Robotics: Principles and Practice

Module 3: Mobile Robots

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

David Vernon
Carnegie Mellon University Africa

www.vernon.eu

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

A topological map: a graph or network of connected locations

Which aisles are blocked and which provide a connection?

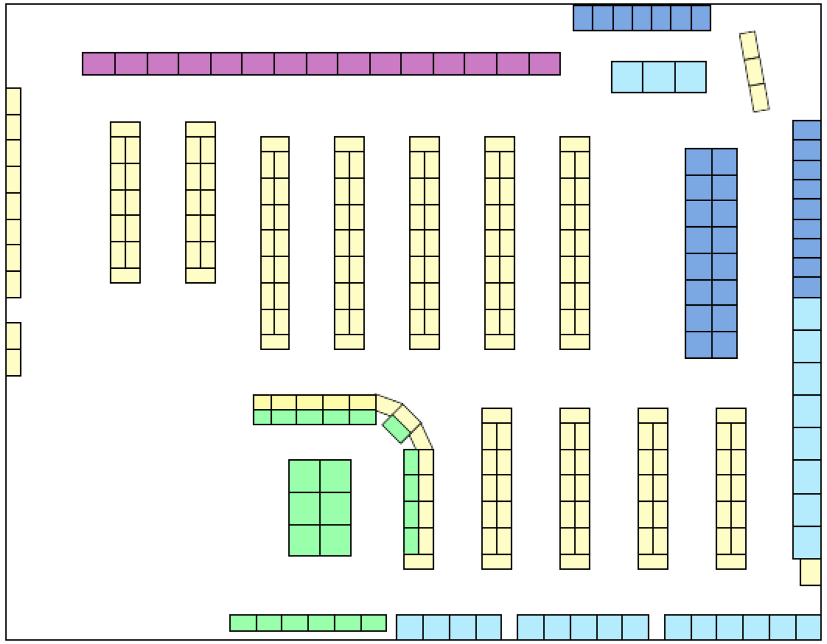
– Must include geometric information

A metric map, showing locations and distances between locations

How many meters to travel before turning left?

– The problem is to find the right level of detail

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



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.

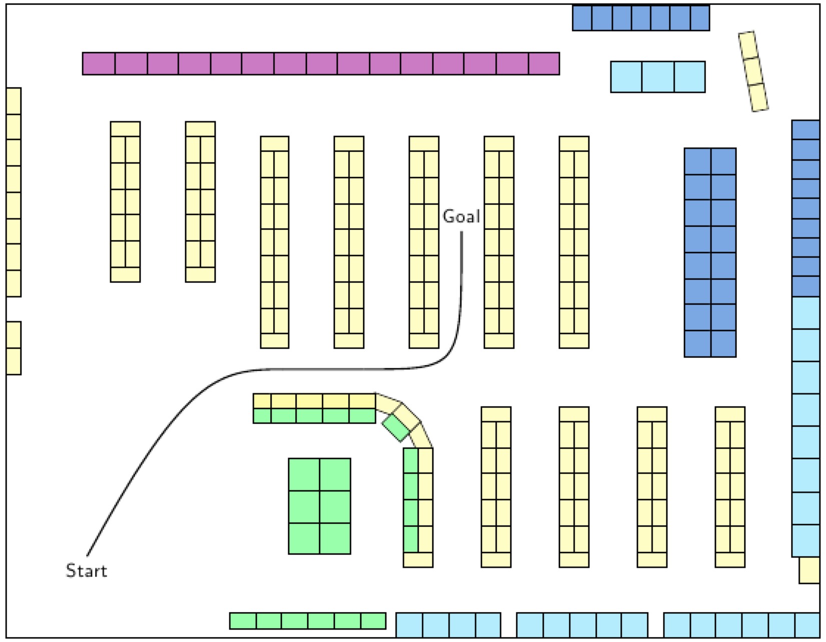
Challenges of Robot Navigation

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

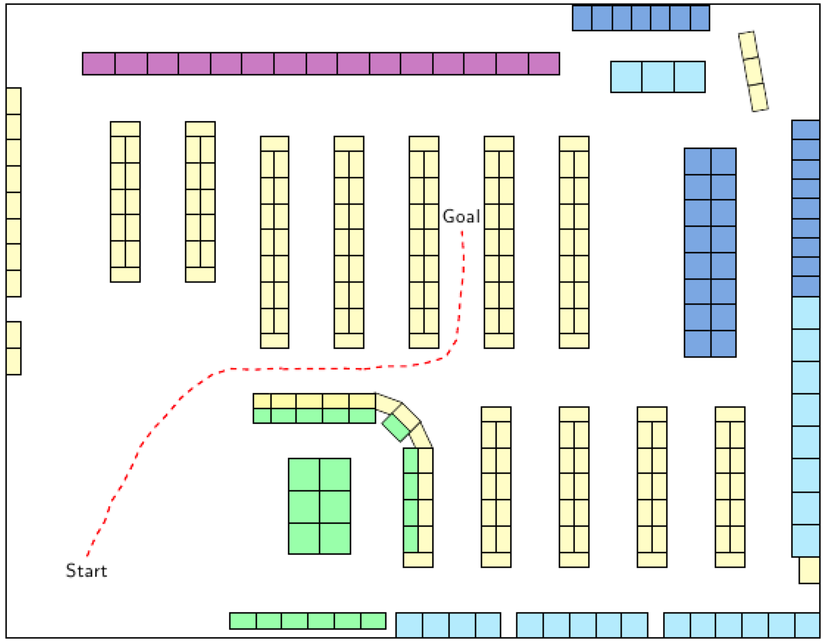
  In real environments, the configuration of the space
  may not be fully known in advance
  and may change at any point



Challenges of Robot Navigation

Execution

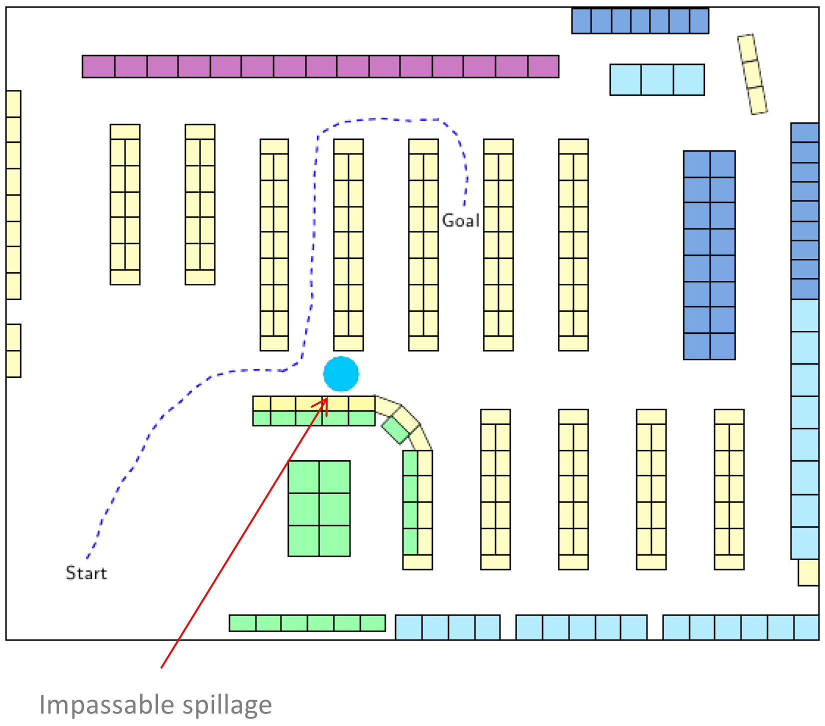
- Follow the planned trajectory
  - Guarantee physical stability
  - Keep track of your position in the map
- React to unexpected events
  - Use sensors to detect obstacles
  - Use sensors to detect failures in the plan
- Problem: uncertainty
  - Sensor data may be noisy
  - Locomotion may be imperfect



Challenges of Robot Navigation

Re-planning

- Detect major discrepancies from the plan
  - the plan is not feasible anymore, or
  - there is a new better opportunity
- Modify the plan
- Problem: when to re-plan?
  - we want to react quickly to any new situation,
    but we do not want to change our mind all the time



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

Education

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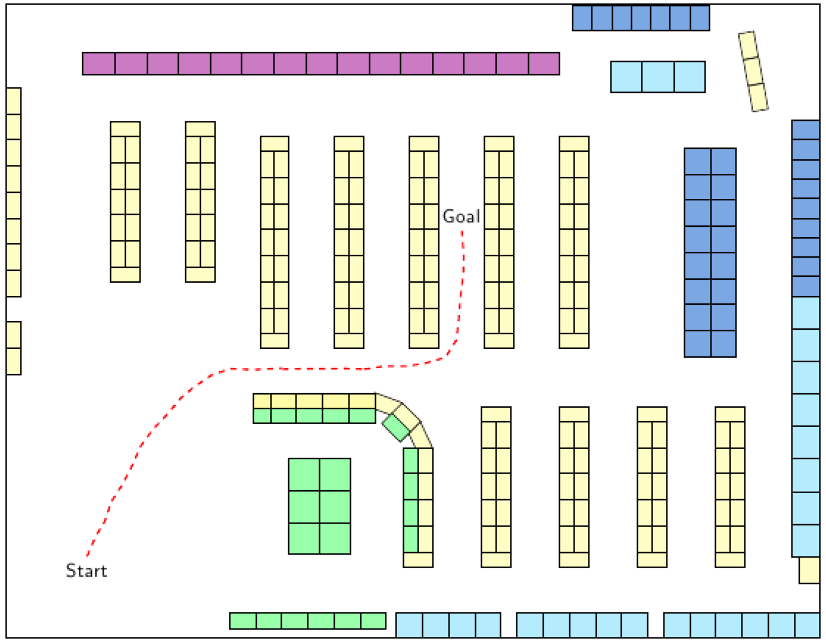
Localization: The Position Estimation Problem

Robot must keep track of its position in the map

- in order to plan a trajectory to the goal
- in order to follow the planned trajectory

This gives rise to the Position Estimation Problem

- establish the position of the robot in the environment
- use both proprioceptive and exteroceptive sensors

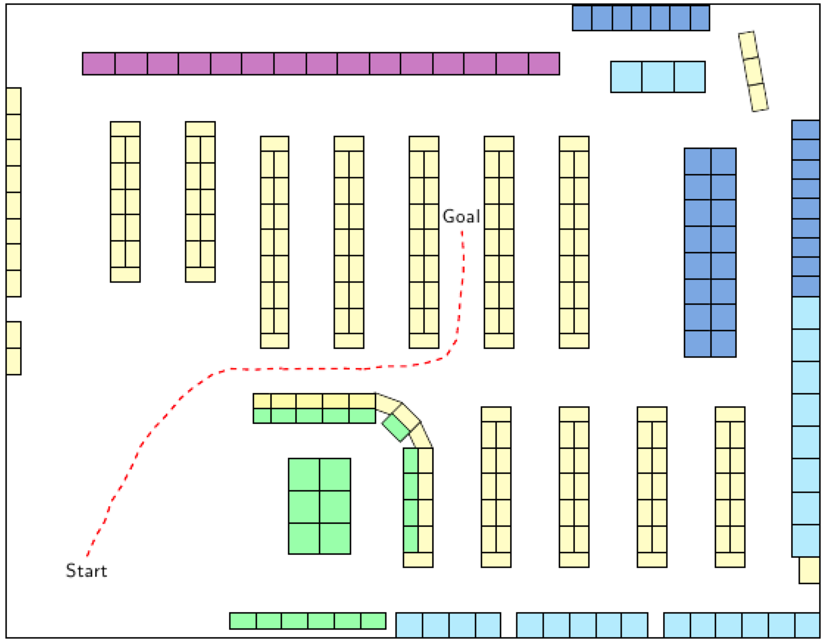


Localization: The Position Estimation Problem

Two approaches

1. Absolute position estimation

2. Relative position estimation



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