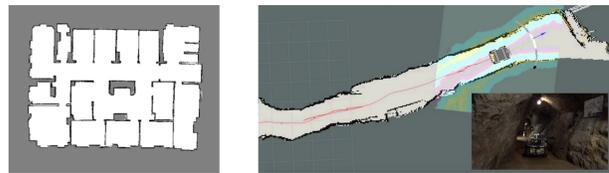


Background and Motivation

- ▶ **Mapping:** generate a map representing the environment surrounding a robot
- ▶ **Autonomous Exploration:** traverse initially uncertain space based on mapping knowledge
- ▶ **Motivation for Mapping and Exploration**
 - ▶ Search and Rescue: find targets with physical/health hazards
 - ▶ Surveillance: gather information of enemy locations
 - ▶ Convenience: autonomous robotic cleaning

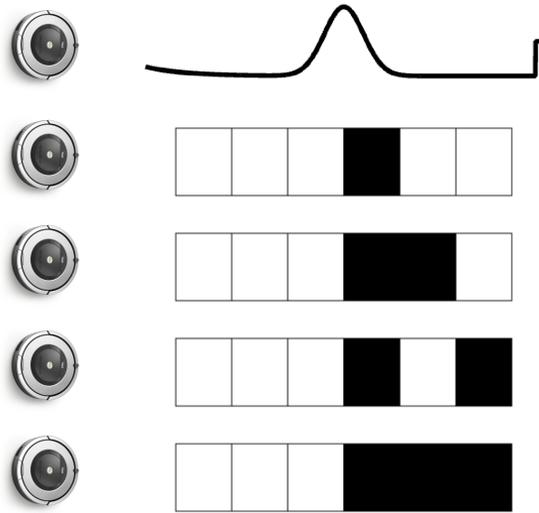


Occupancy Grid Map

Mining Autonomous Exploration

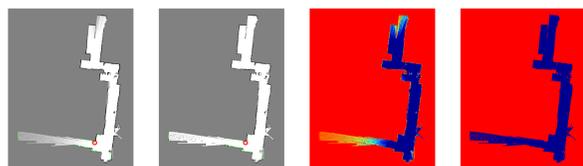
Exact Occupancy Grid Mapping

- ▶ The **probabilistic** map is composed of evenly-space **grid cells** that are either **occupied** or **free**
- ▶ Given the sensor **forward sensor model**: $P(z|m, x)$
- ▶ Goal: obtain the **inverse sensor model**: $P(m|z, x)$
- ▶ Map outcomes can be grouped together:



The forward sensor model (top) refers to the four mapping cases below.

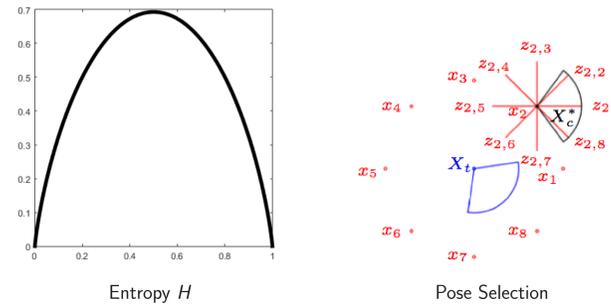
- ▶ For n grid cells, algorithm is $\frac{n}{n+1} \times 2^n$ times faster
- ▶ Exact and approximate inverse sensor models in 2D:



Approx. $P(m)$ Exact $P(m)$ Approx. H Exact H

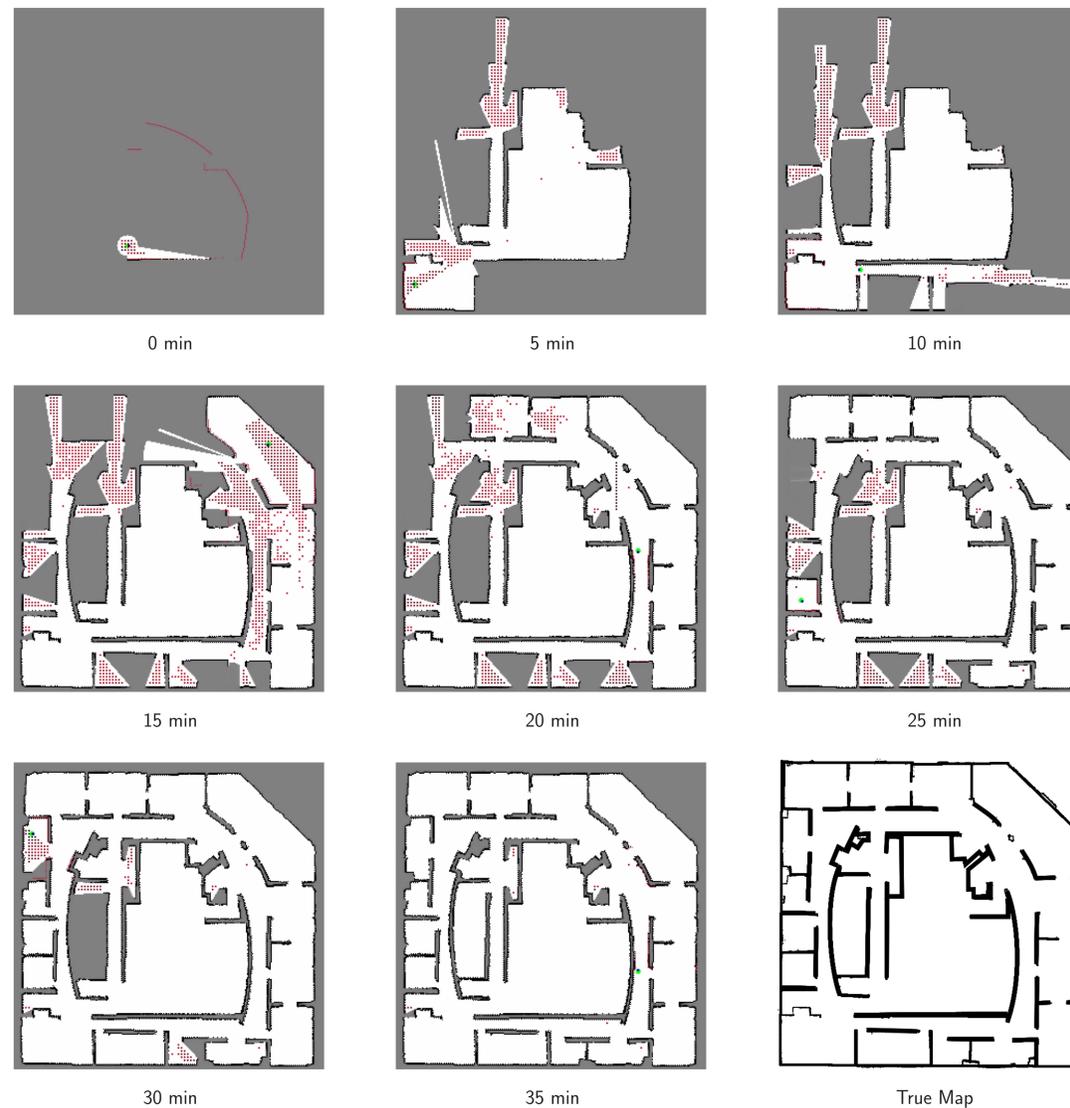
Autonomous Exploration

- ▶ Autonomous exploration policy is governed by **map uncertainty**, measured by **entropy H**
- ▶ The robot chooses actions to **minimize entropy**, or equivalently **maximize map information gain**
- ▶ The optimal location and attitude are chosen **optimally** with map information maximization
- ▶ **Collision-free** motion planning: Dijkstra's algorithm, constrained polynomial least squares, and onboard control



Autonomous Exploration Result: Benchmark Simulation Example

- ▶ The Intel Research Lab serves as a benchmark environment for a simulated robot to autonomously explore
- ▶ The Robot Operating System (ROS) provides effective frameworks for simulation and experimentation



Experimental Result: Ground Robot Exploration

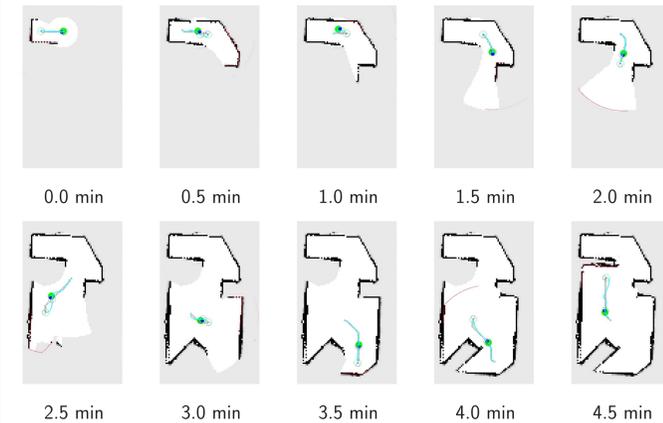
- ▶ Exact occupancy grid mapping and autonomous exploration are tested simultaneously at the US Naval Research Laboratory (NRL)
- ▶ A Pioneer 3 ground vehicle is equipped with a Microsoft Kinect depth sensor, where Vicon motion capture provides the robot pose
- ▶ The robot explores an environment consisting of Styrofoam walls



Pioneer 3

Bottom-left view

Bottom-right view



- ▶ The robot simultaneously builds a probabilistic map and autonomously explores the space collision-free

Conclusions and Future Steps

- ▶ Exact occupancy grid mapping is accurate and computationally-efficient for real-time algorithms
- ▶ Autonomous exploration, based on maximizing map information gain, effectively governs robotic motion
- ▶ Both algorithms are applied simultaneously in simulations and experiments
- ▶ The most recent research focusses on 3D mapping and exploration for flying robots



SEH 3D Map

Multiple Quadrotors

- ▶ Future steps: experimentation with a flying vehicle and multi-vehicle autonomous exploration involving a bidding-based optimization