Exploration of unknown environment

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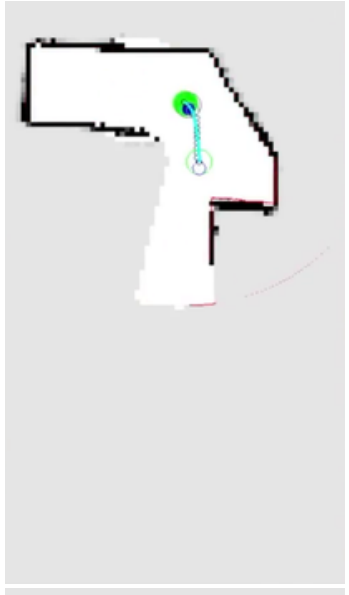
Robotic exploration

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

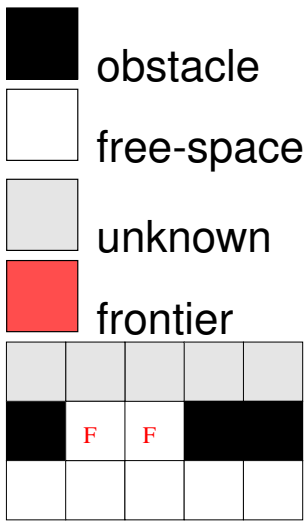


Topic for this lecture

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

Frontier-based exploration

- 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) $p(occupied) < T$
  - Obstacle $p(occupied) > T$
  - 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



☛ YAMAUCHI, B., et al. Frontier-based exploration using multiple robots. Agents. 1998; 47-53.

Frontier-based exploration

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

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☛ KEIDAR, Matan; KAMINKA, Gal A. Ecient frontier detection for robot exploration. The International Journal of Robotics Research, 2014, 33.2: 215-236.

Frontiers detection

- 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

obstacle
free-space
unknown
frontier

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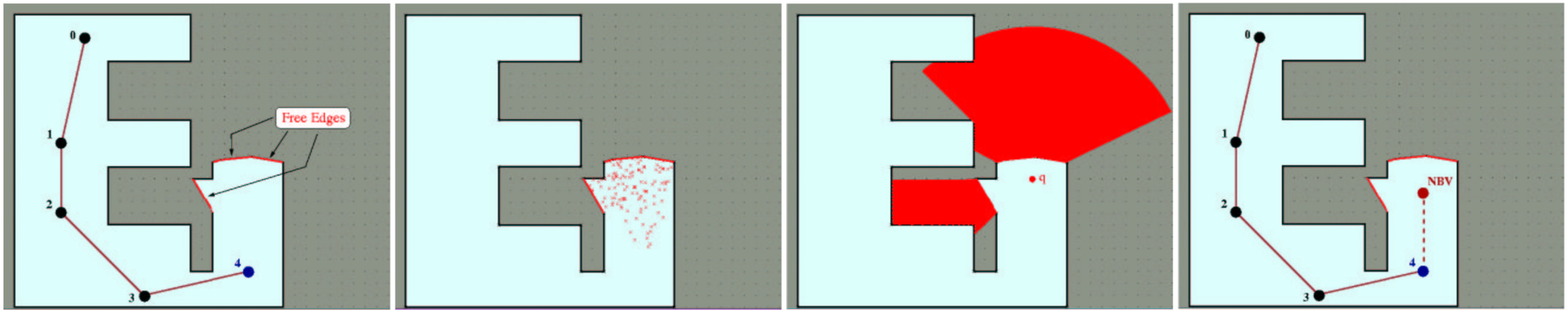
Improved Frontier-based exploration

Several ideas to get better (faster) exploration

1. Consider cost of path to the frontier for frontier selection
2. Consider how much are is 'behind' the frontier (aka 'view'), visit the most promising frontiers first $\rightarrow$ next best view approach
3. Combination of above



☛Gonzalez-Banos, H. H.,Latombe, J. C. (2002). Navigation strategies for exploring indoor environments. The International Journal of Robotics Research, 21(10-11), 829-848.

Frontier-based exploration: resources

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- KEIDAR, Matan; KAMINKA, Gal A. Ecient frontier detection for robot exploration. The International Journal of Robotics Research, 2014, 33.2: 215-236.