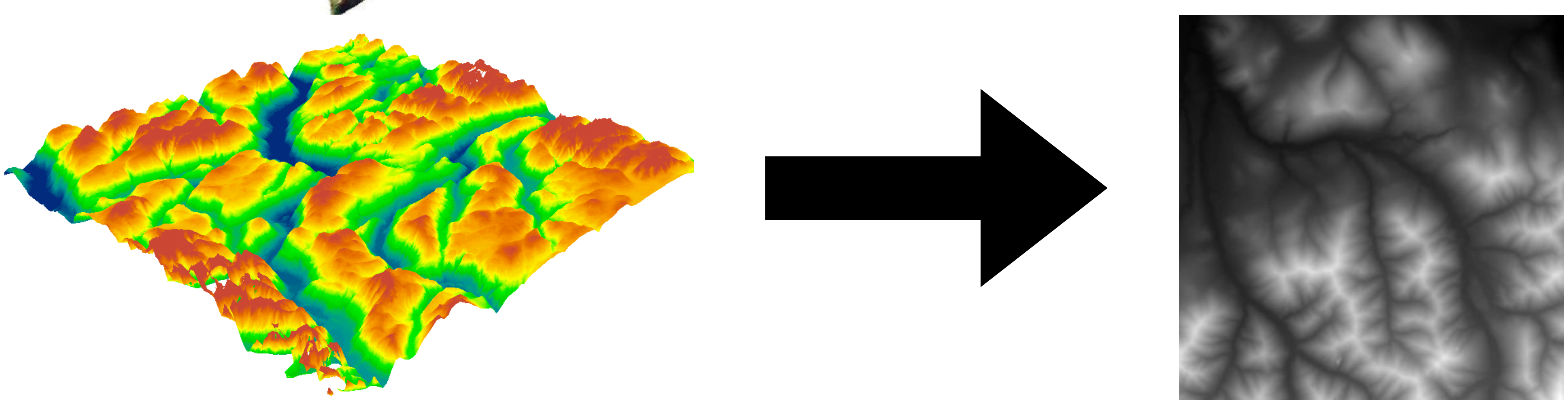
Category	Details
Information	
Query	
Update	
Memory	

~~Is the world always 3D?~~

Do we care about 3D?

Example 3: 2.5D height map



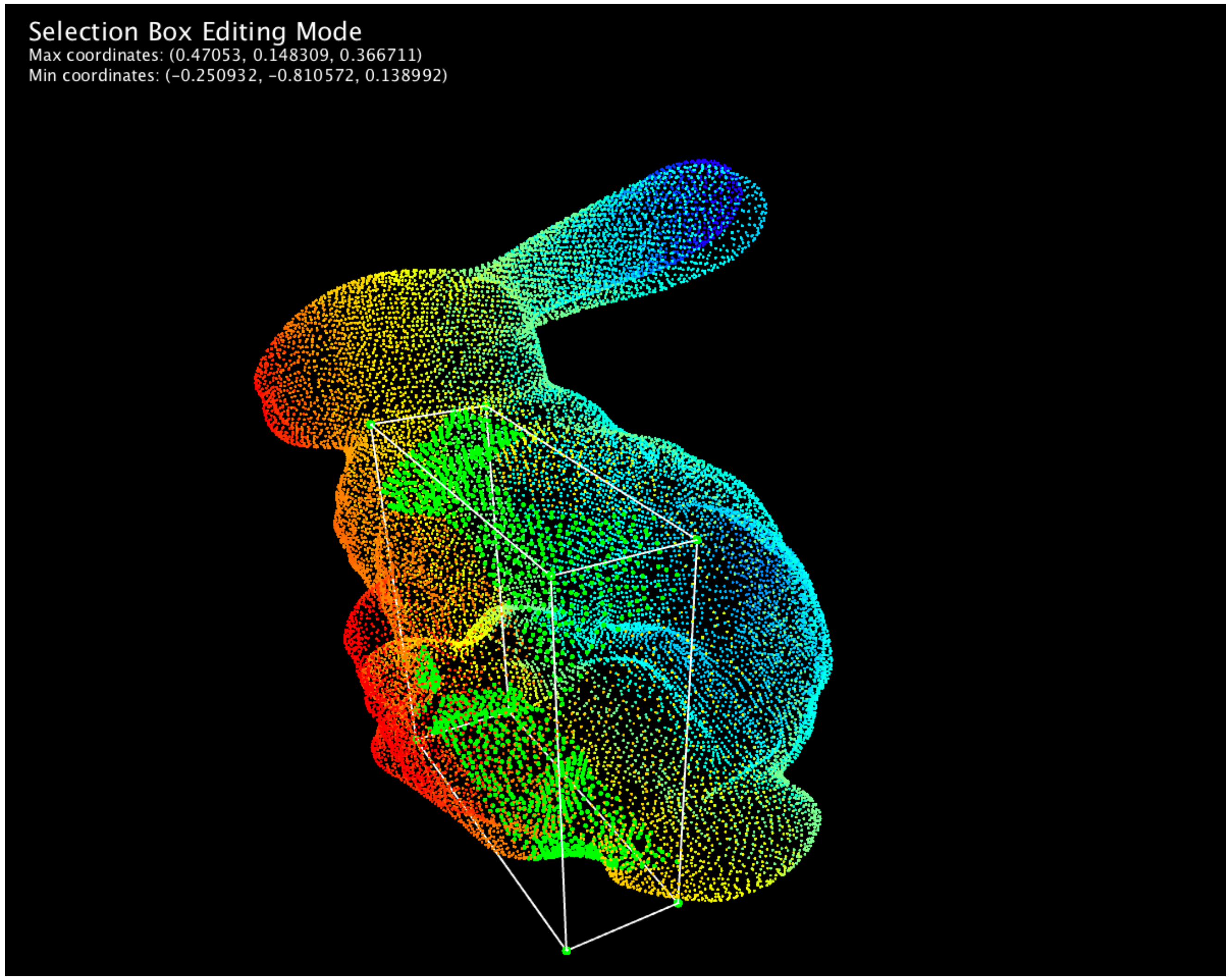


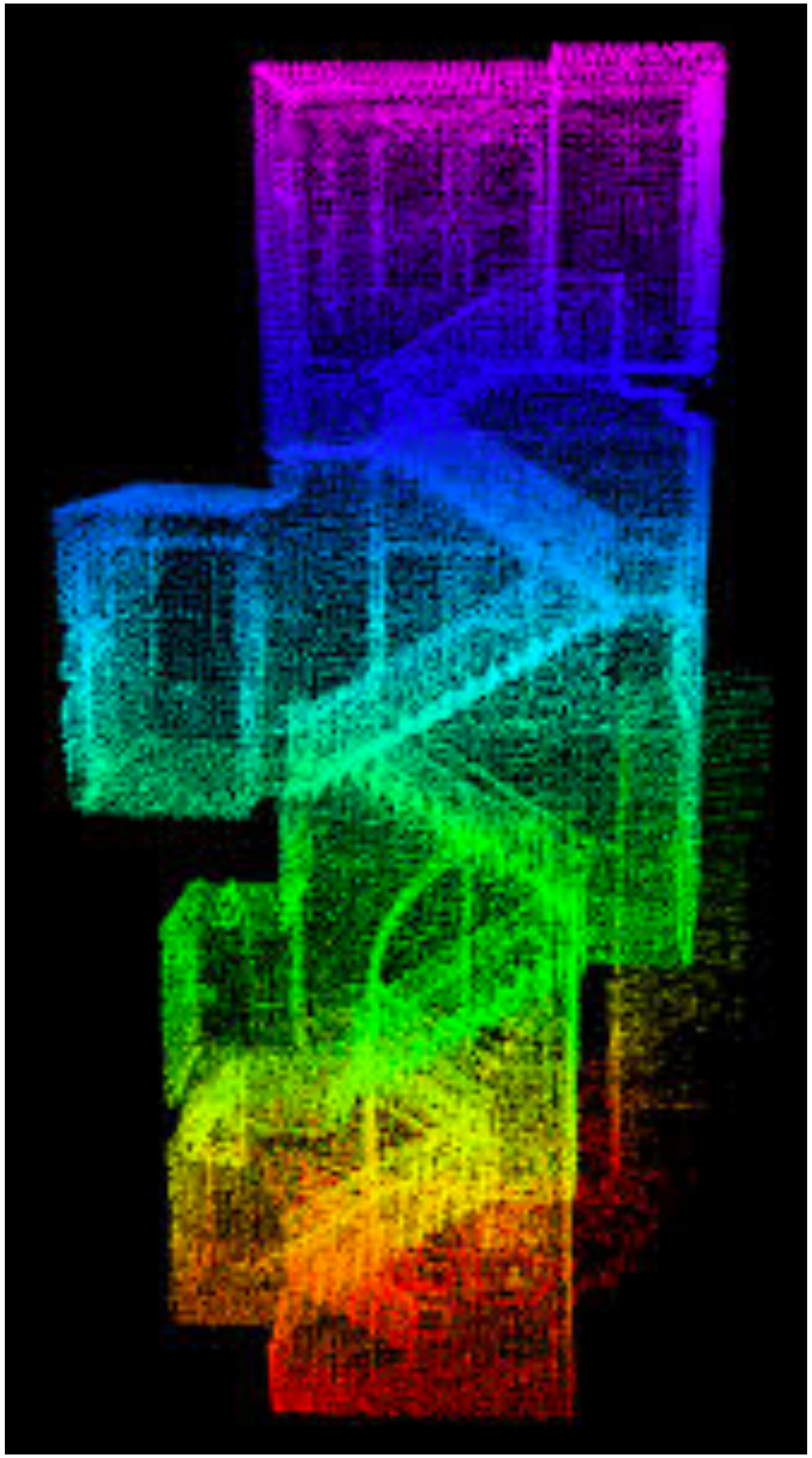
Example 3: 2.5D height map

Category	Details
Information	
Query	
Update	
Memory	

What are my options if I don't want to discretize?

Example 4: Point cloud





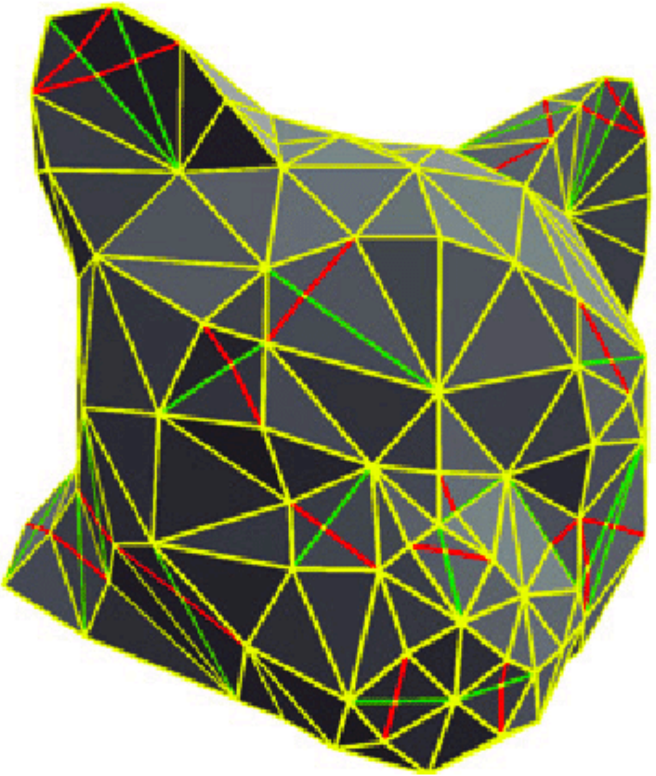
courtesy Ji Zhang

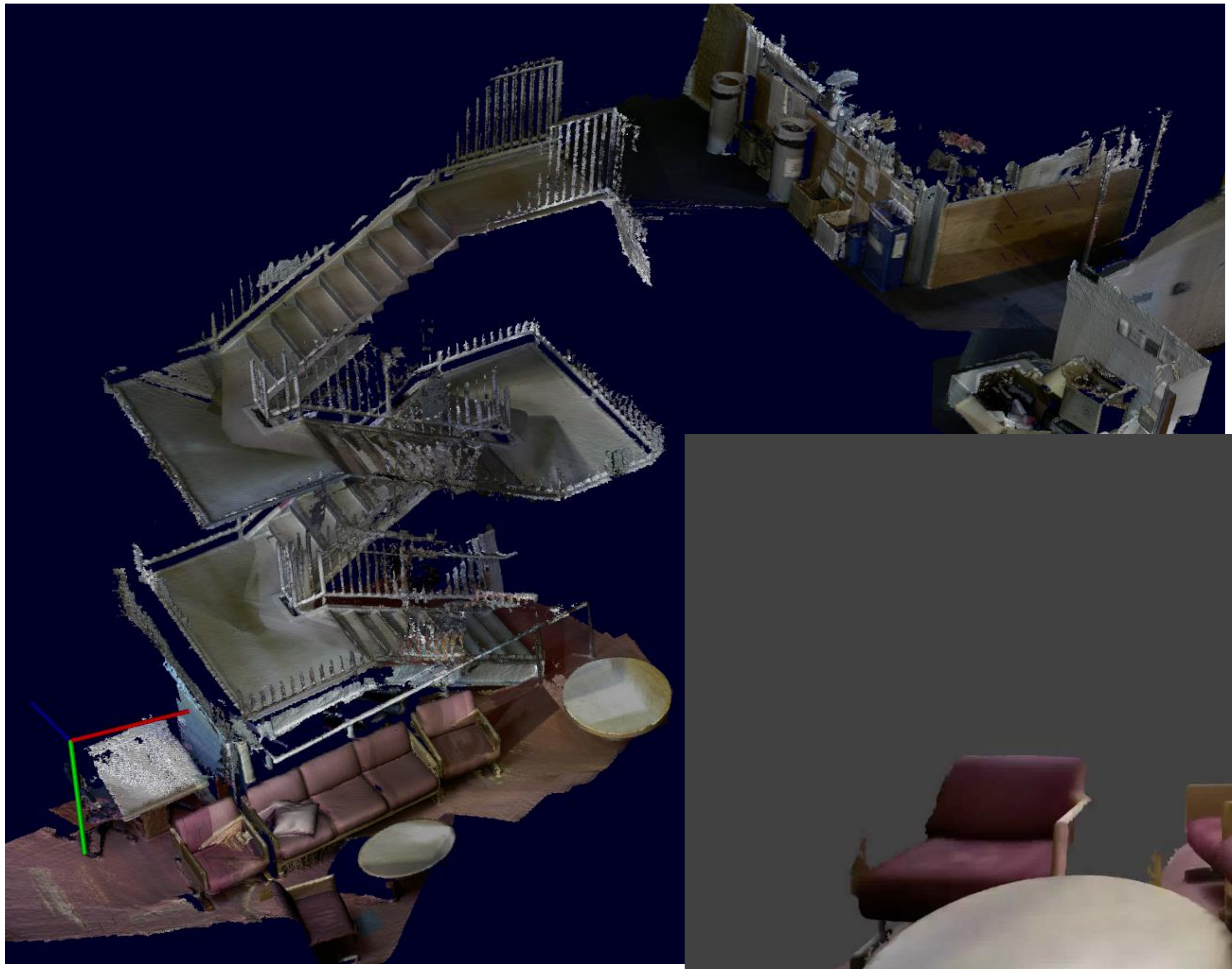
Example 4: Point cloud

Example 4: Point clouds

Category	Details
Information	Surface of obstacles (no discretization) Useful for 3D reconstruction Very accurate laser based odometry.
Query	Typical query - give me the closest point / set of points Naive query is O(N) (remember N is huge!!!)
Update	Easy to update (just dump points) Cannot deal with noisy measurements
Memory	Unbounded - can always keep adding points on top of each other indefinitely.

Example 5: Surface representations





- Handheld RGB-D sensor ($180)
- Real-time with GPU processing

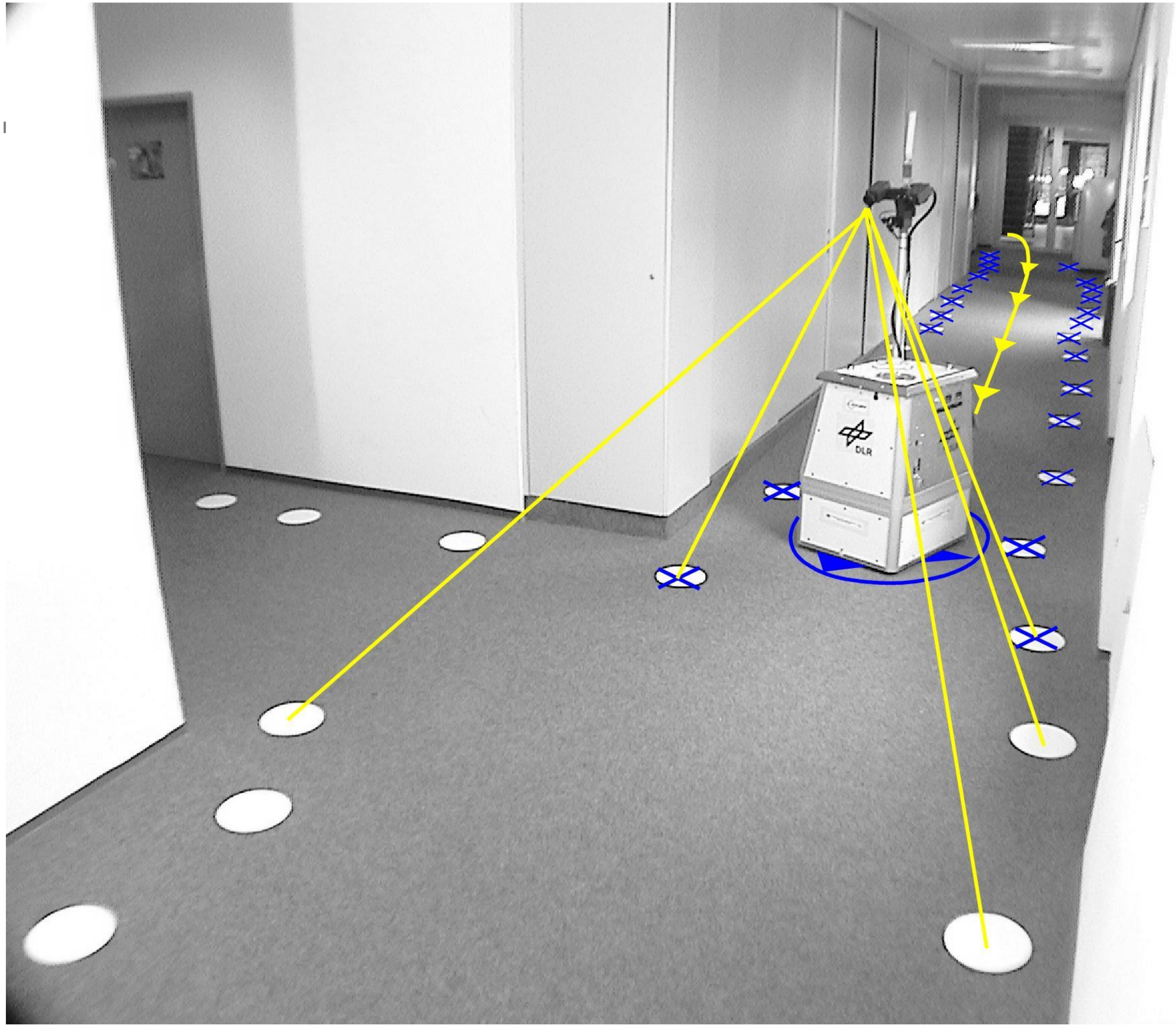
courtesy M.Kaess

Example 5: Surface representations

Category	Details
Information	List of triangles representing surface No discretization, arbitrary surfaces Used for computing object object interactions
Query	Find the closest surface. Very naively O(N) but can get massive speedups
Update	Can be updated online (albeit non-trivial) Very susceptible to noisy sensors
Memory	Proportional to amount of surface

Maps that help robots localize

Example 6: Landmark maps

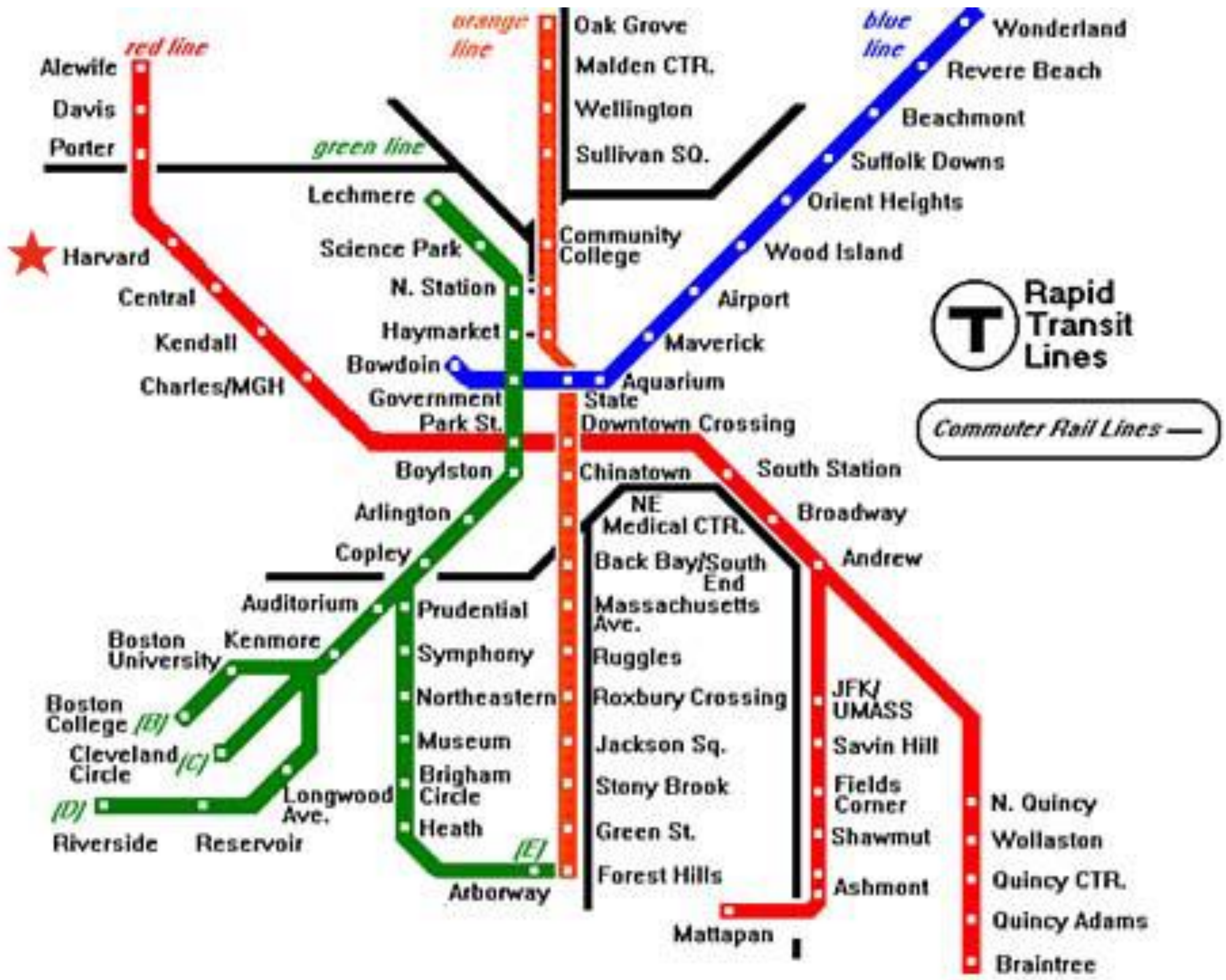


http://www.informatik.uni-bremen.de/~ufrese/slamvideos1_e.html Courtesy U. Frese

Example 6: Landmark maps

Category	Details
Information	Localization (correspondence between images at different timesteps)
Query	Typical query - give me the closest landmark Naive query is O(N)
Update	Easy to update (just dump landmarks) Need outlier rejection
Memory	Unbounded (but usually small as landmarks are sparse)

Example 7: Topological representations

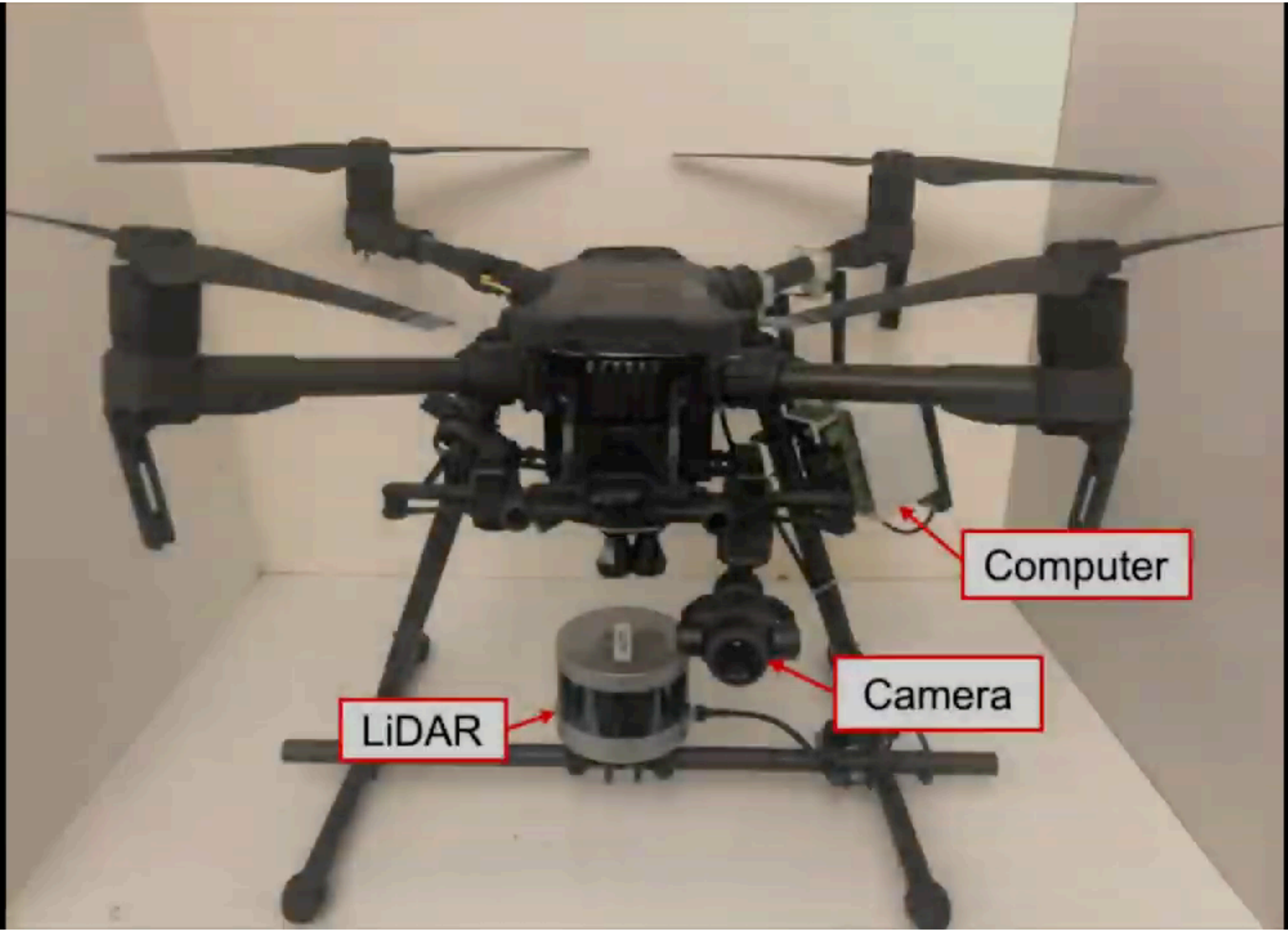


Courtesy M.Kaess

Example 7: Topological representations

Category	Details
Information	Graph where vertices are landmarks (e.g. rooms in a building), and edges represent relationships (connections) High level navigation tasks which are specified on the topomap. Localize robot on the map by finding correspondence with vertices.
Query	Cheap graph query
Update	Non-trivial / mostly done offline
Memory	Low

Applications with multiple map representations



Bonnatti et al. 2019

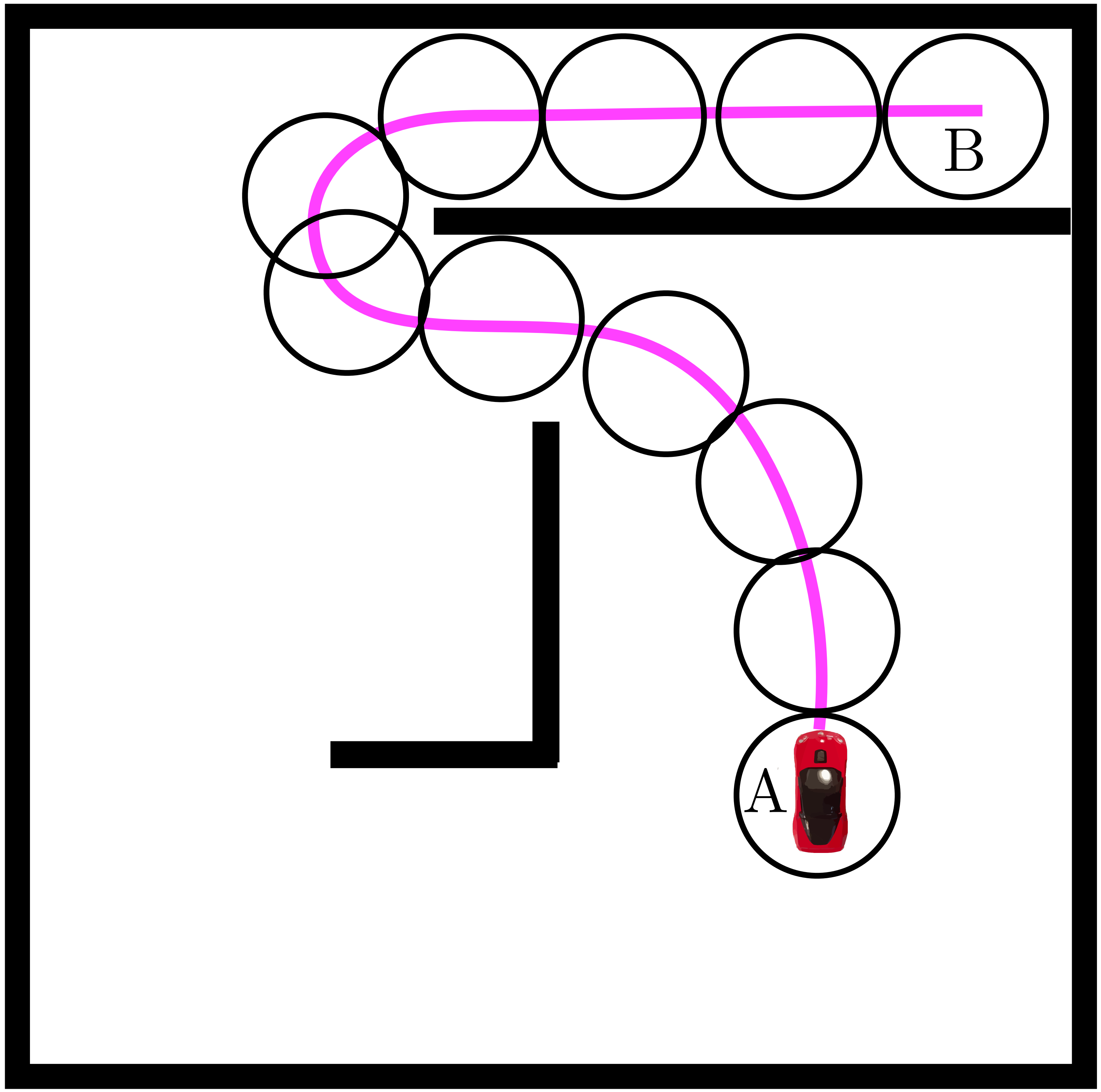
Maps are not just ways of storing sensor data

Some maps are computational operations on other maps

Distance map

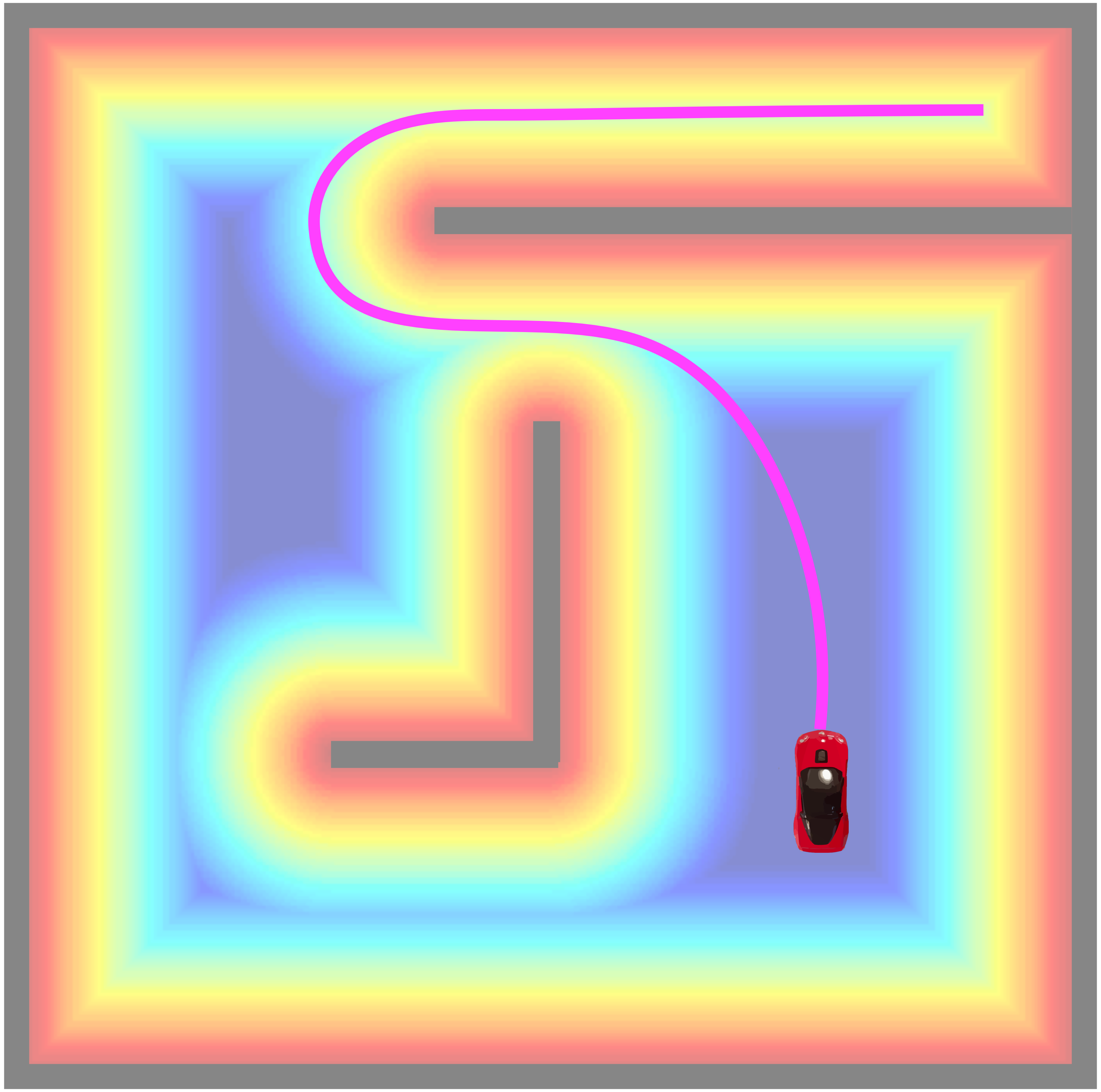
Why do we need distance?

Plan path that penalizes proximity to obstacles



Desiderata: Map storing (truncated) distance

Input:
Binary map
of the world



Output:
Map of
same size
storing
truncated
distance

Example 8: Distance map

Category	Details
Information	Truncated distance to obstacles
Query	O(1)
Update	We want to incrementally update this map Ideally O(k) where k is the number of cells which changed distance value
Memory	Same as the underlying occupancy grid

Euclidean distance Transform

0	0	0	0	0	0	0	0
0	1	1	1	1	1	1	0
0	1	1	1	1	1	1	0
0	1	1	1	1	1	1	0
0	1	1	1	1	1	1	0
0	1	1	1	1	1	1	0
0	0	0	0	0	0	0	0

$\Rightarrow$

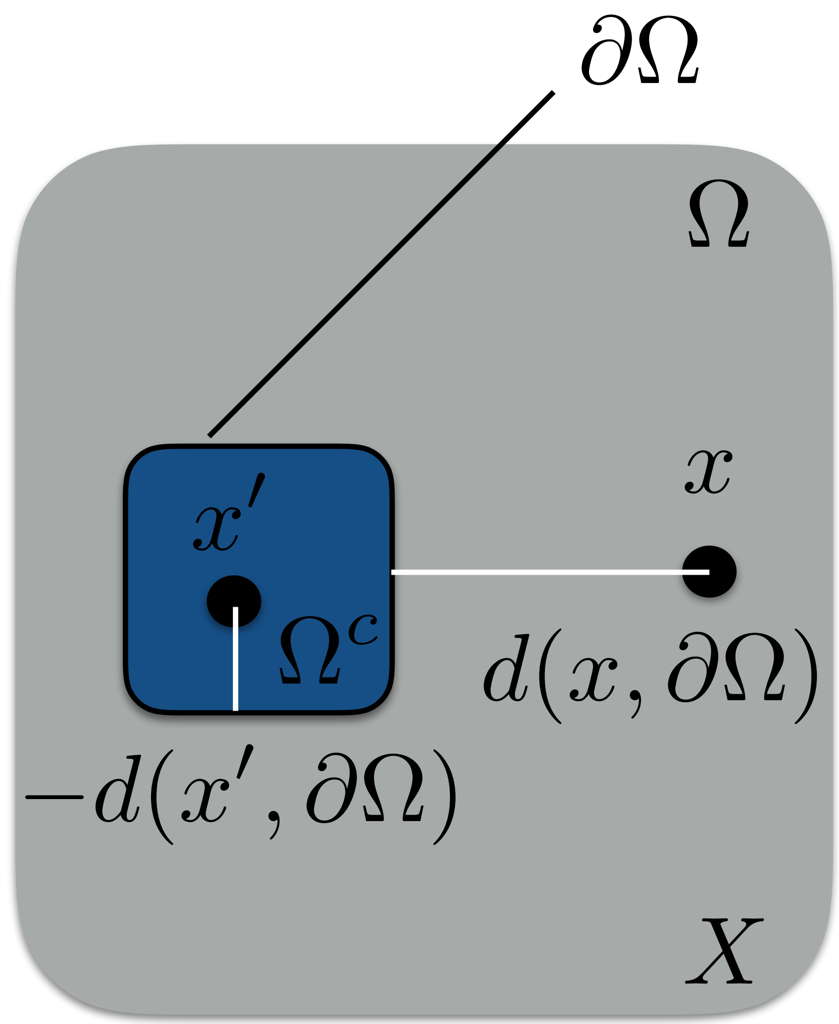
0	0	0	0	0	0	0	0
0	1	1	1	1	1	1	0
0	1	2	2	2	2	1	0
0	1	2	3	3	2	1	0
0	1	2	2	2	2	1	0
0	1	1	1	1	1	1	0
0	0	0	0	0	0	0	0

https://homepages.inf.ed.ac.uk/rbf/HIPR2/figs/distance.gif

Signed distance Transform

$$f(x) = \begin{cases} d(x, \partial\Omega) & \text{if } x \in \Omega \\ -d(x, \partial\Omega) & \text{if } x \in \Omega^c \end{cases}$$

$$d(x, \partial\Omega) := \inf_{y \in \partial\Omega} d(x, y)$$



$\boxed{\text{Important for motion planning}}$

Coming up next: SLAM...