Autonomous Robotics

Robot Mapping

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Some figures taken from Probabilistic Robotics and Drew Bagnell's course notes.

Programming Assignment #2

- Questions?
- Comments?

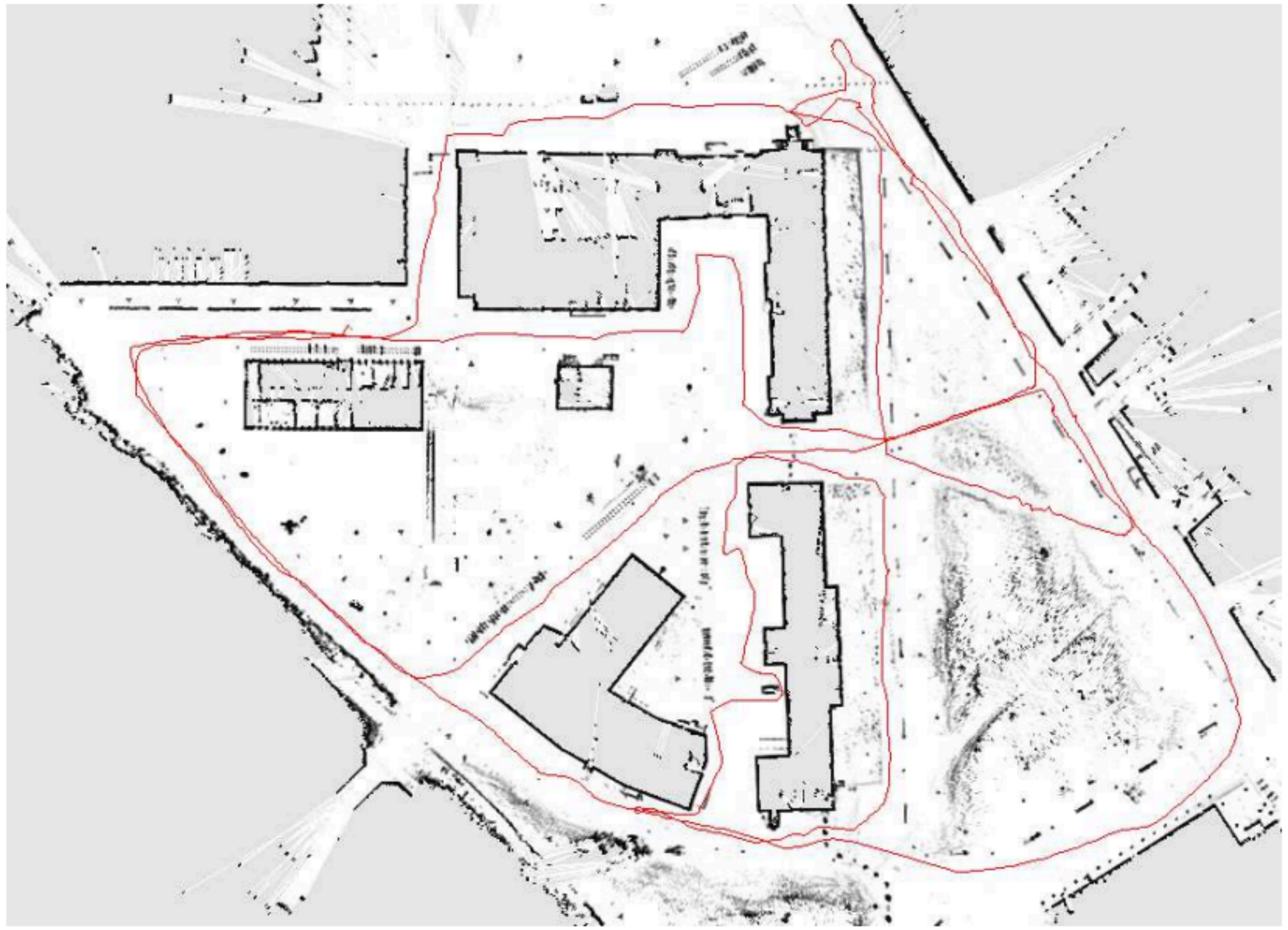
Learning Outcomes

After today's lecture, you will:

- Be able to define the robot mapping problem.
- Be able to compare and contrast different types of maps for robot applications.
- Instantiate map estimation using state estimation techniques.

The Mapping Problem

- Recall localization
  - Estimate $p(x_t \mid z_{1:t}, u_{1:t}, m)$
- Now we flip the problem.
  - Assume that we know $x_{0:t}$ and estimate the static map m.
  - $p(m \mid x_{1:t}, z_{1:t})$
  - Example: robot is outdoors and has a GPS sensor.



http://www2.informatik.uni-freiburg.de/~stachnis/pdf/grisetti07tro.pdf

Mapping Challenges

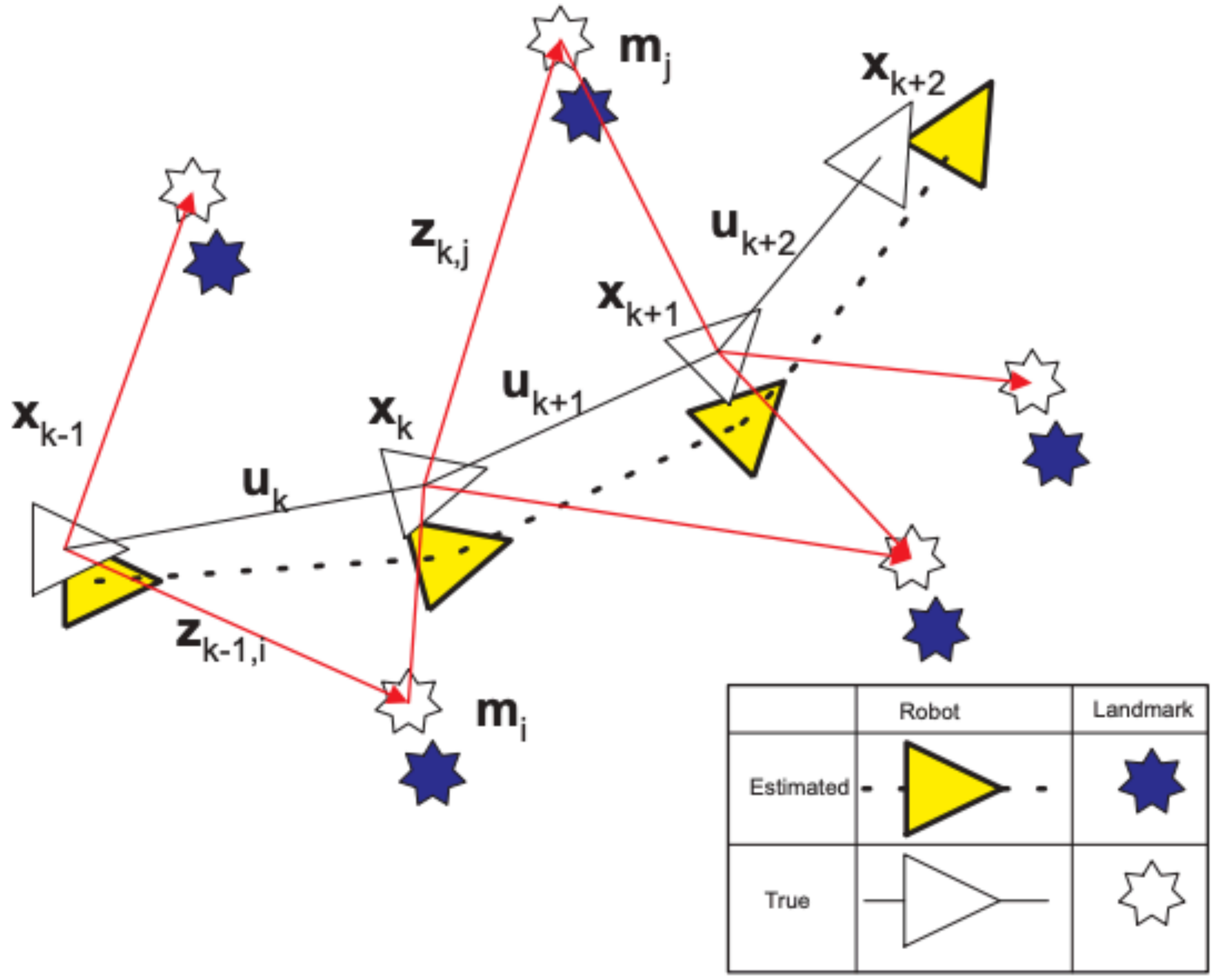
- What to include in the map?
  - Coarse vs. fine-grained detail?
  - The exact distance between places vs just connectivity?
- Maps are high-dimensional objects.

Map Representations

- Several different choices for the map representation.
- Choice depends on downstream application.
- May need to combine multiple types of maps.

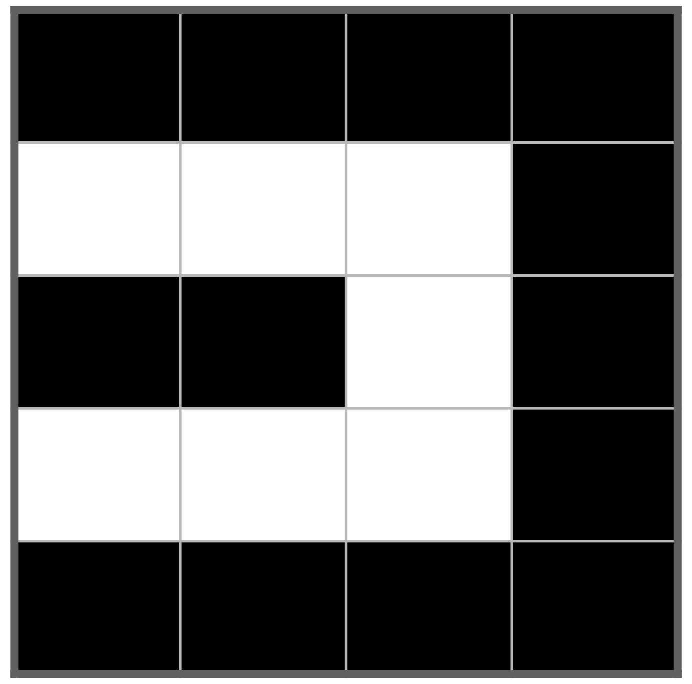
Feature-based Maps

- The map is defined by the locations of a set of key features.
  - AKA landmarks
  - $m = (m_x^1, m_y^1, \ldots m_x^k, m_y^k)$
- The mapping problem then amounts to estimating the coordinates of these features.
- Advantages: low storage requirement, works well with cameras.
- Disadvantages: requires identifiable features, lacks fine-grained details.



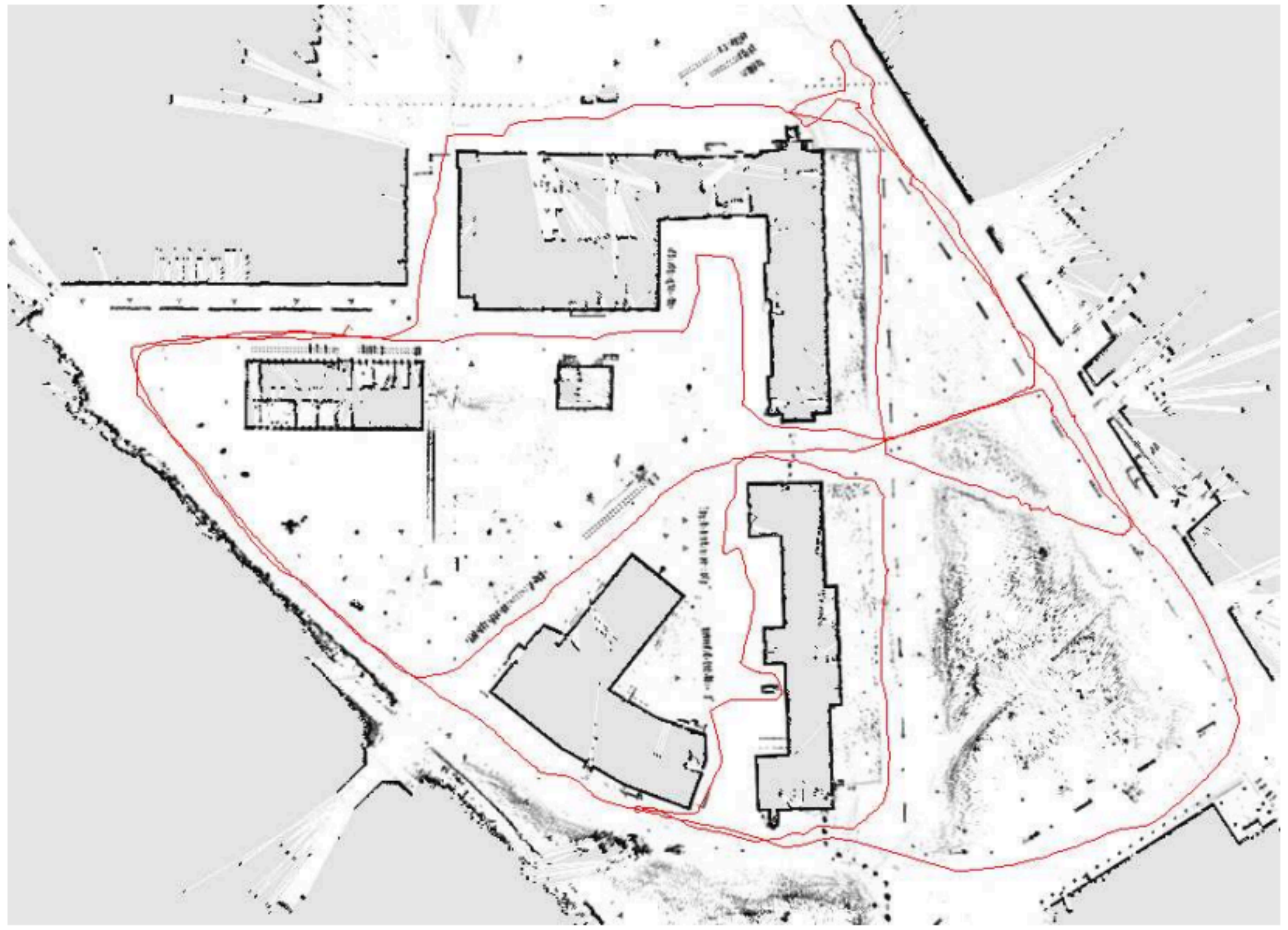
Grid Maps

- Represent map as a grid that covers the space of possible locations.
- Grid cells can be either occupied or free (binary valued).
- Assume k = l * w cells in the map.
  - Map is a vector that can take on 2^k possible values (all length k binary strings).
  - For estimation tractability, often assume conditional independence of grid cells.
    - $p(m \mid x_{0:t}, z_{1:t}) = \prod_{i=1}^{k} p(m_i \mid x_{0:t}, z_{1:t})$



Grid Maps (cont.)

- Advantages: works in feature poor environments, high detail.
- Disadvantages: high storage, resolution-dependent.

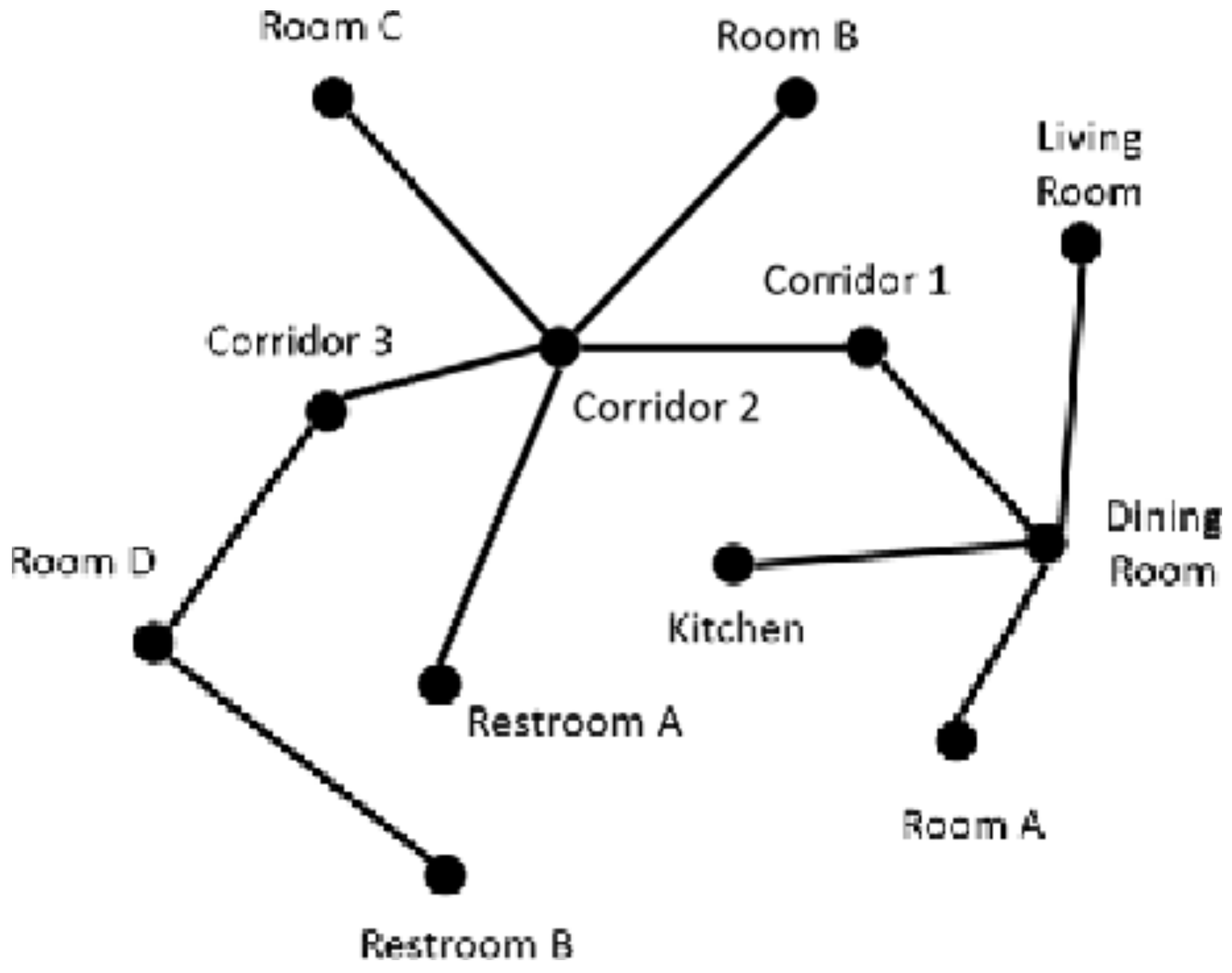


Topological Maps

- Feature-based and grid maps attempt to capture the exact spatial structure of the robot's environment.
    - Map distances and angles should match the real environment.
- Sometimes you just want the connectivity of the map.
    - Example: the robot can reach the dining room by going through the kitchen.
- A topological map represents the connectivity between a set of locations but not necessarily the distance between locations.

Topological Maps (cont.)

- Advantages: low storage requirement, good for planning methods that only require connectivity.
- Disadvantages: lacks fine-grained details, only considering connectivity could lead to sub-optimal paths, difficult in featureless environments.

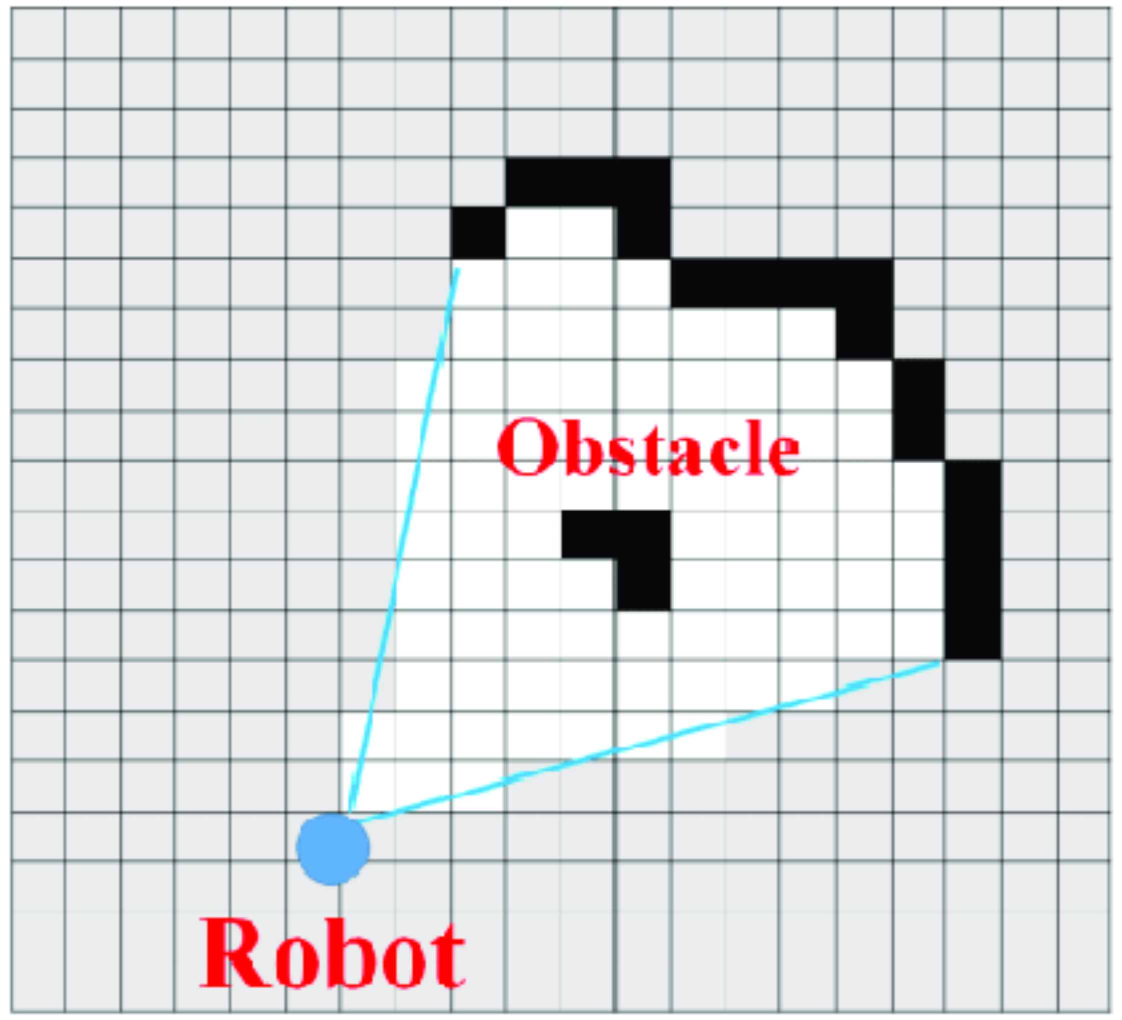


Semantic Maps

- Robots need to know more about their environments than just getting around (physical maps).
    - Examples: room numbers, room purpose, location of key objects.
- Semantic maps add semantic information to a physical map.

Grid-mapping with Bayes Filter

- Goal: estimate $p(m^i \mid x_{0:T}, z_{1:T})$ where m^i is the (binary) value of cell i.
- Can compute estimates with a Bayes filter on map posterior, $\texttt{bel}(m_t^i)$.
- For $t \in 1,\ldots,T$:
  - For grid cell i:
    - No prediction step (we assume a static map).
    - Update step: $\texttt{bel}(m_t^i) \propto \texttt{bel}(m_{t-1}^i)p(z_t \mid x_t, m_{t-1}^i)$



EKF Mapping with Landmarks

- Map representation: a set of landmarks with unknown locations.
  - Let m_x^i, m_y^i be the coordinates of the ith landmark and $m = (m_x^1, m_y^1, \ldots, m_x^k, m_y^k)$ be the vector of all landmark coordinates.
  - Define observations as $z_t^i = (r_t^i, \phi_t^i)$
  - Assume $p(z_t^i \,|\, m_x^i, m_y^i) = \mathcal{N}(h(x_t, m_x^i, m_y^i), R)$.
  - Initialize belief $\texttt{bel}(m) = \mathcal{N}(m; \mu_0, \Sigma_0)$

EKF Mapping with Landmarks

- For $t \in 1,...T$:
  - For landmark i
    - No prediction step (we assume a static map).
    - Update step: EKF update on μ_t^i and Σ_t^i.
- Note: if x_t is known, landmark observations are independent of each other.

Data Association

- How to determine which landmark z_t corresponds to?
  - Defined observations based on (noisy) polar coordinates relative to robot. Could be unclear which landmark an observation represents.
- Challenging cases:
  - What if the robot has discovered a new landmark?
  - What if two landmarks are close together?
- Solution:
  - Estimate maximum likelihood correspondence.
  - Choose spatially far apart landmarks for the map.

Summary

- Introduced the robot mapping problem as the complement to the robot localization problem.
- Introduced several different methods for representing maps.
- Introduced two approaches for estimating a posterior belief on the map.

Action Items

- Finish programming assignment #2.
- 2nd SLAM reading for next week; send a reading response by 12 pm on Monday.