Autonomous Navigation and Mapping with a UAV

Group: auto

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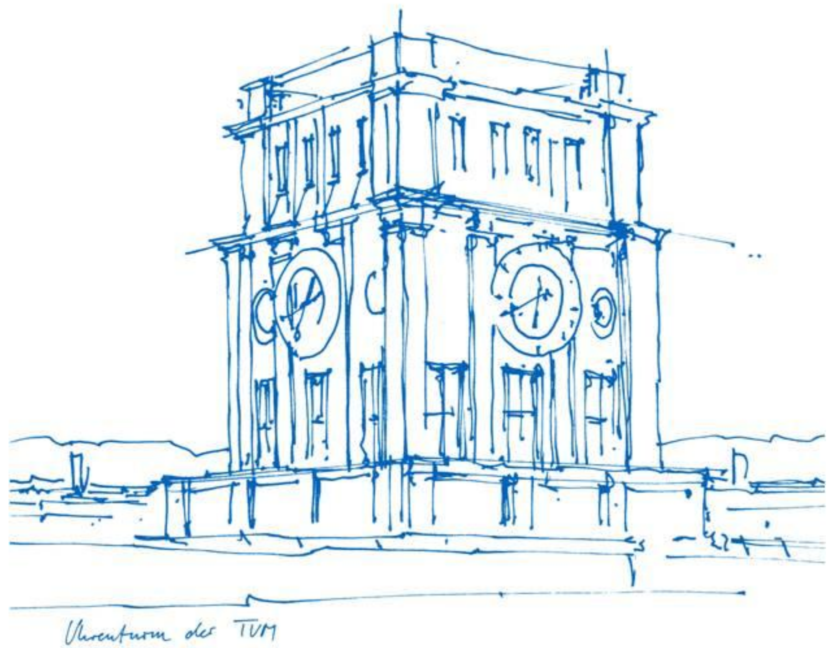
Technical University of Munich

Project: *Autonomous Systems* WS2122

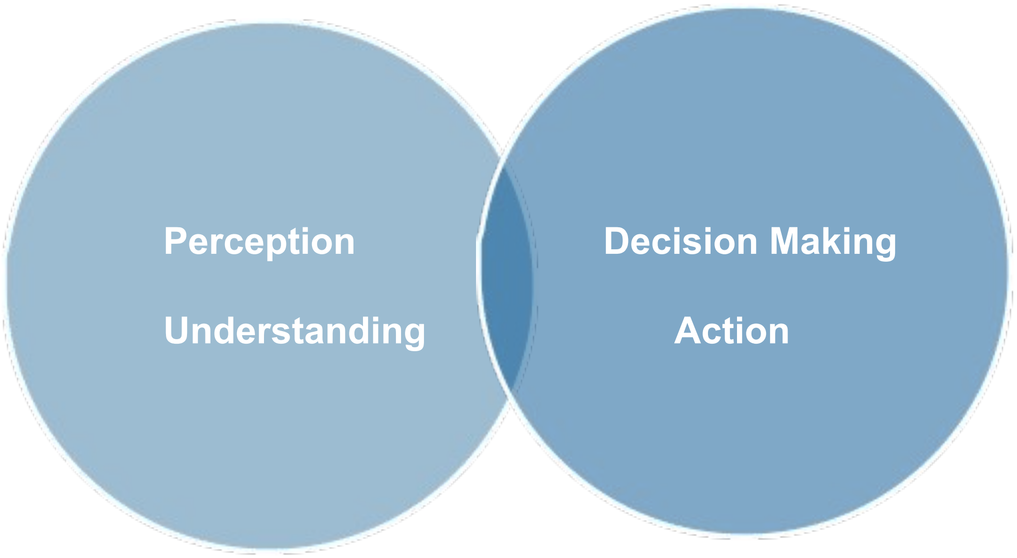
Advanced Challenge 1: Simulation & Mapping

Munich, 24. Mar 2022

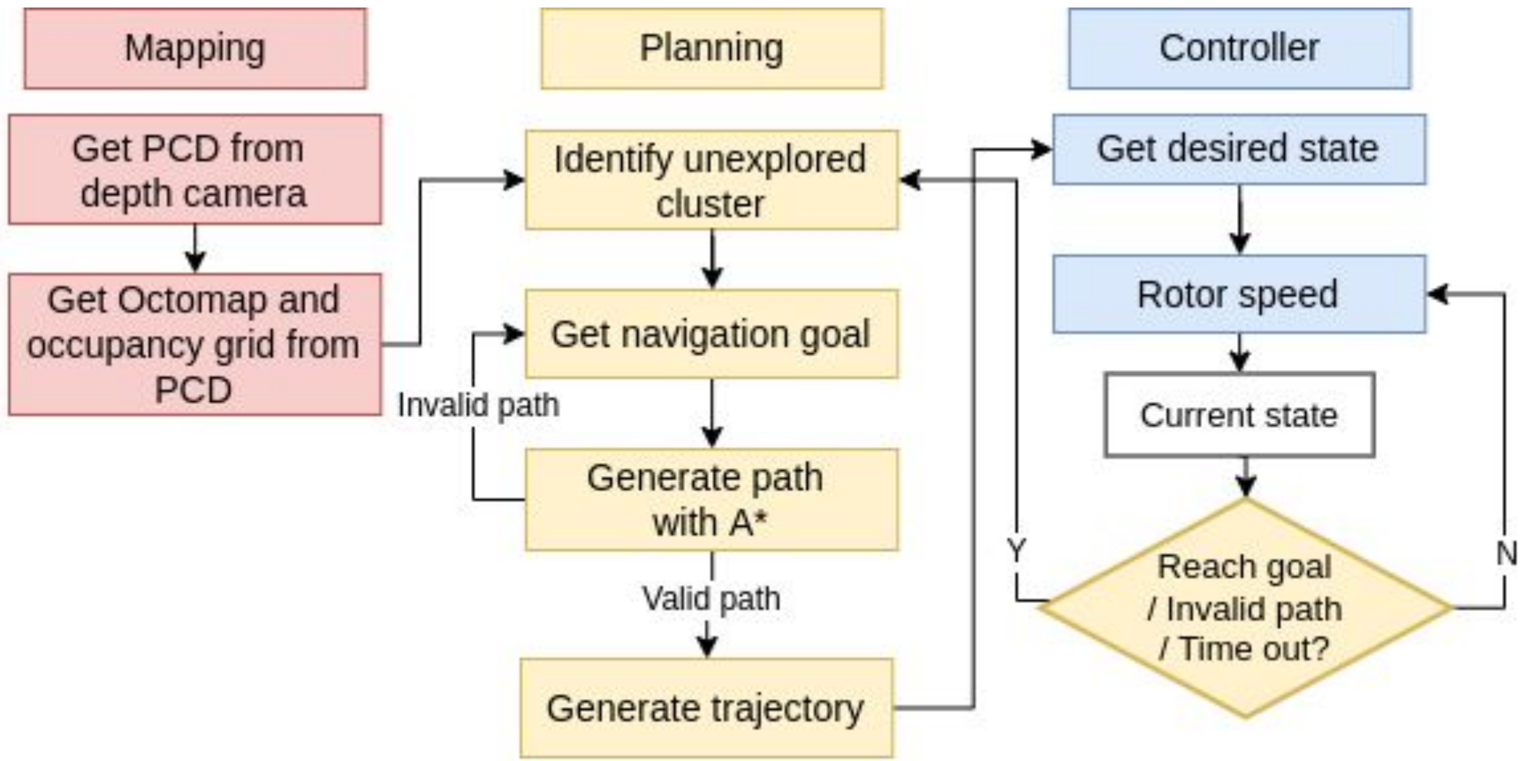


Autonomous system

What are the goals of an autonomous system?



System Architecture



Outline

Simulation | Perception | Mapping | Navigation | Conclusion

Unity Environment

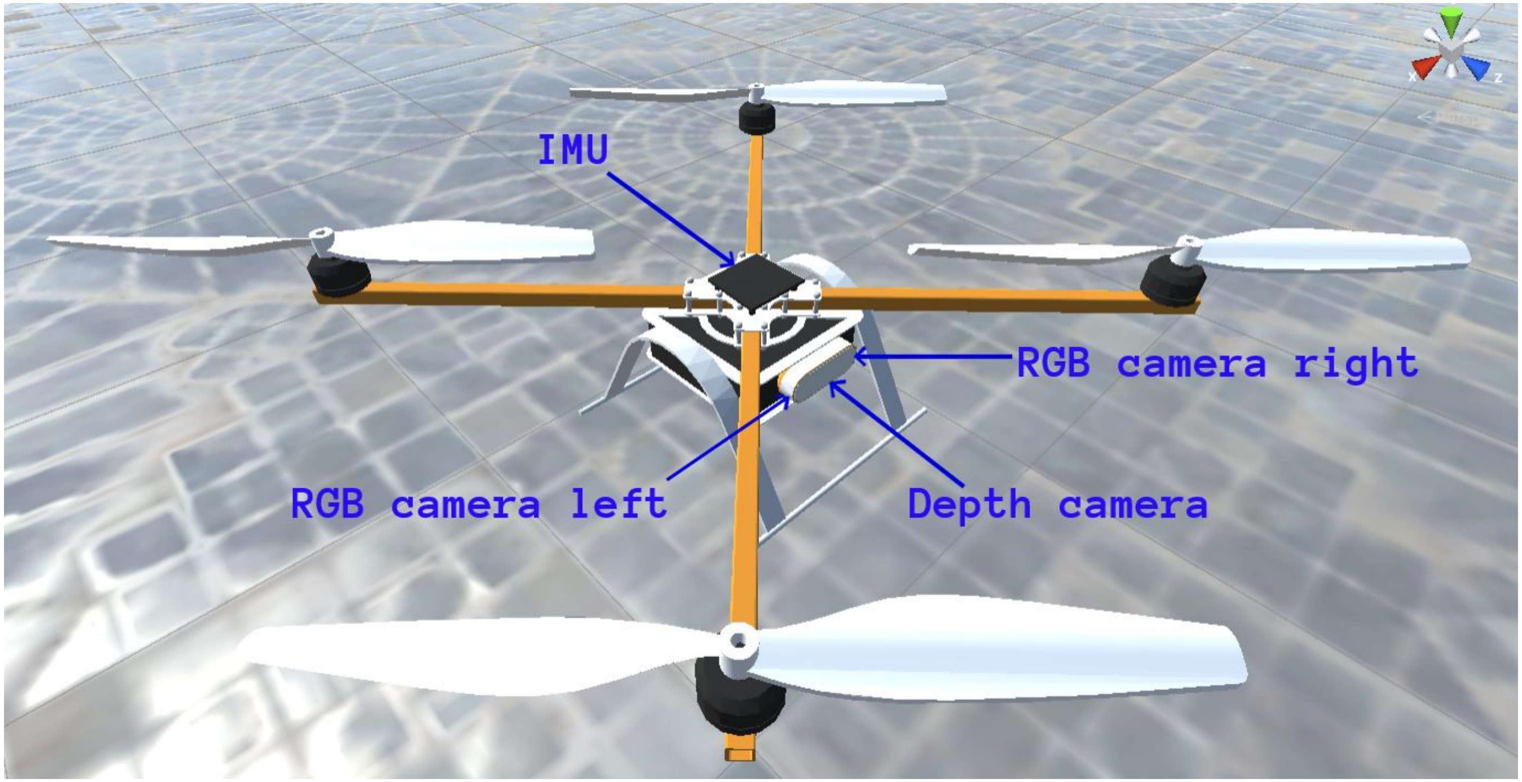
- 200 x 200

Unity Environment

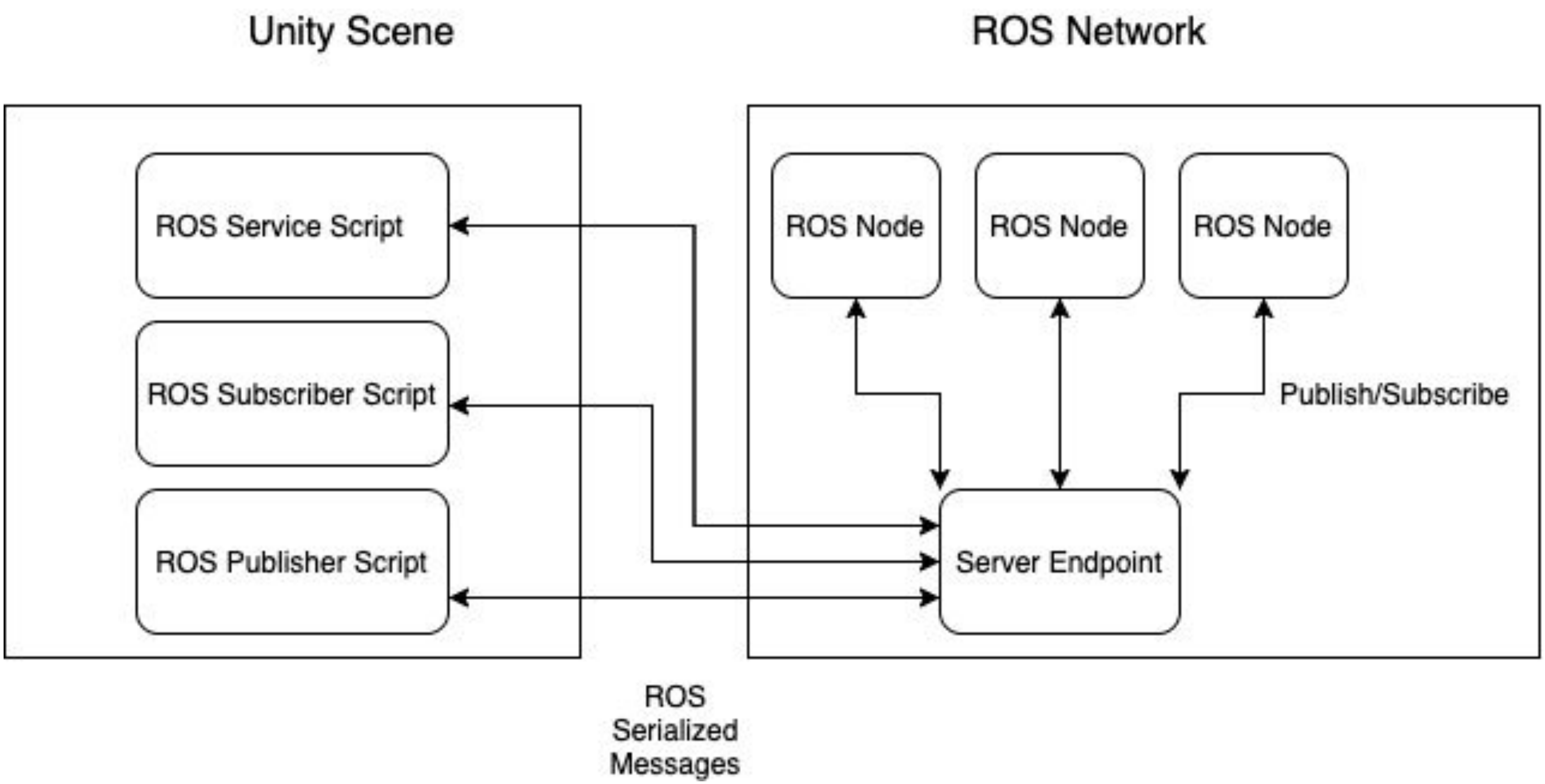
- Sun Temple, Flooded Grounds, Parks and Nature Pack, Temple

Perception

- Inertial measurement unit (IMU)
- 2 RGB cameras
- Depth camera



Unity-ROS communication



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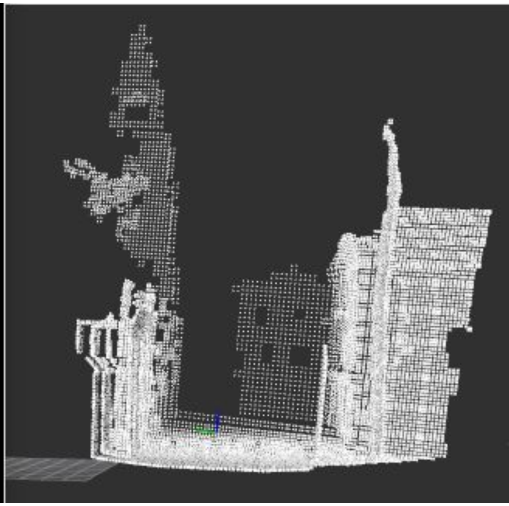
Generating Point Clouds

Raw Image

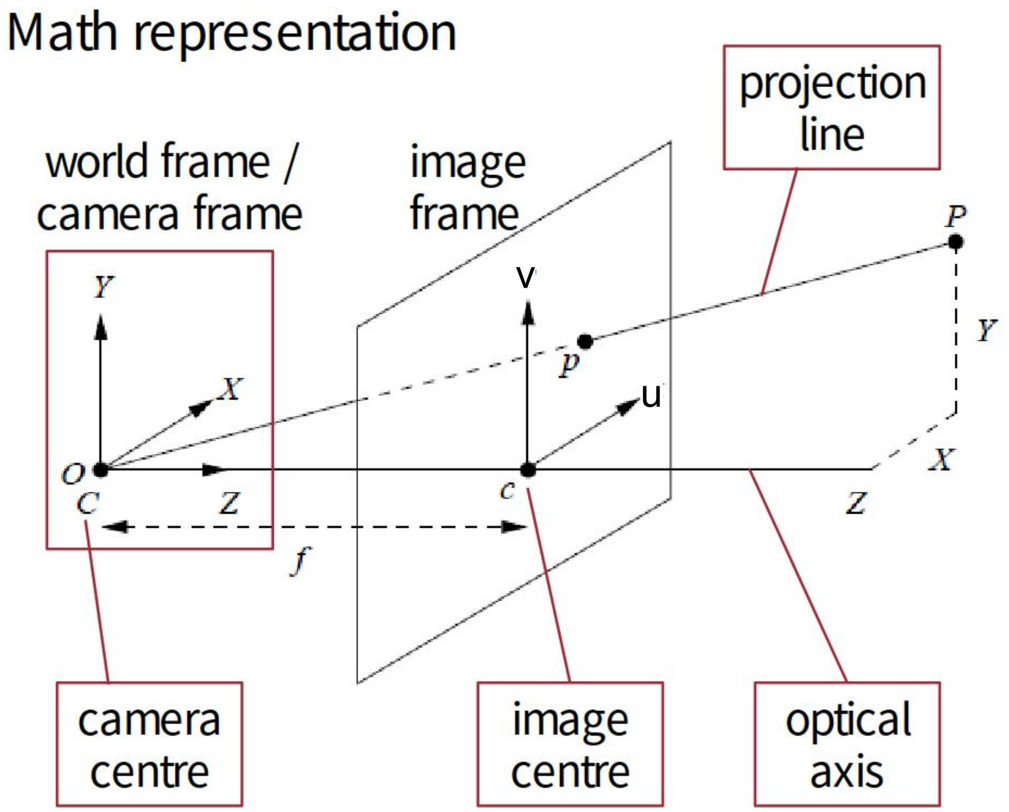
Depth Image

$$(u, v, d) \Rightarrow (x, y, z)$$

PointCloud



Generating Point Clouds



(https://www.comp.nus.edu.sg/~cs4243/lecture/camera.pdf)

$$x = \frac{(u - c_x)z}{f_x}$$

$$y = \frac{(v - c_y)z}{f_y}$$

The intrinsic matrix of the camera,

$$\mathbf{K} = \begin{vmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{vmatrix}$$

Downsampling PointCloud by VoxelGrid filter

Why?

Reduce the size of data.

Less noisy and outliers

How?

All the points inside the same voxel will be approximated with their centroid.

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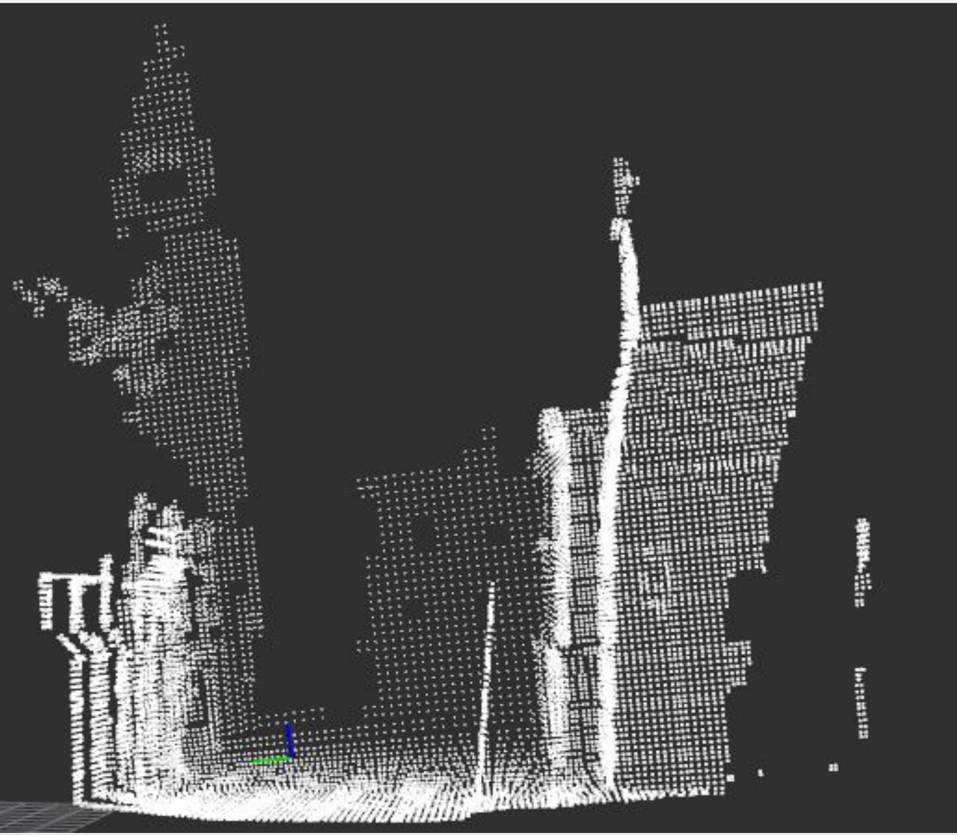
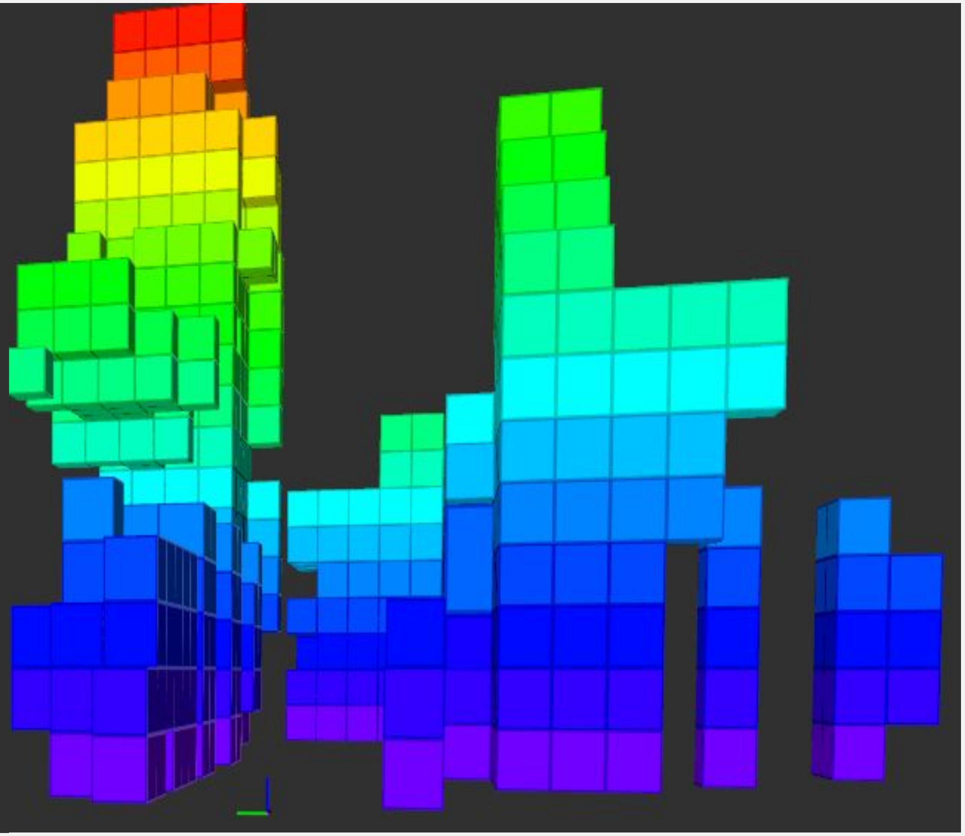
From Point Clouds to Octomap

Point Clouds



OctoMap



OctoMap Framework

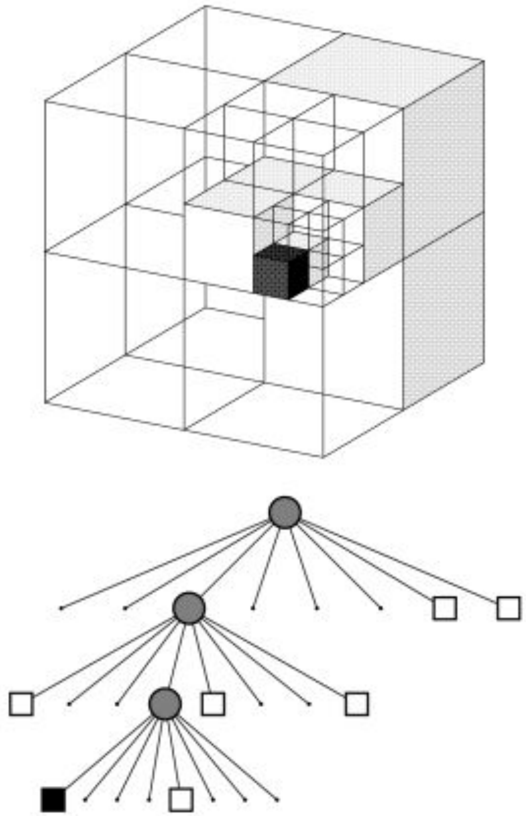
Octree-based Representation

Pro:

- Full 3D model
- Probabilistic
- Inherently multi-resolution
- Memory efficient

Contra:

- Implementation can be tricky
  (memory, update, map files, ...)



Probabilistic Map Update

Occupancy modeled as recursive binary Bayes filter

$$P(n \mid z_{1:t}) =$$
$$\left[1 + \frac{1 - P(n \mid z_t)}{P(n \mid z_t)} \frac{1 - P(n \mid z_{1:t-1})}{P(n \mid z_{1:t-1})} \frac{P(n)}{1 - P(n)}\right]^{-1}$$

Efficient update using log-odds

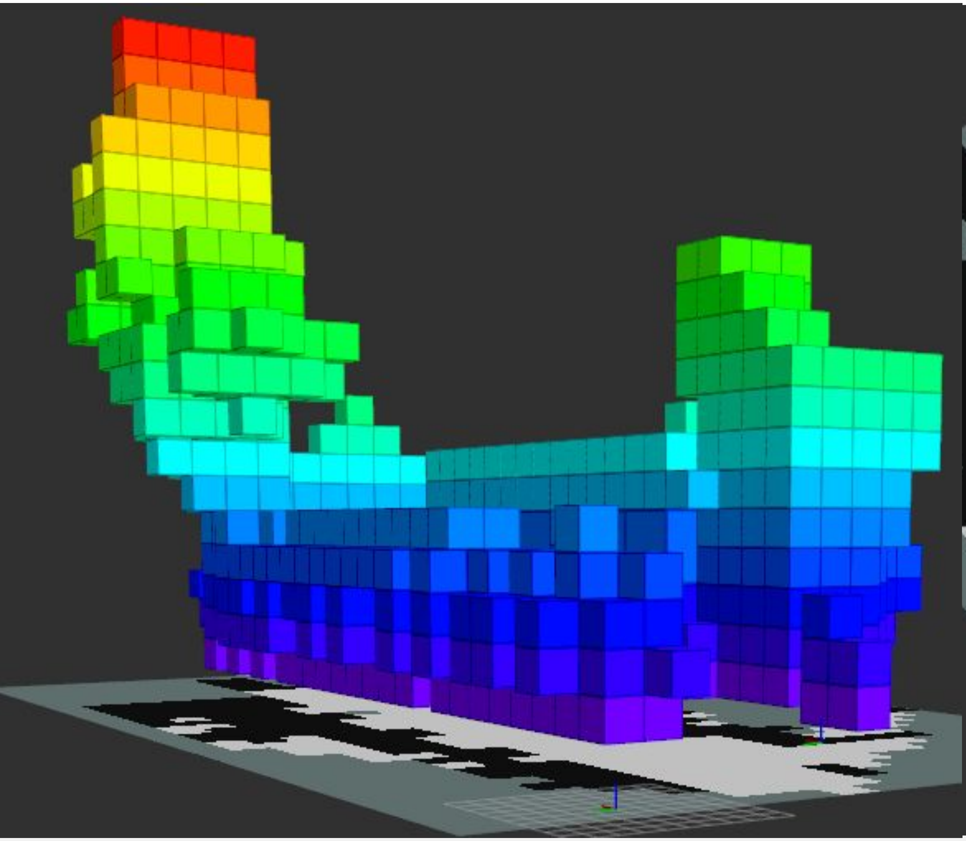
$$L(n \mid z_{1:t}) = L(n \mid z_{1:t-1}) + L(n \mid z_t)$$

Clamping policy ensures updatability

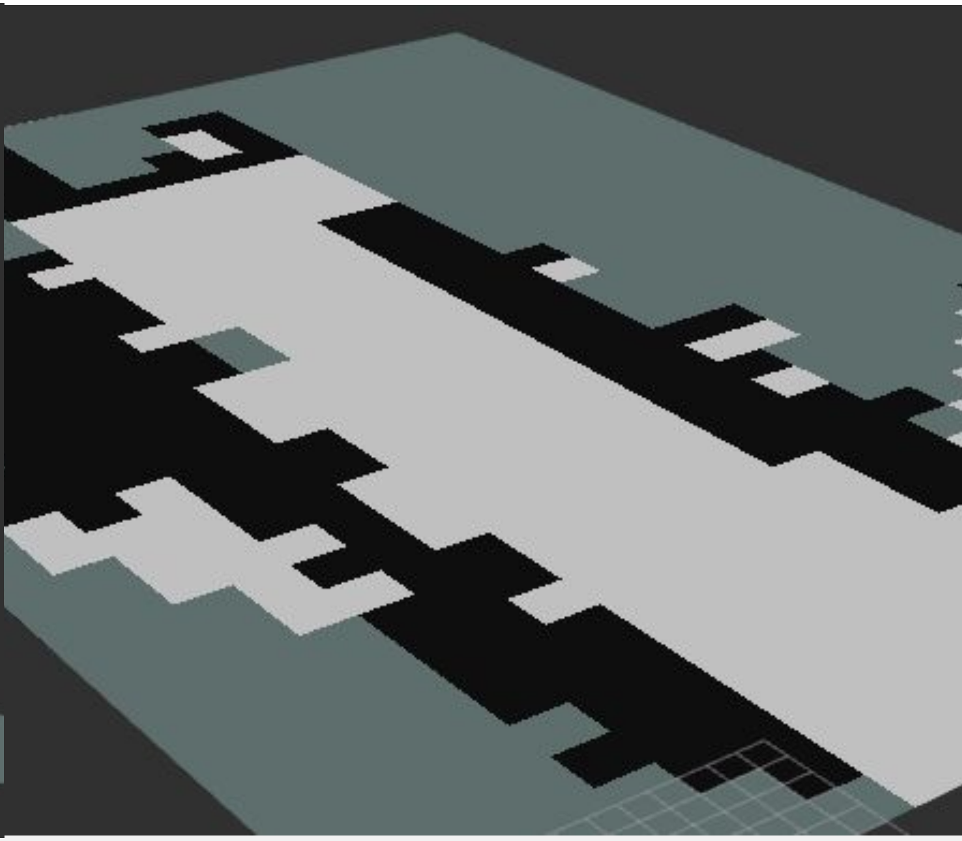
$$L(n \mid z_{1:t}) = \max(\min(L(n \mid z_{1:t-1}) + L(n \mid z_t), l_{\max}), l_{\min})$$

Project Octomap to Occupancy Grid Map

OctoMap



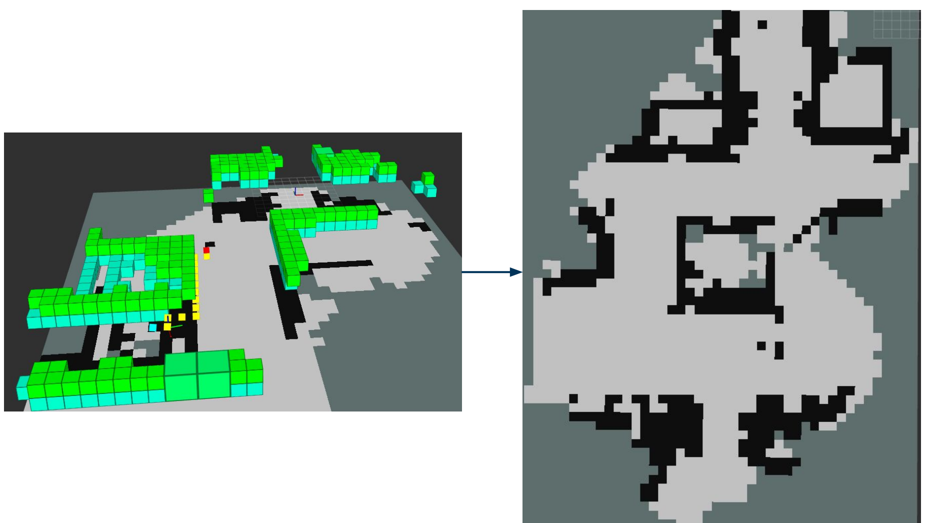
Occupancy Grid Map



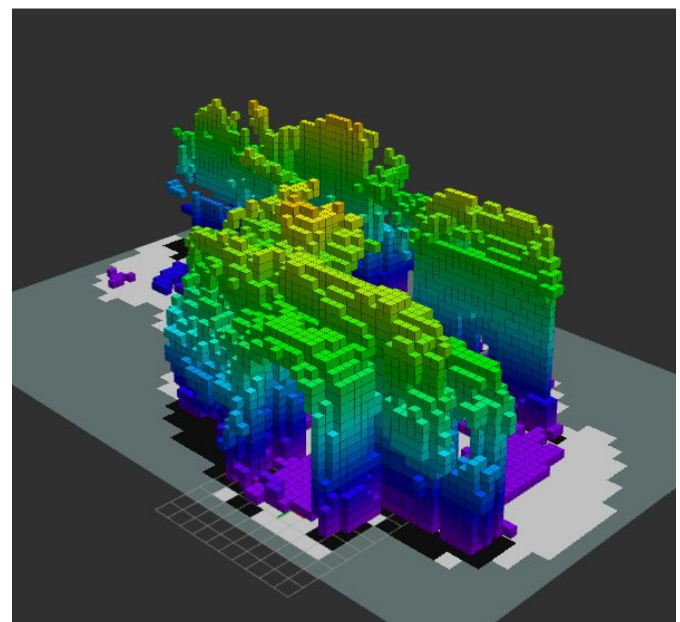
Two octomap server nodes

This enables the generation of a 2D map for navigation, and a 3D map for modelling purposes
The “2D node” only considers point clouds that are around the same height as the goal height of the drone
The “3D node” considers point clouds from the ground up, and it uses a higher resolution

2D



3D



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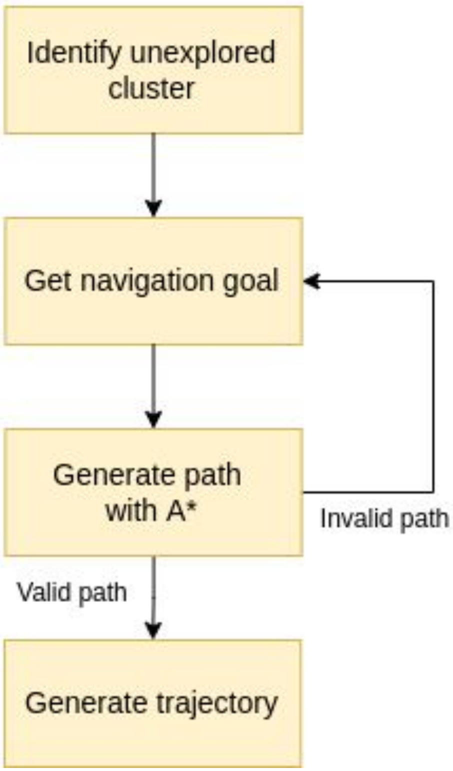
Navigating in unknown space



Locating unmapped space

There are multiples points marked as “unknown” (-1) in the occupancy grid, what is the next desired point?

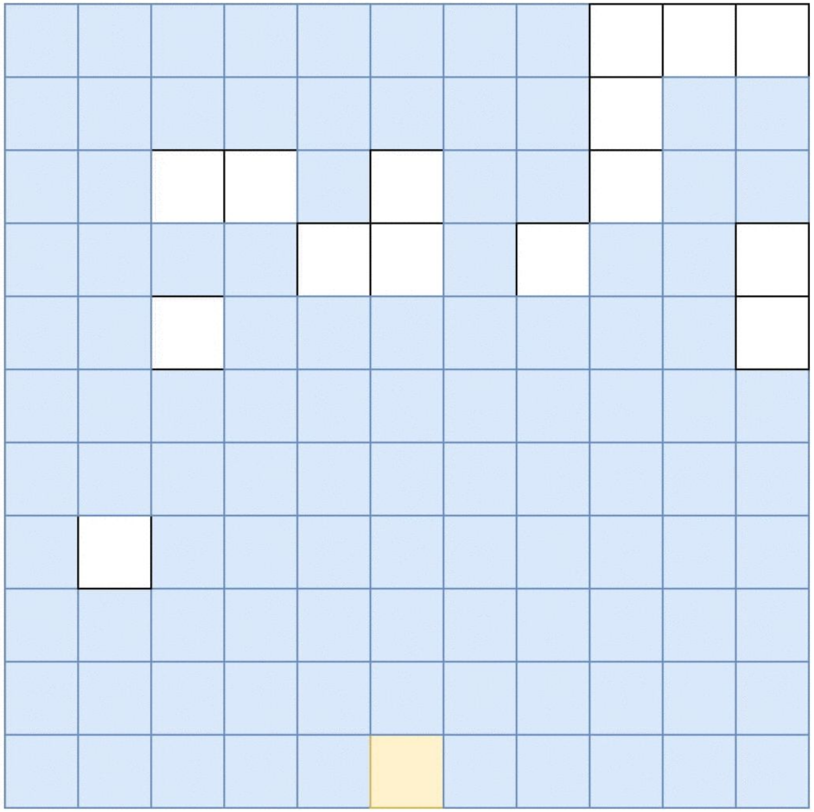
We want to find the center of the rectangle that contains the most unknowns
The occupancy grid is therefore converted into a binary matrix

Intuition

- Finding the maximum height of the rectangle by iterating upwards until a filled area is reached

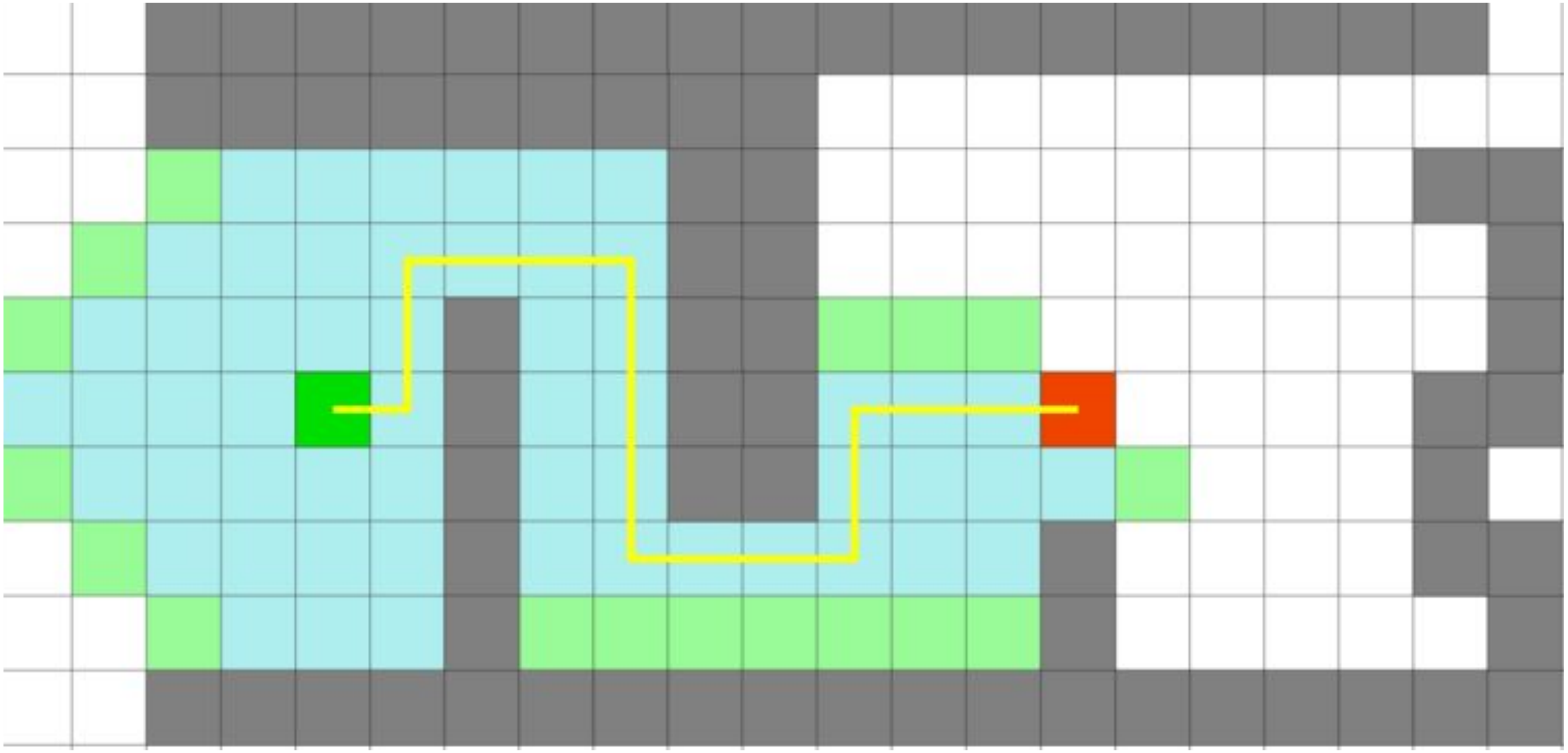
- Finding the maximum width of the rectangle by iterating outwards left and right until a height that doesn't accommodate the maximum height of the rectangle

For example finding the rectangle defined by the yellow point:



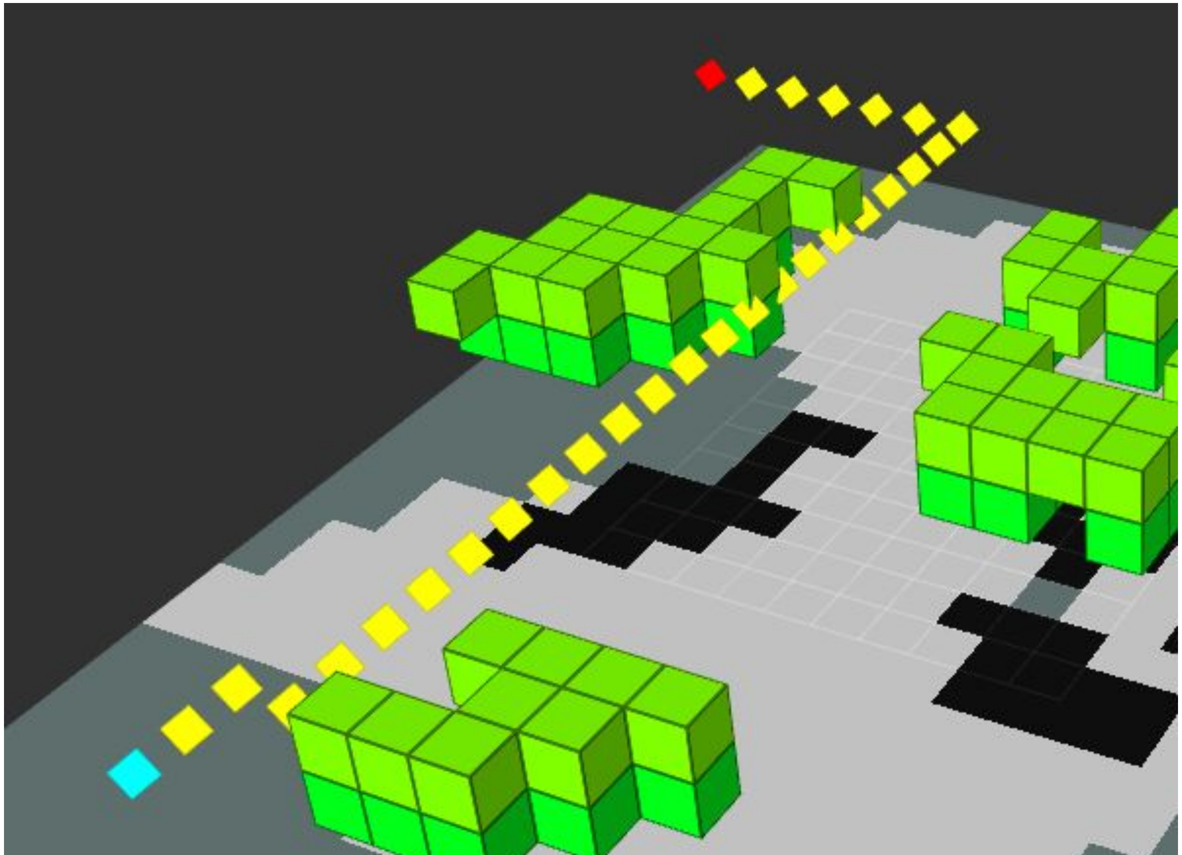
Waypoints from A* Algorithm

Finding a collision-free path



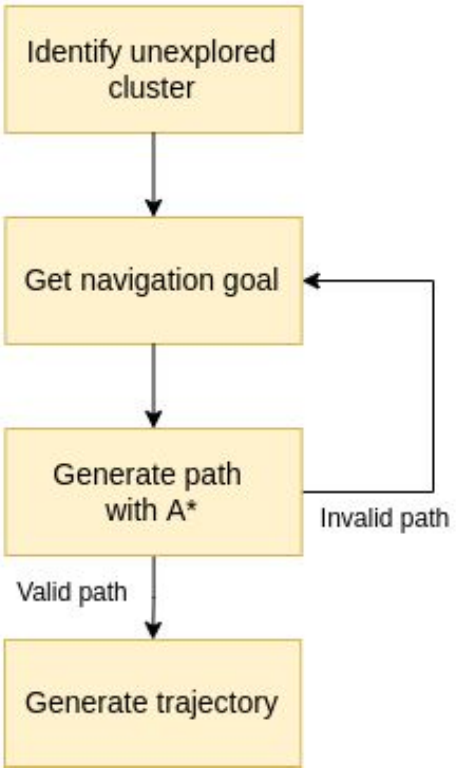
Example path

The current location is marked in red.
The goal location is blue.
The waypoints are marked in yellow.



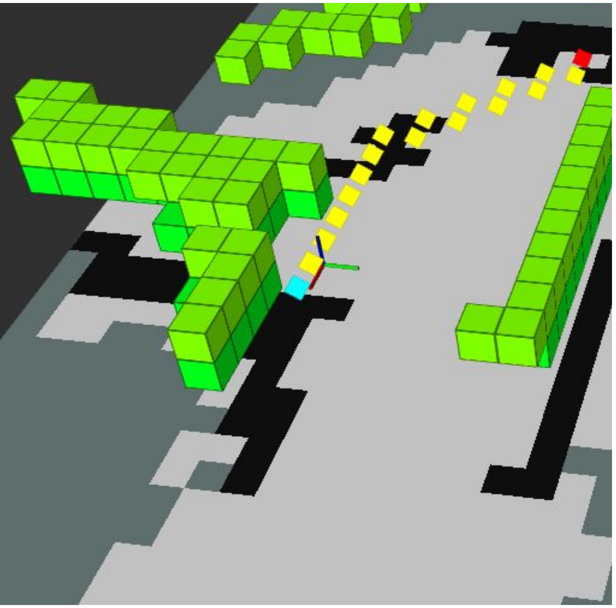
No valid path found?

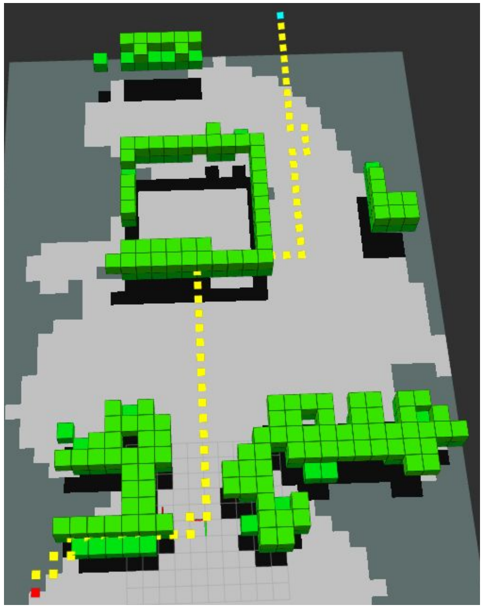
Sample a new goal point.
This time the first unknown location in the map is chosen.
Re-iterate until a collision-free path is found.



When to generate new waypoints?

A. When the goal is reached
B. When new information (updated map) shows that the path is invalid
C. When the drone has been stationary for too long


A

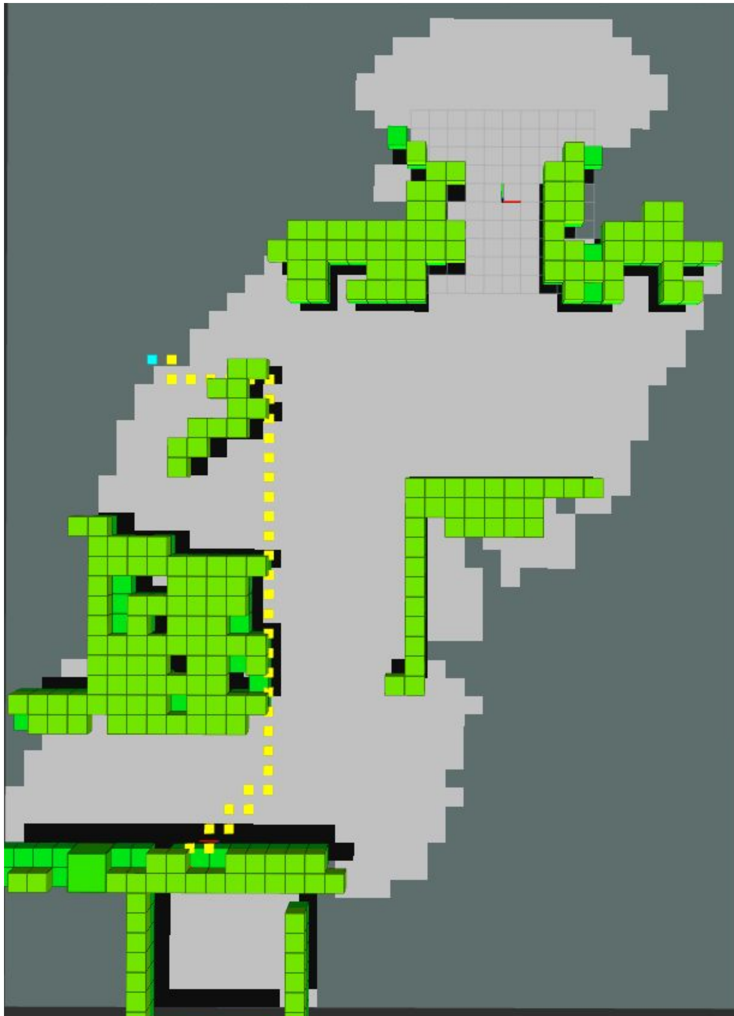

B


C

Challenges

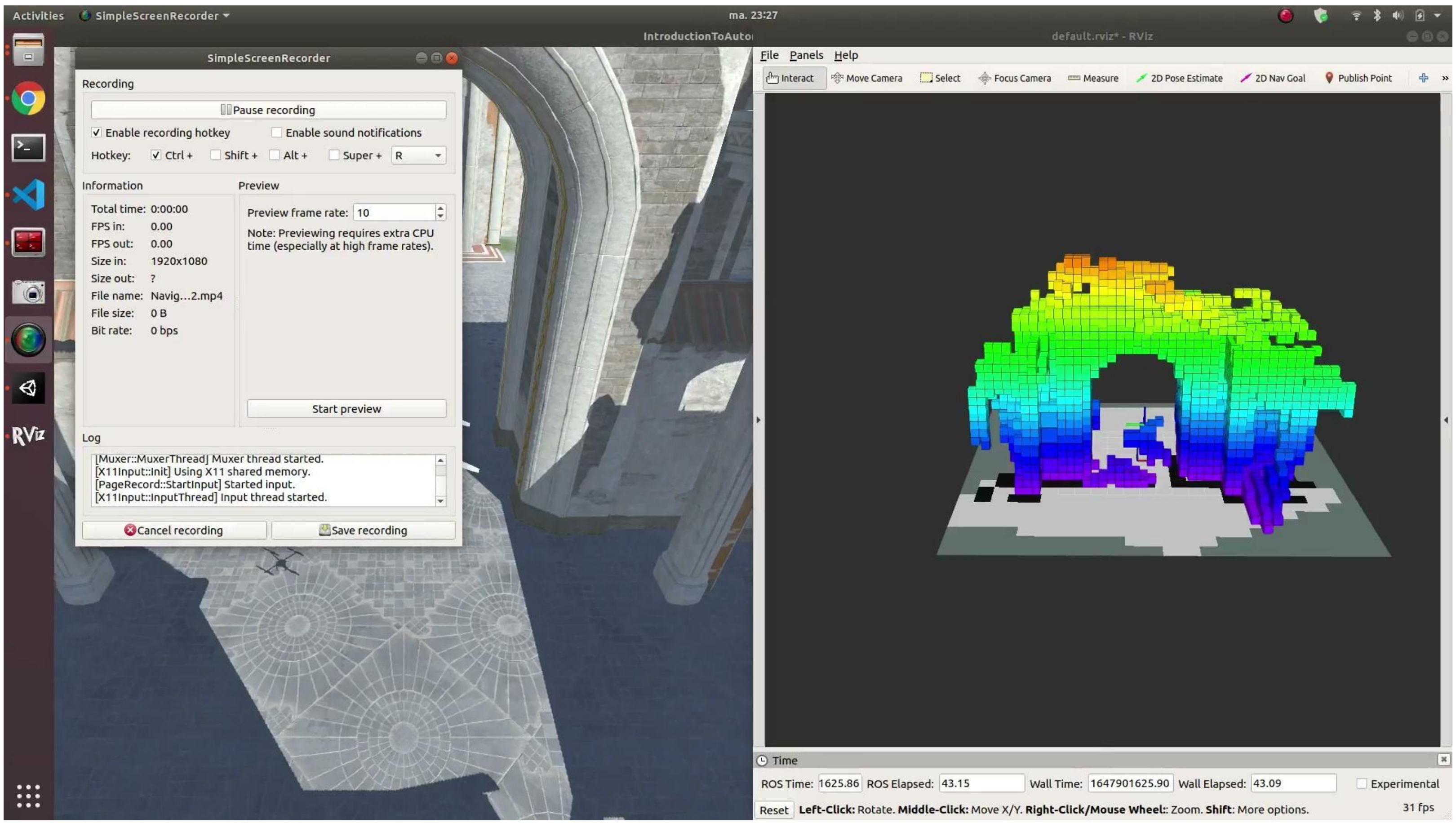
- A* path might be too close to obstacles
  - Attempted to solve this by defining points as obstacles if they are in a certain range of an obstacle
- Computational load
  - Increases with the resolution (more points to consider)
- Conversion between occupancy grid and world frame sometimes fails
  - The below formula is used. It can lead to negative values for the indices in the occupancy grid, which should not be possible

$$grid_x = \frac{world_x - map.origin.position.x}{map.resolution}$$



Video demonstration

https://drive.google.com/file/d/1o1_DpZDkf9Uj6yPlwlonBVh6s8JgjkKo/view?usp=sharing



Trajectory Generation

Minimum snap

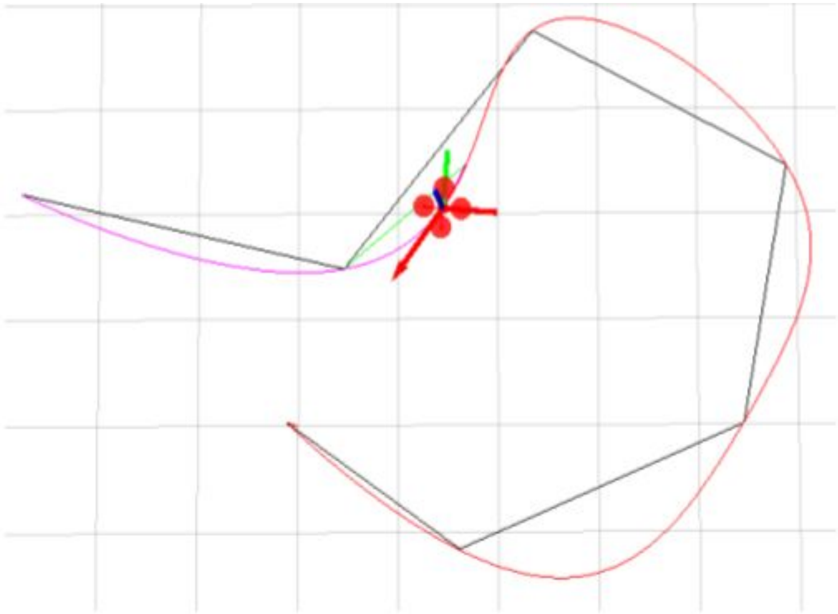
Boundary conditions: start and goal positions, start and goal velocities
The start velocity is set to the current velocity, and the end velocity is set to (0, 0, 0)

Intermediate conditions: waypoint positions

Smoothness criteria

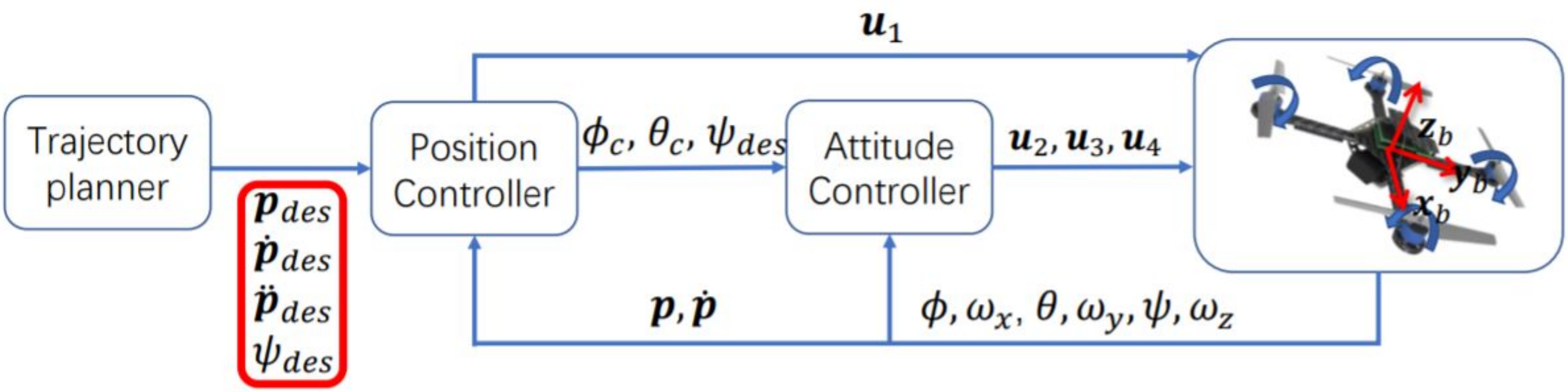
- Generally translates into minimizing rate of change of “input”

This [mav_trajectory_generation] package from ETH Zurich is used



Geometric Controller

Finely tuned



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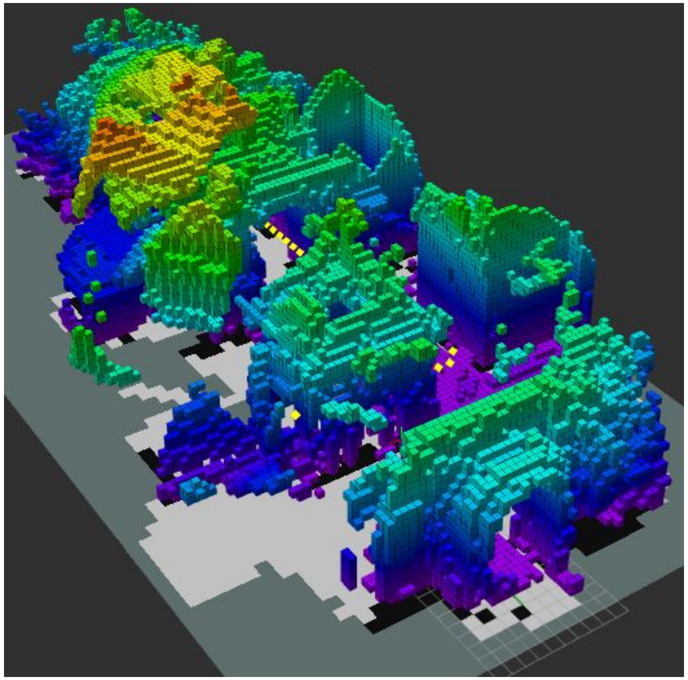
Conclusion

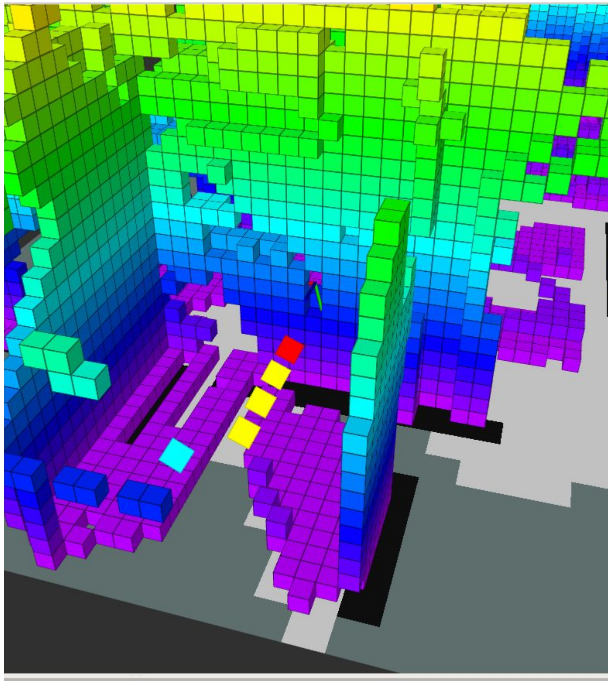
A large part of the environment is autonomously mapped

The drone crashes pretty often

Running a separate collision-avoidance system could improve redundancy

Controller performance is affected by how many processes are being run on the hosting PC





Contributions

Simulation - Luca

Perception - Junpeng

Controller - Autumn

Mapping - Shervin, Weihang

Navigation - Shervin

References

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