

Robotics: Principles and Practice

Module 3: Mobile Robots

Lecture 1: Locomotion vs. navigation;
challenges of navigation: localization; search, path planning, coverage, SLAM

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Navigation is Hard

"Getting from one place to another is remarkably challenging for a robot.

...

Getting any body part where it needs to be is hard, and the more complicated the robot's body, the harder the problem."

M. Mataric, *The Robotics Primer*, MIT Press, 2007

Locomotion vs. Navigation

Locomotion

- How to **control the mobile robot motors** so that the robot moves towards some **well-specified target location**
- How to **control the mobile robot motors** so that the robot moves along some **well-defined path or trajectory**

Navigation

- How to determine the strategy required to get from one point in the environment to another by **planning an effective and efficient path**

Locomotion vs. Navigation

Locomotion

- Following an arbitrary given path or trajectory is harder than having to get to a particular destination by using any path
 - Some paths are impossible to follow for some robots because of their holonomic constraints
 - For others, some paths can be followed, but only if the robot is allowed to stop, change directions (in place or otherwise), and then go again
- A large subarea of robotics research deals with enabling robots to follow arbitrary trajectories.

Why?

Locomotion vs. Navigation

Locomotion

- Trajectory planning, also called **motion planning**, is a computationally complex process
 - Involves searching through all possible trajectories and evaluating the to find one that will satisfy the requirements
 - Depending on the task, it may be necessary to find the very best (shortest, safest, most efficient, etc.), so-called optimal trajectory
- Since robots are not just points, we need to take into account their
 - Geometry (shape, turning radius)
 - Steering mechanism (holonomic properties)

Locomotion vs. Navigation

Locomotion

- Trajectory planning is used in
 - Mobile robots, in two dimensions
 - Robot arms, in three dimensions, where the problem becomes even more complex
- Depending on their task, practical robots may not be so concerned with following specific trajectories as with just getting to the goal location
- The ability to get to the goal is quite a different problem from **planning a particular path** and is called **navigation**

Challenges of Robot Navigation

The goal of navigation

- To reach a given location P
- Examples
 - Go to $[x = 100, y = 200, \theta = 90]$ ← Which frame of reference?
 - Go to room T 2224 ← Where is this room?
 - Go to the cafeteria ← Where is the cafeteria? Where in the cafeteria?
 - Go to the city centre ← Where is the city centre? Which city?
 - Go to a good observation position ← For observing what? What is a criterion for "good"?

Challenges of Robot Navigation

The goal of navigation

- To reach a given location P
- Possible ways to complicate the problem
 - Go to P in shortest time (optimal control)
 - Go to P with least energy (optimal control)
 - Go to P with max speed 1 m/s (constraints)
 - Be at P at 4:12 pm (deadlines)

Challenges of Robot Navigation

Facets of the navigation problem

- Get a map of the environment
- Make a navigation plan using this map
- Execute the plan
 - **move** in a stable and safe way
 - **keep track of your position** in the map
 - **detect** and avoid obstacles and dangers
 - **notice** exceptional situations and **modify the plan**
- All this needs the use of sensors

Challenges of Robot Navigation

Environment map

- Must include **topological** information

Which aisles are blocked and which provide a connection?

- Must include **geometric** information

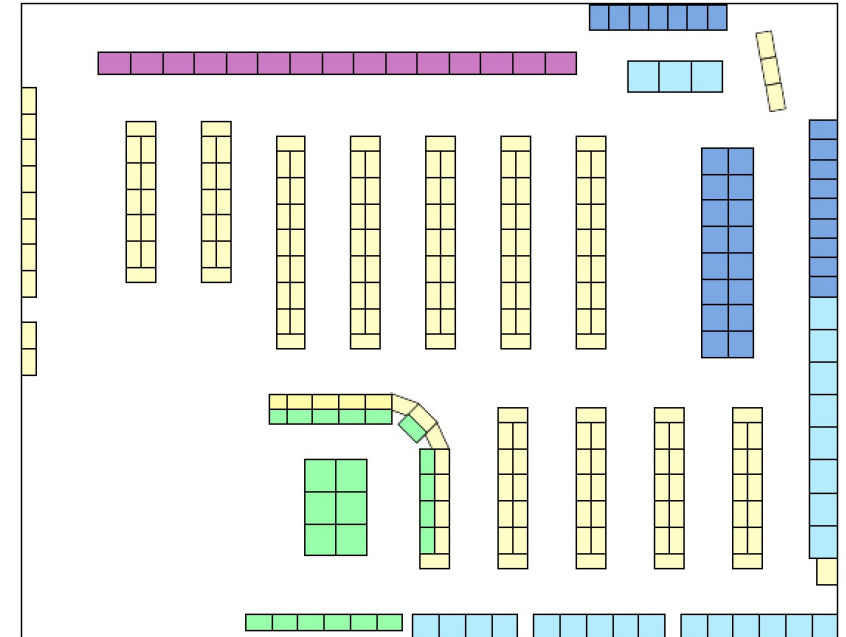
How many meters to travel before turning left?

- The problem is to find the right level of detail

- Too abstract \Rightarrow insufficient information to be useful
- Too detailed \Rightarrow too much information for stable navigation

A topological map:
a graph or network of
connected locations

A metric map,
showing locations and
distances between
locations



Map recreated from the following papers:

Joho, D., Senk, M., & Burgard, W. (2009). Learning wayfinding heuristics based on local information of object maps. Proceedings of the European Conference on Mobile Robots (ECMR) 2009, 117–122.

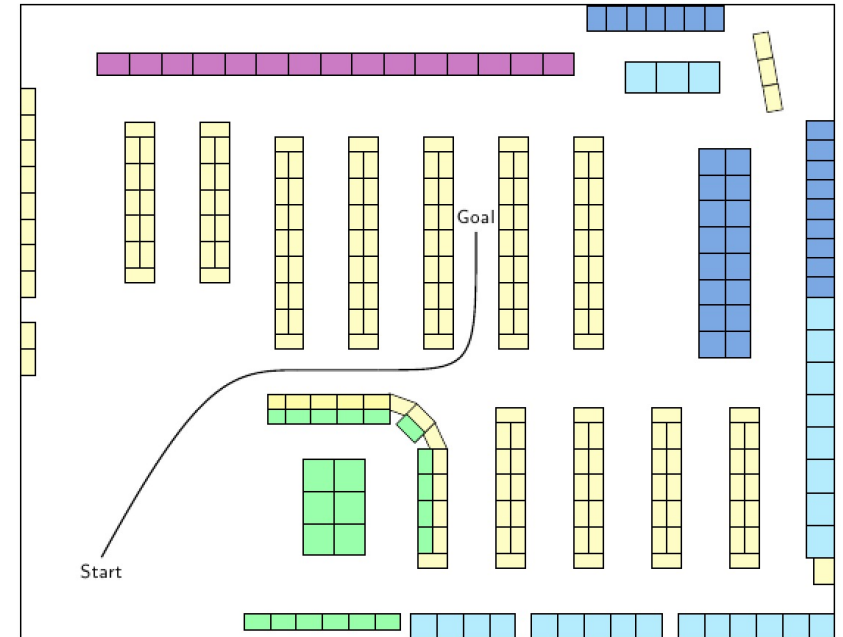
Kalff, C., & Strube, G. (2009). Background knowledge in human navigation: a study in a supermarket. Cognitive Processing, 10(2), 225-228.

Challenges of Robot Navigation

Planning

- Find a path in the map that
 - Goes from the **start** position to the **goal** position
 - Is **collision-free**
 - Is **feasible** given the robot's **kinematics** and **dynamics**
 - **Satisfies** the extra **constraints**
- Problem: **uncertainty**

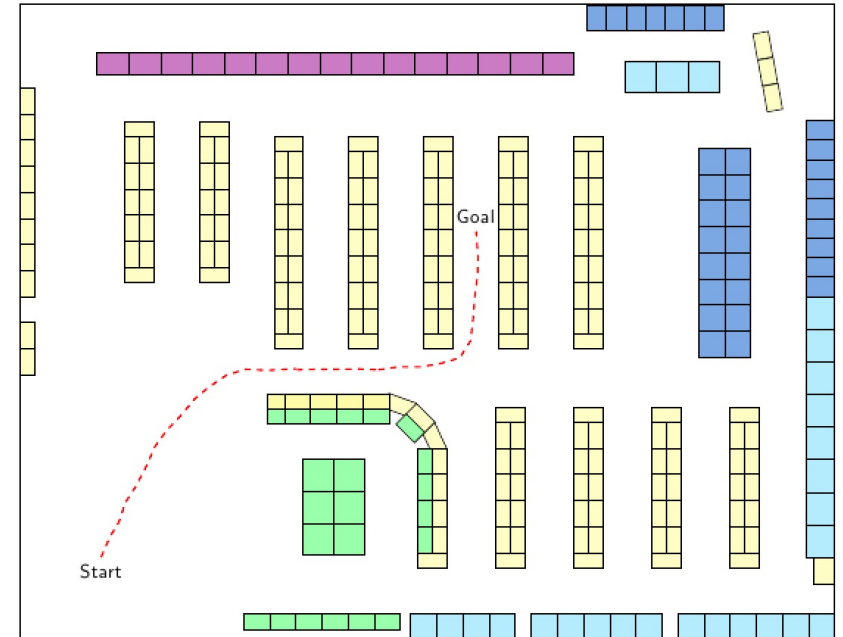
In real environments, the configuration of the space may not be fully known in advance and may change at any point



Challenges of Robot Navigation

Execution

- Follow the planned trajectory
 - Guarantee physical stability
 - Keep track of your position in the map
- React to unexpected events
 - Use sensors to detect obstacles
 - Use sensors to detect failures in the plan
- Problem: **uncertainty**
 - Sensor data may be noisy
 - Locomotion may be imperfect



Challenges of Robot Navigation


Components of the navigation problem

- Localization: finding out where you are
- Search: looking for the goal location (or target object)
- Path planning: planning a path to the goal location
- Coverage: ensuring the search strategy covers all the possibilities when looking for the goal location.
- SLAM: localization and constructing a map at the same time

Either with a map or without a map



"This is a 'chicken or egg' problem: to make a map, you have to know where you are, but to know where you are, you have to have a map. With SLAM, you have to do both at the same time." M. Mataric.



Types of Robot

Consumer



Roomba

Roomba is an autonomous vacuum and one of the most popular consumer robots in existence. It navigates around clutter and under furniture cleaning your floors, and returns to its charging dock when finished.

CREATOR

iRobot [↗](#)

COUNTRY

United States 

YEAR

2002

TYPE

Consumer

Source: <https://robots.ieee.org/robots/roomba/>

Video

<https://robots.ieee.org/robots/roomba/?gallery=video2>

Types of Robot

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Reading

M. Mataric, The Robotics Primer, MIT Press, 2007. Chapters 5 and 19.

Videos

Daniel Wolpert's TED Talk on the real reason for brains <https://www.youtube.com/watch?v=7s0CpRfyYp8>