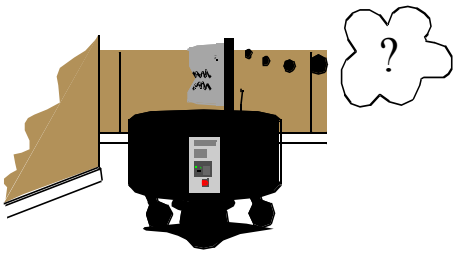
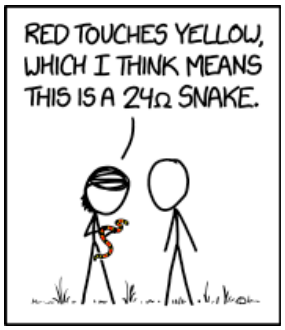
Localization

where am I? (again?)



Bookkeeping

- Assignment 3
  - Comments?
- Next Reading: none
  - Unless you are behind; catch up
- Today
  - Knowledge Representation
    - Maps
    - Belief states
- Upcoming
  - Grades



The last band of color indicates the snake's tolerance for being held before biting.

Localization Review (1)

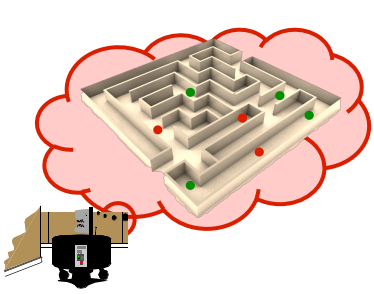
3

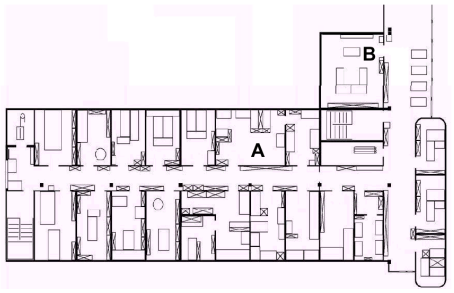
- What is localization?
  - Figuring out location wrt. a model of the world
- What are the two purely proprioceptive approaches?
  - Odometry: belief about motion only
    - Wheel encoders, mostly
  - Dead reckoning: belief about motion + heading sensors

Localization Review (2)

4

- What is sensor aliasing?
  - Different locations giving the same sensor readings
- What is behavior-based navigation?
  - Navigating without localizing





Belief Representations

5

- (Model of) the *map* or *environment*
  - Discrete vs. continuous
  - Probabilistic vs. labeled
  - Geometric vs. topographical vs. semantic
- Beliefs about the robot's *state* or *location*
  - Discrete vs. continuous
  - Probabilistic vs. bounded vs. point
  - Single vs. multiple hypotheses
- Paths
  - Consecutive vs. kidnapped

Design decisions: based on storage efficiency, reasoning speed, sensor capability, intended task, …

Map Representations

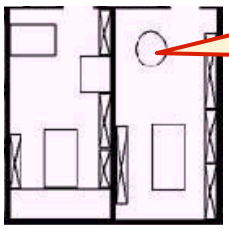
6

- How precise does it have to be?
  - To accomplish what?
- What types of features are represented?
  - Depends on robot's sensors
    - If the robot can't see it, no point storing it
  - How much processing power do we have?
- What characteristics does it have?

Characterizing Maps (1)

7

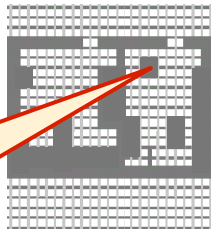
- Discrete vs. continuous



Continuous

Obstacles represented as polygons

Obstacles represented as blocks in a grid

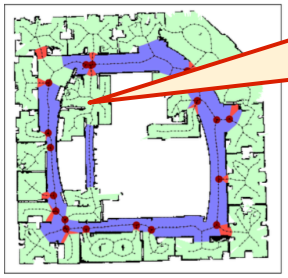


Discretized

Characterizing Maps (2)

8

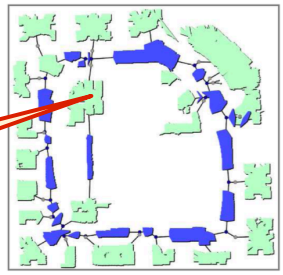
- Geometric vs. topological



Geometric

Actual locations of obstacles and areas

Relative locations

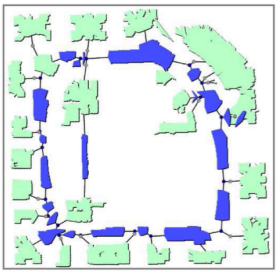


Topological

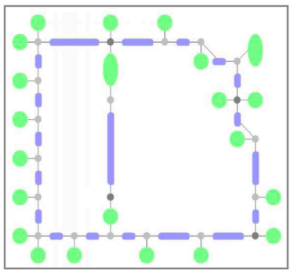
Characterizing Maps (3)

9

- Semantically labeled
  - Example: semantically *labeled topological map*



Topological



Semantic

Room

Hall

Junction

Location (Belief) Representation

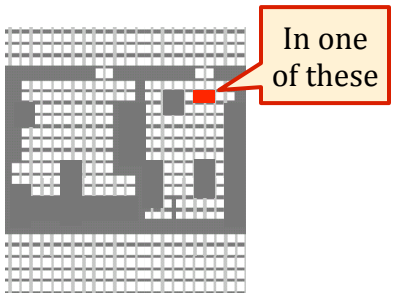
10

- What characteristics does it have?
- Discrete vs. continuous
  - Fixed to a grid, or anywhere?
- Single vs. multiple hypotheses
  - At any given time, how many possible locations are being considered?
- Probabilistic vs. bounded vs. point
  - The first two are multiple-hypothesis

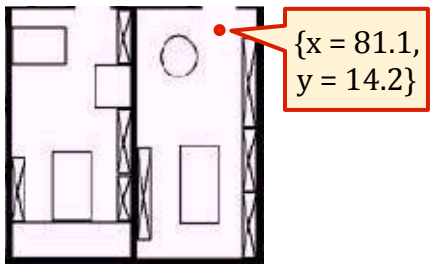
Characterizing Belief R. (1)

11

- Discrete vs. continuous
  - Fixed to a grid vs. infinitely fine resolution



Discrete

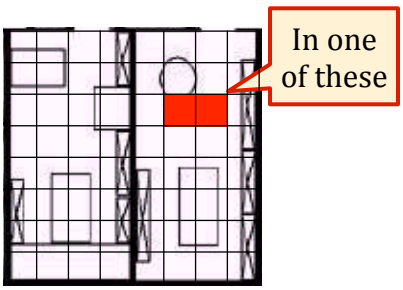


Continuous

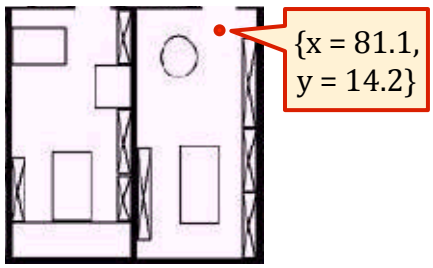
Characterizing Belief R. (1.1

12

- Discrete vs. continuous
  - Belief can be discretized on a continuous map



Discrete

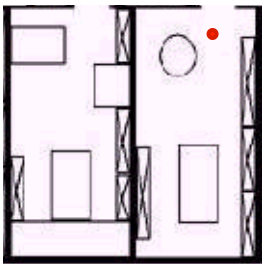


Continuous

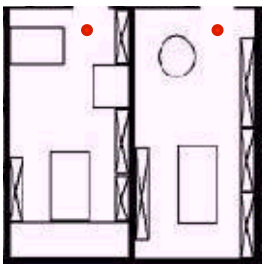
Characterizing Belief R. (2)

13

- Single hypothesis vs. multiple hypothesis



Single

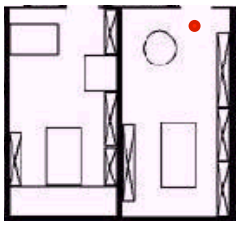


Multiple

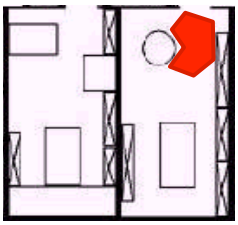
Characterizing Belief R. (3)

14

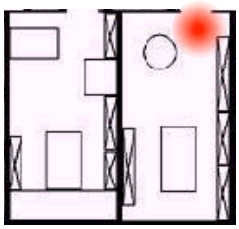
- Probabilistic vs. bounded vs. point



Point



Bounded Polygon



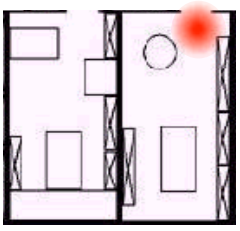
Probabilistic

- You are here
- Somewhere in here (undifferentiated)
- Spread of likelihood

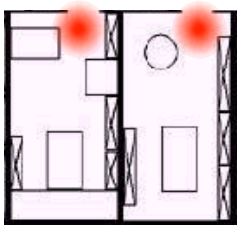
Probability & Combinations

15

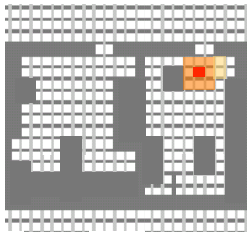
- Single or multiple, discrete or continuous



Single Hypothesis



Multiple Hypothesis



Discrete

- Point: these are orthogonal choices

Belief Representation

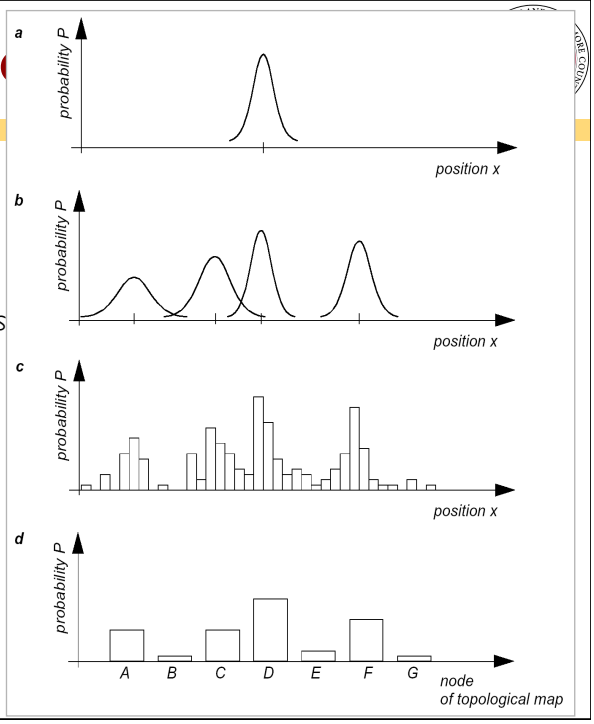
16

- a) Continuous map with *single hypothesis*
- b) Continuous map with *multiple hypothesis*
- d) Discretized map with probability distribution
- d) Discretized topological map with probability distribution

Belief Repr

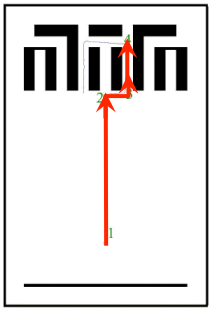
17

- a) Continuous map with *single hypothesis*
- b) Continuous map with *multiple hypothesis*
- d) Discretized map with probability distribution
- d) Discretized topological map with probability distribution



Example

18



Path of the robot

Belief states at positions 2, 3 and 4

- Location: Probabilistic? Discrete? yes, no
- Map: Discretized? Topological? maybe? no, geometric

The Environment

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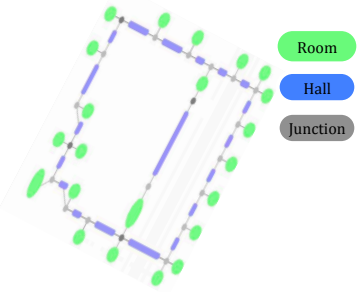
- Can contain:
  - Static or dynamic obstacles
  - Features (e.g., doors, floor tiles)
- Can be semantically labeled
- Environment Representation
  - Continuous Metric → $\{x,y,\theta\}$
  - Discrete Metric → metric grid (eg, sq. D76)
  - Discrete Topological → topological grid



The Environment: Features

20

- Raw sensor data (ex.: laser range, grayscale images)
  - Lots of data, low distinctiveness (per reading)
  - Uses all acquired information
- Low level features (ex.: line extraction)
  - Some data, average distinctiveness
  - Filters out some useful information, still ambiguities
- High level features (ex.: doors, a car, the Eiffel tower)
  - Little data, high distinctiveness
  - Filters out the useful information, few/no ambiguities, insufficient environmental information

easy to get

hard to get

About Map Representations

21

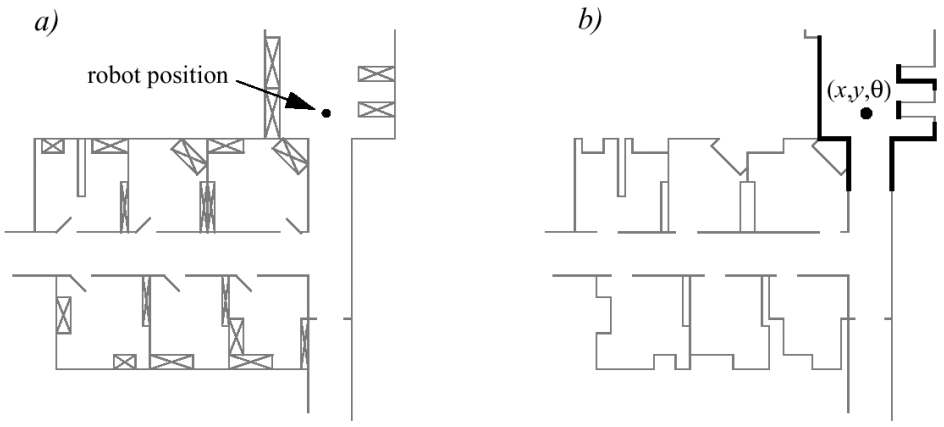
1. Map precision vs. application
   - How precise does it need to be?
2. Features precision vs. map precision
   - 20cm. map precision ≠ 20cm. obstacle avoidance
3. Precision vs. computational complexity
   - More capability = more computational complexity

- Continuous Representation
- Decomposition (Discretization)

Map Representations

22

- Continuous line, single hypothesis

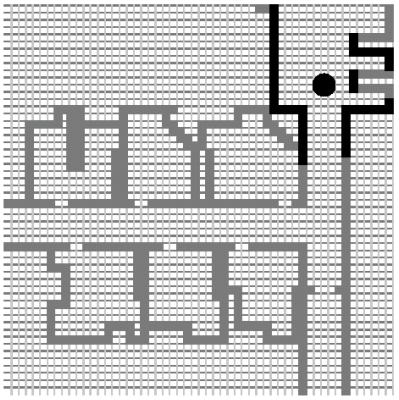


Map Representations

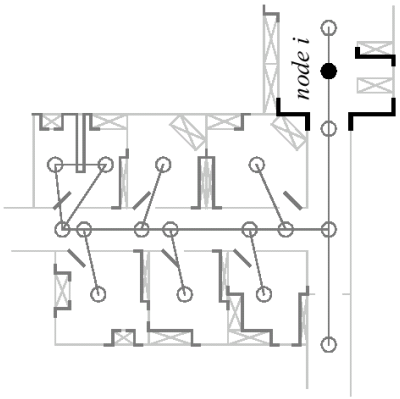
23

- Single hypothesis – Grid and Topological Map

c)



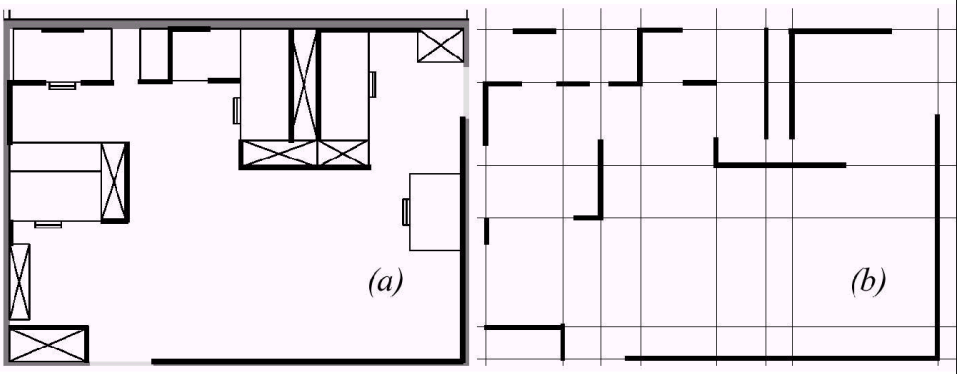
d)



Continuous Line Based

24

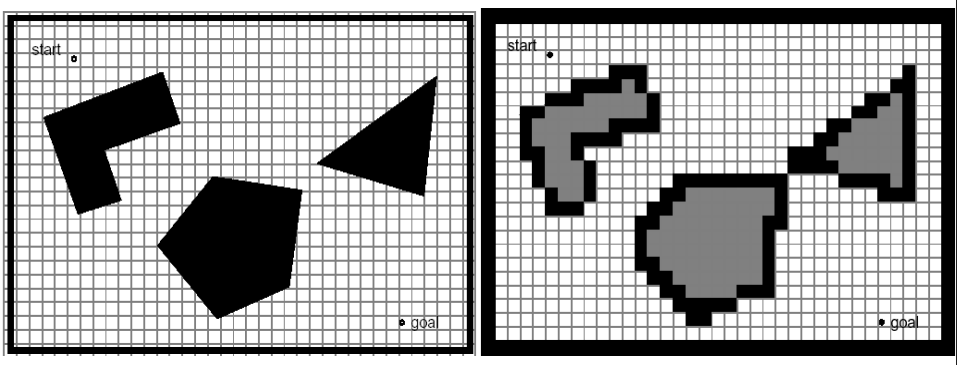
a) Representation with set of infinite lines (line extraction)



Map Decomposition (1)

27

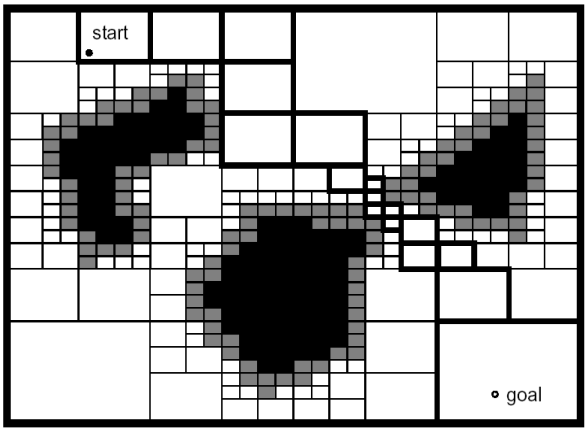
- Fixed cell decomposition
  - Narrow passages disappear



Map Decomposition (2)

28

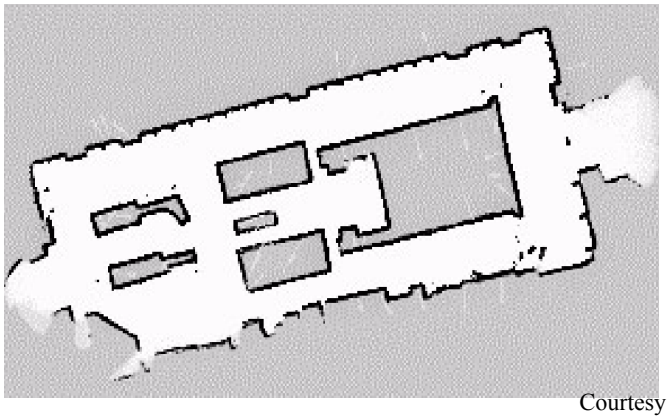
- Adaptive cell decomposition



Map Decomposition (3)

29

- Fixed cell decomposition – Example with very small cells

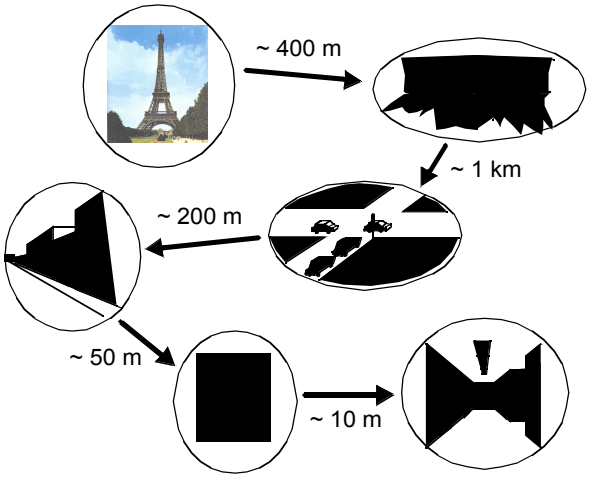


Courtesy of S. Thrun

Map Decomposition (4)

32

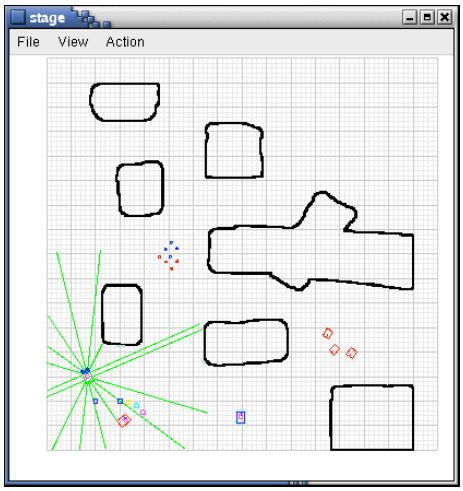
- Topological Decomposition



Map Decomposition (5)

33

- Occupancy Grid



Probabilistic Map-Based Localization

35

- Consider a mobile robot moving in a known environment
- As it starts to move from a precisely known location, it might keep track of its location using odometry.
- However, after a certain movement the robot will get very uncertain about its position.

➔ update using an observation of its environment.

- observation lead also to an estimate of the robots position which can than be fused with the odometric estimation to get the best possible update of the robots actual position.

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- Improving belief state by moving