Mapping

A Robot's Navigation Problems

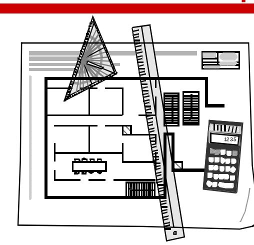
- Where am I? *Localization*
- Where have I been? *Map making*
- Where am I going? *Mission planning*
- What's the best way there? *Path planning*

Why Mapping?

- Learning maps is one of the fundamental problems in mobile robotics
- Maps allow robots to efficiently carry out their tasks, allow localization …
- Successful robot systems rely on maps for localization, path planning, activity planning etc.

How to Form a Map

1. By Hand



2. Automatically: **Map Building**

The robot **learns** its environment

Motivation:

- by hand: hard and costly
- dynamically changing environment
- different look due to different perception

3. Basic Requirements of a Map:

- a way to incorporate newly sensed information into the existing world model
- information and procedures for estimating the robot's position
- information to do path planning and other navigation tasks (e.g. obstacle avoidance)

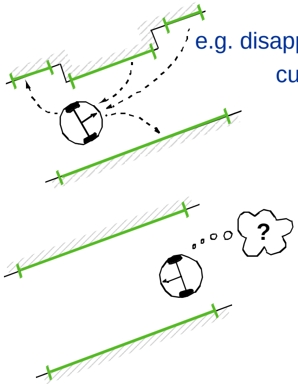
- Measure of Quality of a map
  - topological correctness
  - metrical correctness
- But: Most environments are a mixture of predictable and unpredictable features $\rightarrow$ hybrid approach

model-based vs. behaviour-based

The Problems

1. Map Maintaining: Keeping track of changes in the environment

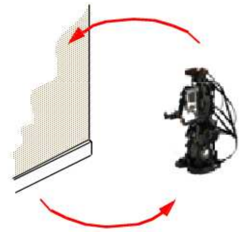
e.g. disappearing cupboard



- e.g. measure of belief of each environment feature

2. Representation and Reduction of Uncertainty

position of robot -> position of wall



position of wall -> position of robot

- probability densities for feature positions
- additional exploration strategies

Mapping

- Things to consider:
  - Map precision must match application
  - Precision of features on map must match precision of the robot's sensory data
  - Map complexity directly affects computational complexity, and reasoning about localization and navigation
- Two basic approaches
  - Continuous
  - Decomposition (discretization)

Representation of the Environment

- Environment Representation
  - Continuous Metric → coordinates and heading (x, y, θ)
  - Discrete Metric → metric grid
  - Discrete Topological → topological grid

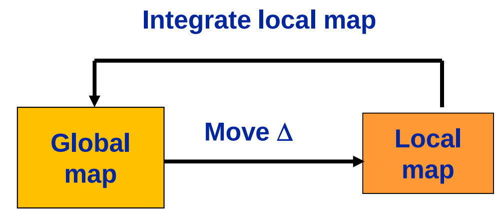
Environment Modeling

- Raw sensor data, e.g. laser range data, images
  - large volume of data, low distinctiveness on the level of individual values
  - makes use of all acquired information
- Low level features, e.g. lines and other geometric features
  - medium volume of data, average distinctiveness
  - filters out the useful information, still ambiguities
- High level features, e.g. doors, a car, a monument
  - low volume of data, high distinctiveness
  - filters out the useful information, few/no ambiguities, not enough information

Representing the robot

- How to represent the robot itself on a map?
- Point-robot assumption
  - Represent the robot as a point
  - Assume it is capable of omnidirectional motion
- Robot in reality is of nonzero size
  - Dilation of obstacles by robot's radius
  - Resulting objects are approximations
  - Leads to problems with obstacle avoidance

Basic Idea



- Sense and create a local map
- Move a little
  - Record change in position, orientation
- Sense and create a local map
  - Fuse/tile together

Problems in Mapping

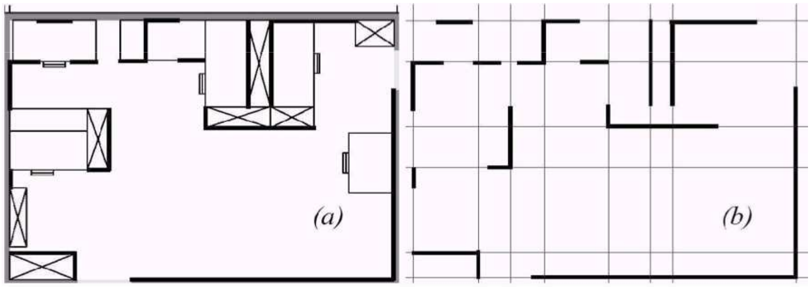
- Sensor interpretation
  - How do we extract relevant information from raw sensor data?
  - How do we represent and integrate this information over time?
- Robot locations have to be estimated
  - How can we identify that we are at a previously visited place?
  - This problem is the so-called data association problem.

Continuous representation

- Exact decomposition of the environment
- Closed-world assumption
  - Map models all objects
  - Any area of map without objects has no objects in the corresponding environment
  - Map storage proportional to the density of objects in the environment
- Map abstraction and selective capture of features to ease computational complexity

Continuous representation

- Match map type with a sensing device
  - In case of laser ranger finder, may represent the map as a series of infinite lines
  - Fairly easy to fit laser range data to series of lines



Continuous representation

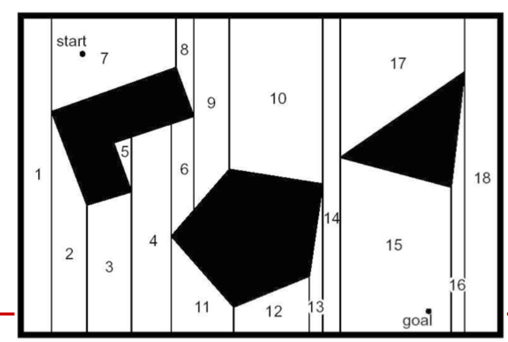
- In conjunction with position representation maintain:
  - Single hypothesis: extremely high accuracy possible
  - Multiple hypothesis:
    - Either, depict as geometric shape
    - Or, as a discrete set of possible positions
- Advantages of continuous representation
  - High accuracy possible
- Disadvantages
  - Can be computationally expensive
  - Typically only 2D

Decomposition Approach

- Capture only the useful features of the environment
- Computationally better for planning, particularly if the map is hierarchical

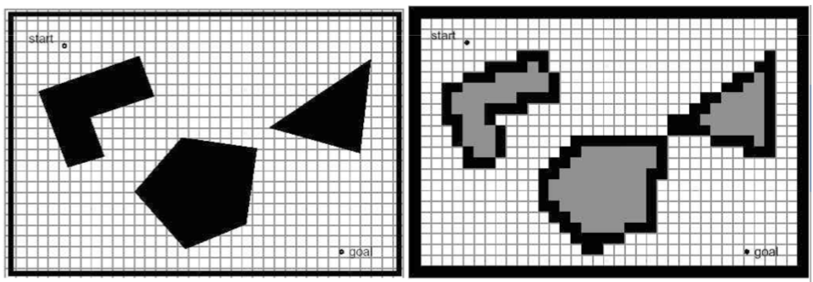
Exact cell decomposition

- Model empty areas with geometrical shapes, e.g. trapezoids
- Can be extremely compact (18 nodes in this figure)
- Assumption: the robot position within each area of free space is not important



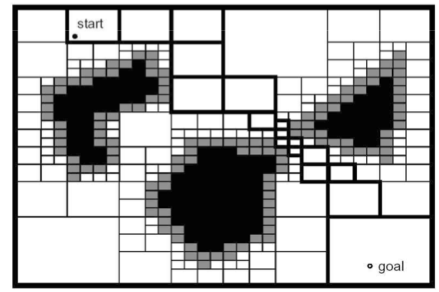
Fixed cell decomposition

- Tessellate world: use a discrete approximation
- Each cell is either empty or full
- Inexact (note loss of narrow passageway on right)



Adaptive cell decomposition

- Multiple types of adaptation: quadtree, exact, etc.
- Recursively decompose until a cell is completely free or completely an object
- Very space efficient compared to the fixed cell approach

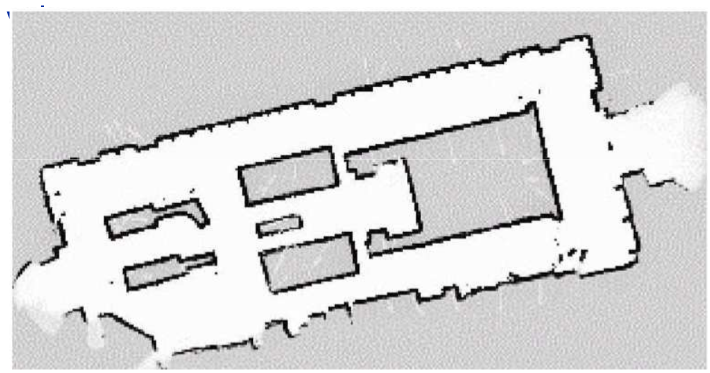


Occupancy Grid Representation

- Typically fixed cell decomposition
- Each cell is either filled or free
  - Counter for cell: zero indicates a free cell, above a certain threshold the cell is considered to be filled with an object
- Particularly useful with range-based sensors
  - If the sensor strikes something in a cell, increase cell counter
  - If sensor goes over cell and strikes something else, decrease cell counter (presuming it is free space)
  - By also discounting cell values over time, can deal with transient obstacles
- Disadvantages
  - Map size a function of the size of environment and size of cell
  - Imposes an a priori geometric grid on the world

Occupancy Grid Example

- Shade of grey of cell proportional to the cell counter



Occupancy Grid Map updates

- Occupancy grid representation
  - Each cell indicates probability is free space and probability is occupied
  - Need method to update cell probabilities given sensor readings at time t
- Update methods
  - Sensor model
  - Bayesian
  - Dempster-Shafer

Topological Decomposition Approach

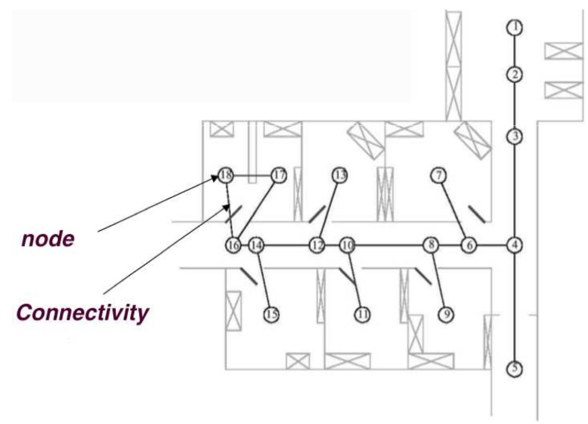
- Use environment features most useful to robots
- A graph specifying nodes and the connectivity between them
  - Nodes are not of fixed size
  - Free space not explicitly represented
  - A node is an area the robot can recognize its entry to and exit from

Topological Decomposition

- To robustly navigate with a topological map a robot
  - Must be able to localize relative to the nodes
  - Must be able to travel between the nodes
- These constraints require the robot's sensors to be tuned to the particular topological decomposition
- Major advantage is the ability to model non-geometric features (like artificial landmarks) that help localization

Topological Decomposition Example

- Here the robot must be able to detect intersections between halls, and halls and rooms.



Current challenges

- Real world is dynamic
- Perception still very error prone
  - Hard to extract useful information
  - Occlusion of objects
- Traversal of open space
- How to build up topology
- Sensor fusion

The Simultaneous Localization and Mapping (SLAM) Problem

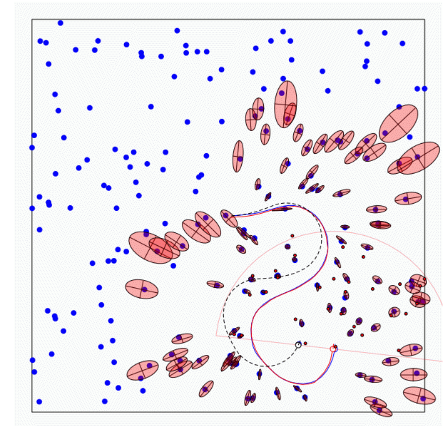
Consider a robot exploring an unknown, static environment

Given:

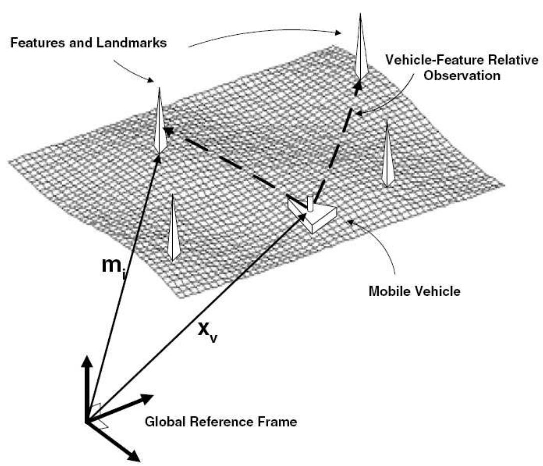
- The robot's controls
- Observations of nearby features

Estimate:

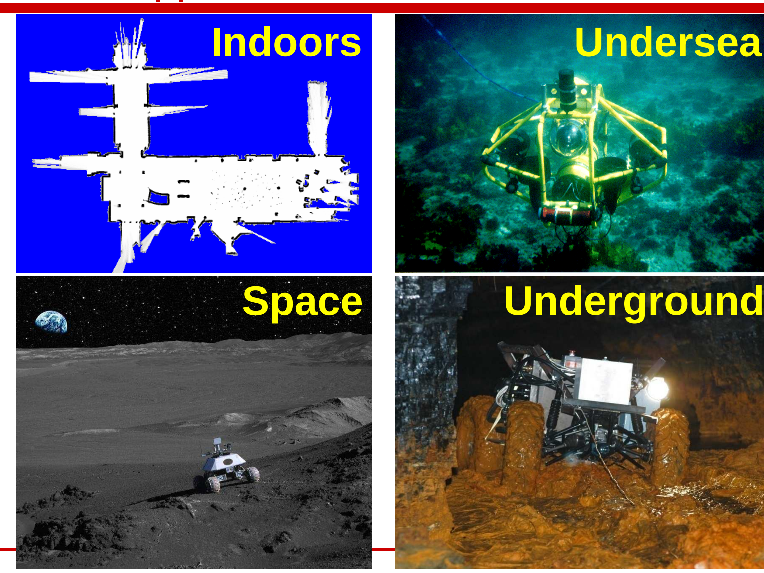
- Map of features
- Path of the robot



Structure of the Landmark-based SLAM-Problem

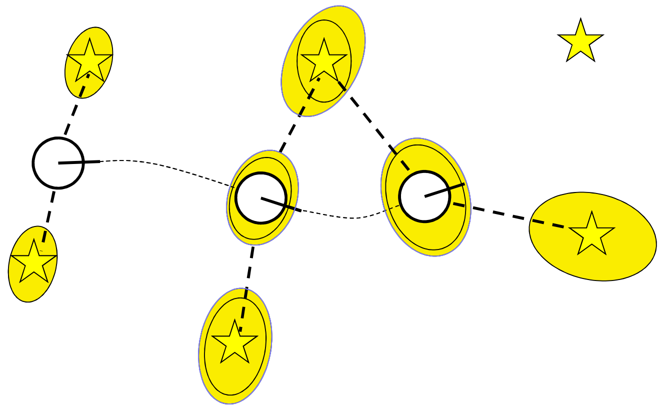


SLAM Applications



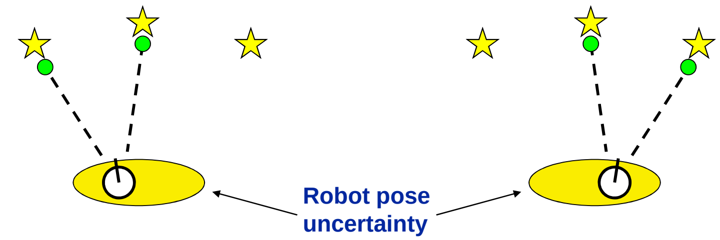
Why is SLAM a hard problem?

SLAM: robot path and map are both unknown



Robot path error correlates with the errors in the map

Why is SLAM a hard problem?



- In the real world, the mapping between observations and landmarks is unknown
- Picking wrong data associations can have catastrophic consequences
- Pose error correlates data associations