

# Exploration of unknown environment

**Vojtěch Vonásek**

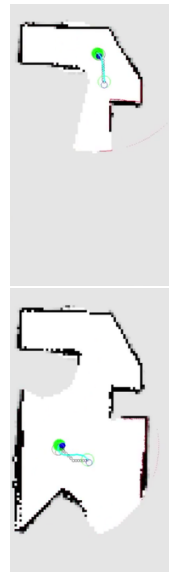
Department of Cybernetics  
Faculty of Electrical Engineering  
Czech Technical University in Prague

**The problem:** is how to explore the unknown environment to obtain its map?

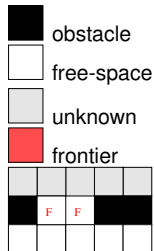
- Fundamental problem in robotics
- Search & rescue, planetary exploration, military
- Single robot vs. multi-robot exploration
- Challenges
  - How to represent the map & update it?
  - How to localize?
  - How to determine where to go?
  - How to get there?
- Criteria: e.g. map size, speed of exploration, area being discovered

## Topic for this lecture

- Frontier-based exploration — principle to decide where to go next
- Assuming you have occupancy grid and localized robot



- Occupancy grid with cells
  - **Known cell**: value of  $c_i \geq 0$  (contains prob. of being occupied)
  - **Unknown cell**: value of  $c_i = -1$
- Interpretation of known cells:
  - Free-space (no obstacle)  $p(\text{occupied}) < T$
  - Obstacle  $p(\text{occupied}) > T$
  - where  $T$  is a threshold, e.g. 0.8
- **Frontier**: the border between known and unknown regions
- **Frontier cell**
  - is a free-space cell that is incident with an unknown cell
  - it may not be reachable





**Principle:** use a frontier as a temporary goal

- 1 Identify frontiers in the map
- 2 Filter out unreachable frontiers (if any)
- 3 Select a frontier and go there
- 4 Goto 1 until no frontier exists

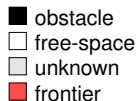
Notes

- Unreachable frontiers detected using path planning
  - Consider navigating to the closest frontier
  - Consider detecting frontiers during movement of the robot
  - Detection of frontiers should be fast
- YAMAUCHI, B., et al. Frontier-based exploration using multiple robots. *Agents*. 1998; 47-53.
- KEIDAR, Matan; KAMINKA, Gal A. Ecient frontier detection for robot exploration. *The International Journal of Robotics Research*, 2014, 33.2: 215-236.



- obstacle
- free-space
- unknown
- frontier

- Image-based
  - Convert occupancy grid to binary image, run edge detection
- Wavefront Frontier Detector (WFD) (Keidar)
  - Graph-search method to detect frontiers
  - Run BFS from actual position of the robot
  - This BFS explores only free cells (i.e., also frontier cells)
  - Run another BFS if frontier cell is visited
  - The second BFS explores only frontier cells
  - The goal of second BFS is to extract all cells belonging to the actually detected frontier



- Both BFS's share open/close list

- YAMAUCHI, B., et al. Frontier-based exploration using multiple robots. Agents. 1998; 47-53.
- KEIDAR, Matan; KAMINKA, Gal A. Ecient frontier detection for robot exploration. The International Journal of Robotics Research, 2014, 33.2: 215-236.











- YAMAUCHI, Brian, et al. Frontier-based exploration using multiple robots. In: Agents. 1998. p. 47-53.
- TOPIWALA, Anirudh; INANI, Pranav; KATHPAL, Abhishek. Frontier Based Exploration for Autonomous Robot. arXiv preprint arXiv:1806.03581, 2018
- USLU, Erkan, et al. Implementation of frontier-based exploration algorithm for an autonomous robot. In: 2015 International Symposium on Innovations in Intelligent SysTems and Applications (INISTA). IEEE, 2015. p. 1-7.
- KEIDAR, Matan; KAMINKA, Gal A. Ecient frontier detection for robot exploration. The International Journal of Robotics Research, 2014, 33.2: 215-236.