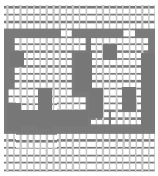
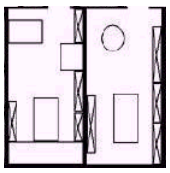
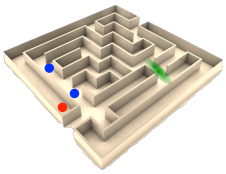
Belief and Map Representations

Last Time…

- Localization
  - Concepts
  - Error
  - Error variance
  - Error sources
- Movement error
  - Error accumulation
  - Deriving error description (differential drive)
  - Calibration
- Behavior-Based Navigation
  - Is…
- Belief State
  - Belief about…

Belief Representation

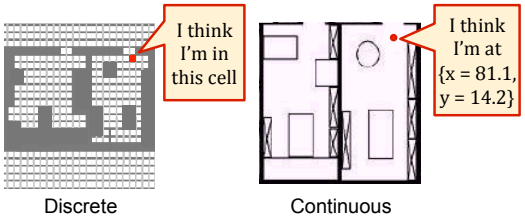
- So what "belief" are we talking about?
- Where the robot believes it is during localization.
  - Lots of ways to think about "where something is"
- "Belief" = Hypothesis (or hypotheses) about location
  - With uncertainty, variance, probability
- AI 101: any stored information about the world must be **represented** in some machine-usable way

Characterizing Belief Representations

- **Discrete** vs. **continuous**
  - Is the robot's location fixed to a grid, or can it be anywhere?
- **Single** vs. **multiple** hypotheses
  - At any given time, how many possible locations is the robot hypothesizing it might be in?
- **Probabilistic** vs. **bounded** vs. **point**

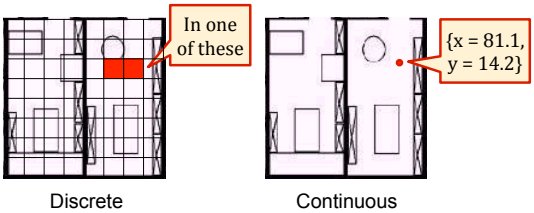
Discrete/Continuous

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



Discrete/Continuous (2)

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



Single/Multiple Hypothesis

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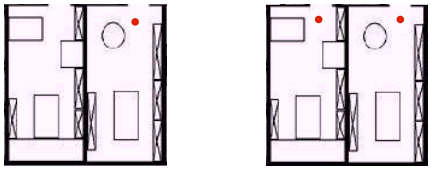
- Single hypothesis vs. multiple hypothesis
  - "Best guess, I'm here" *vs*
  - "Best guess, I'm either here or here"



Single Multiple

- Multiple hypothesis: maintaining a set of "best" locations

Location Representation

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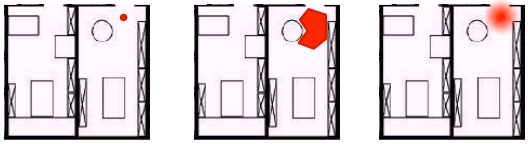
- Probabilistic vs. bounded vs. point



Point Bounded Polygon Probabilistic

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

Belief Rep. Characteristics

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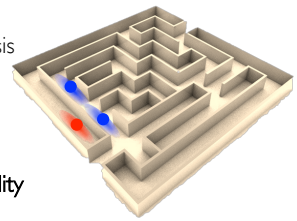
- Beliefs about where robot is can be:
- **Continuous** or **discretized**
- **Single** or **multiple** hypothesis
  - Single hypothesis: "Best guess, I am here"
  - Multiple hypotheses: "Here or here?"
- **Point**, **bounded**, or **probability distributions**
  - In practice we almost always use probabilities.



Possible Combinations

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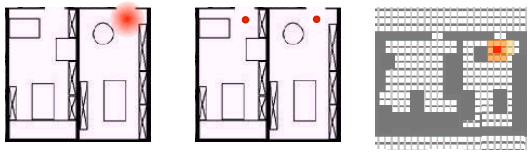
- These are orthogonal choices
- Many combinations are possible



Single Hypothesis, Continuous, Probabilistic

Multiple Hypothesis, Continuous, Point

Single, Discrete, Probabilistic

Probability with Multiple Hypotheses

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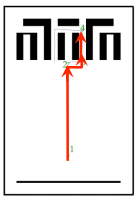
- Robot's belief in its location shown as probability "cloud"
- Darker coloring = higher certainty



Path of the robot

Belief states at positions 2, 3 and 4

Belief Representation

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a) Continuous map with *single hypothesis*

b) Continuous map with *multiple hypotheses*

c) Discretized map with probability distribution

d) Discretized topological map with probability distribution

Belief Repr

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a) Continuous map with *single hypothesis*

b) Continuous map with *multiple hypotheses*

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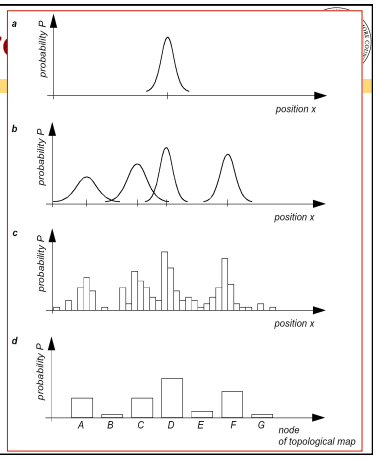
d) Discretized topological map with probability distribution



Continuous *vs.* Discrete

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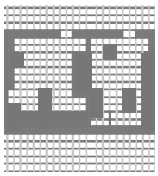
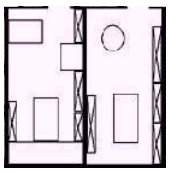
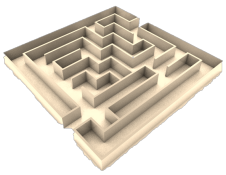
Belief Representation can be…

- Continuous
  - Precision bound by sensor data
  - Often single hypothesis pose estimate
  - Lost when diverging (for single hypothesis)
  - Compact representation
  - Typically reasonable in processing power
- Discrete
  - Precision bound by resolution of discretization
  - Often multiple hypothesis pose estimates
  - Never lost (when diverges, converges to another cell)
  - Less memory and processing power

Belief and Map Representations







Map Representations

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- We use "Map" to mean the robot's representation of the space it's moving through
  - Any stored information about the world must be represented in some machine-usable way
- What does a (robot-usable) "map" look like?

Maps can be…

- Geometric
- Topological
- Semantic

} Many, many variations

Map Representation Types

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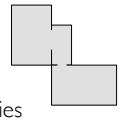
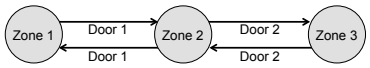
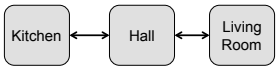
- **Geometric:** Tied to layout of the world
  - This is what we think of as a "map."



- **Topological:** How areas connect / adjacencies
  - "The set of places and edges linking them"



- **Semantic:** What areas actually "are"



Discrete *vs.* Continuous

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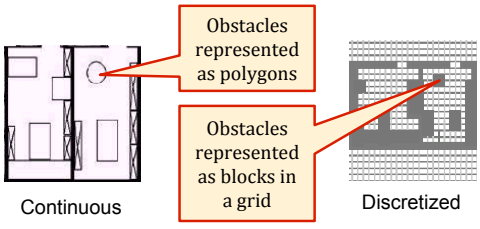
- Actually easier to understand in maps than beliefs…



Geometric vs. Topological

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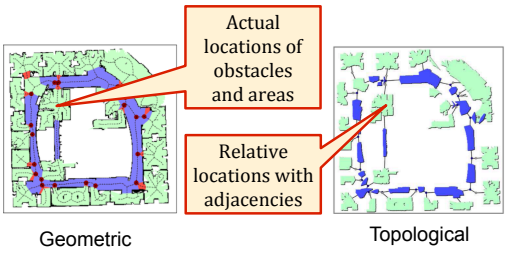
- Aligned to the "real world" vs. just "traversable"



A Note on Topological Maps

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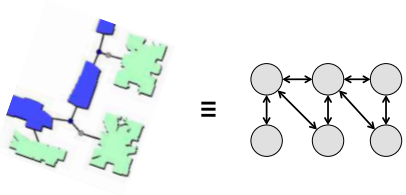
- Often *shown* as semi-geometric
- Doesn't have to be!
- Areas (nodes) and adjacencies (edges) are what matter



Semantic Maps

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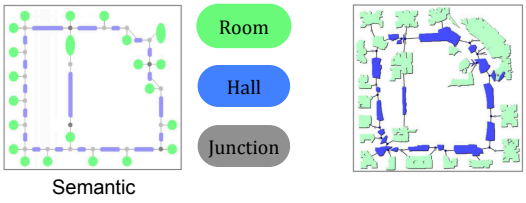
- Areas are labeled by meaningful type
  - *Example:* semantically labeled topological map



Example

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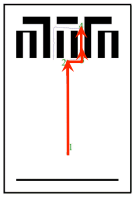

Path of the robot *Belief states at positions 2, 3 and 4*

- Belief Representation: Probabilistic? Discrete? yes, no
- Map Representation: Discretized? Topological? Semantic? maybe, no, no (geometric)

The Environment

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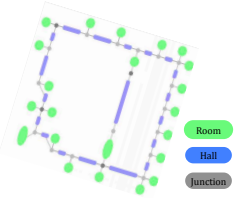
- Can contain:
  - Static or dynamic **obstacles**
  - **Features** (e.g., doors, floor tiles)
- Can be semantically labeled
- Environment Representation
  - Continuous Metric → $\{x,y,\theta\}$
  - Discrete Metric → metric grid (eg, sq. D76)
  - Discrete Topological → topological grid



The Environment: Features

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- 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
  - (Usually) insufficient environmental information

easy to get

hard to get

Choosing Map Representations

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- Map precision vs. application
  - Precision should match goals
  - How precise does it need to be?
- Feature precision vs. map precision
  - Precision of map should match precision of sensors
  - 20cm. map precision ≠ 20cm. obstacle avoidance
- Precision vs. computational complexity
  - More capability = more computational complexity
- Closed-world assumption: if it exists, it's on the map
  - When is this okay? When is it not?

Polygonal Representation

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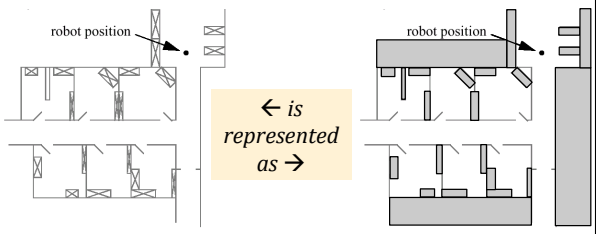
- Everything in the world is represented as polygons



Line Representations

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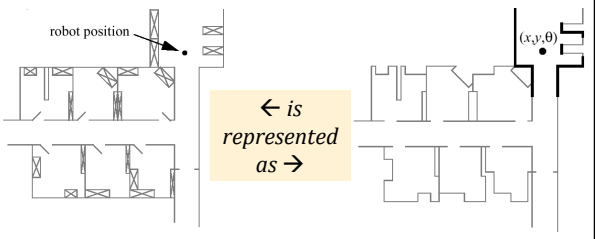
- Everything is lines (usually from edge detection)



Discretized Representations

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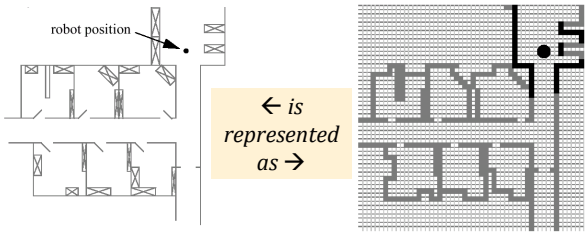
- This example: Fixed cell size, grid layout



Topological Maps

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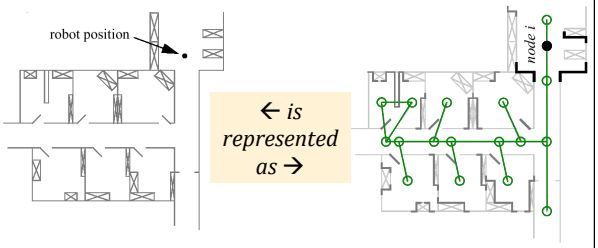
- Areas (nodes) and traversable adjacencies (edges)



Continuous Line Based

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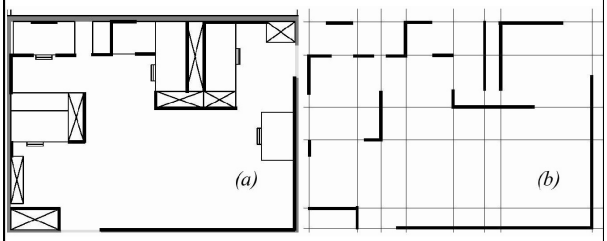
a) Representation with set of infinite lines (line extraction)



How To Build Maps

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- All of these map representations are simplifications of reality
  - Easier to store
  - More intuitive (sometimes)
  - Faster to use computationally
- Simplified maps still derived from sensor data
- How do we get from rich sensor data to representations?

Decomposing Maps

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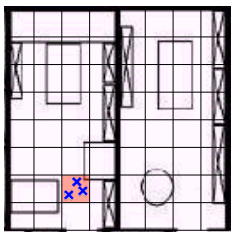
- Map decomposition
  - Break the map into areas we care about (cells)
- Important warning:
  In cell decompositions,
  → every point in a cell is the same as every other ←
  - Can't differentiate, e.g., "the top half of cell C2"
  - Would need a new cell



Exact Cell Decomposition

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- Subdivide a map into blocks of free space
  - Find vertices of objects in area
  - Break up map so all vertices bound cells

Idea:

- It matters how a robot can traverse free cells
- Exact position doesn't matter

Exact Cell Decomposition

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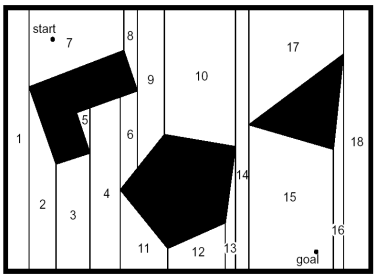

Navigation through Exact Cells

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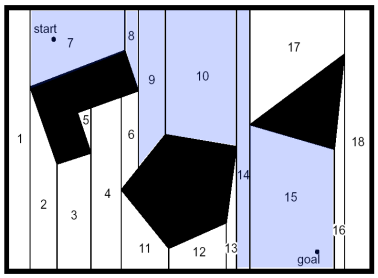
- Sequence: 7, 8, 9, 10, 14, 15



Navigation through Exact Cells

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- One possible sequence (of many)