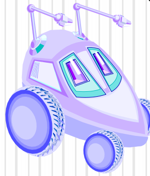
LECTURE 7-2

Localization and Map Making

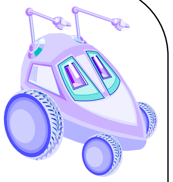
Introduction to AI Robotics (Sec. 11.1 – 11.4)



Quote of the Week

"Genius is 1 percent inspiration and 99 percent perspiration. As a result, genius is often a talented person who has simply done all of his homework."

Thomas Edison



ANNOUNCEMENTS

- Quiz 14 on Sec. 11.1 – 11.4, Lec. 8-1 on *Monday, 5/3/10*
- Lab 8 due on *Tuesday, 5/4/10*
- Lab 8 memo and code is due on Angel by midnight on *Thursday, 5/6/10*

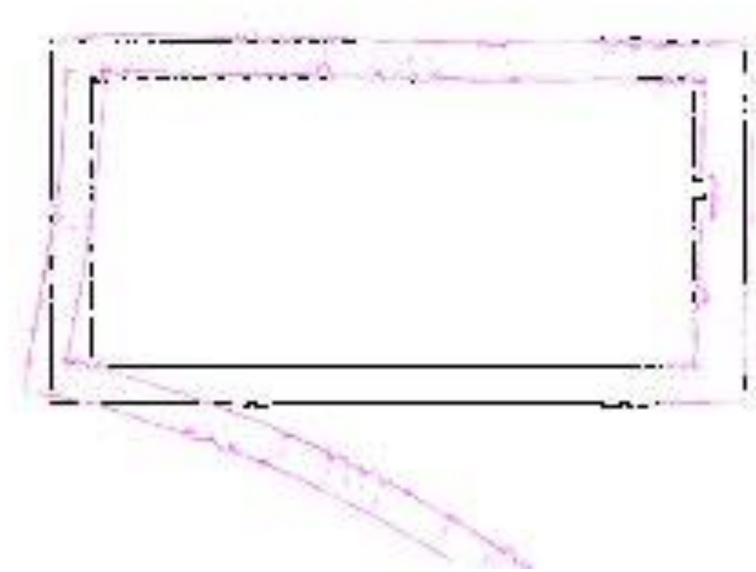
OBJECTIVES

Upon completion of this lecture the student should be able to:

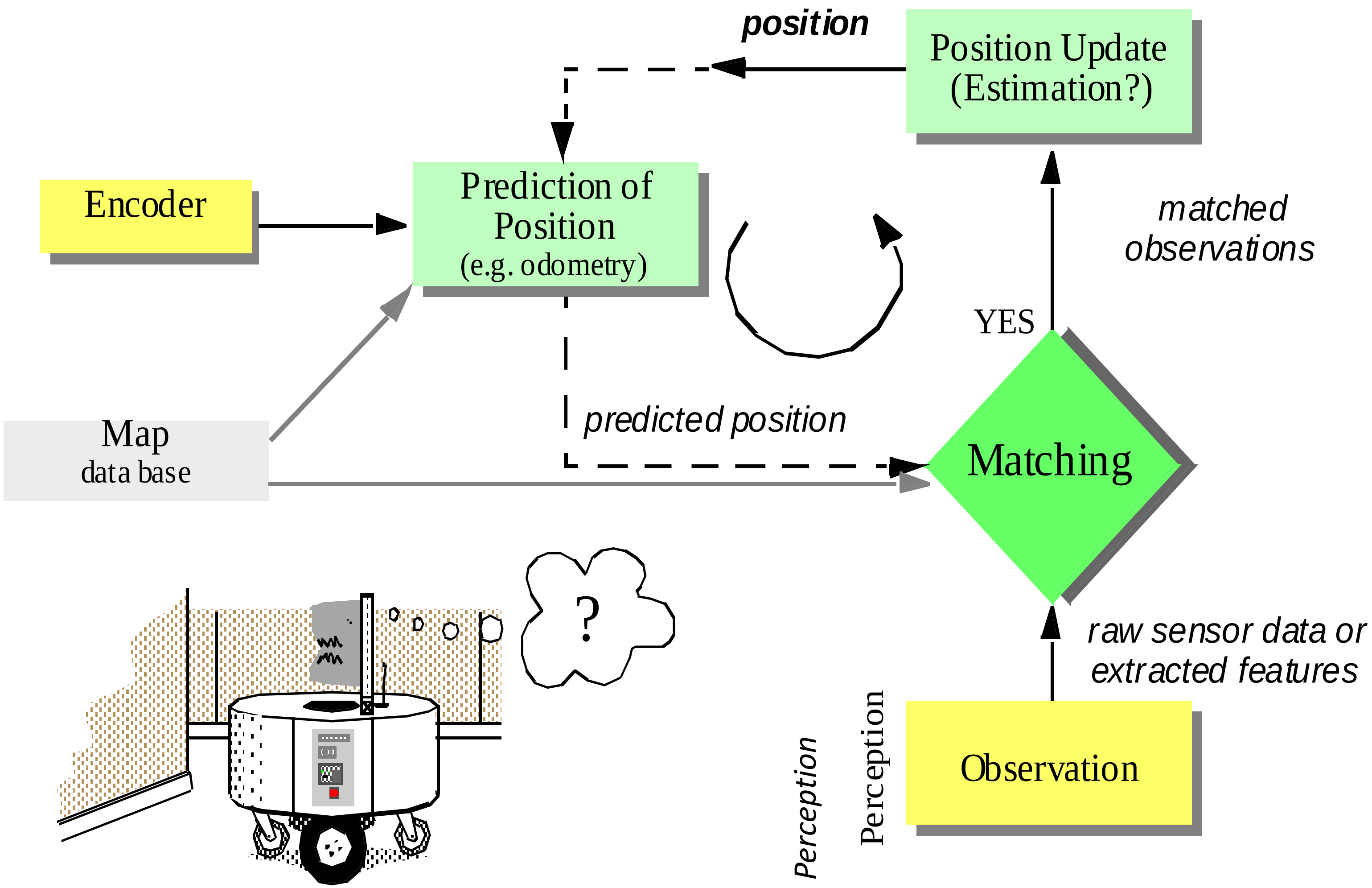
- Describe the difference between iconic and feature-based localization
- Be able to update an occupancy grid using either Bayesian, Dempster-Shafer or HIMM methods
- Describe the two types of formal exploration strategies

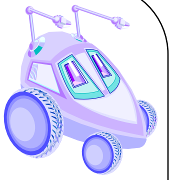
LOCALIZATION AND MAP MAKING

- The two remaining questions in *navigation* are
  - Where am I? *(localization)*
  - Where have I been? *(map making)*
- They are closely related because a robot cannot create an accurate map if it does not know where it is
- However, because shaft encoders are inaccurate this was not always feasible.



WHERE AM I?


position
Position Update
(Estimation?)
Encoder
Prediction of
Position
(e.g. odometry)
matched
observations
YES
predicted position
Map
data base
Matching
?
raw sensor data or
extracted features
Perception
Perception
Observation



LOCALIZATION

- One way for a robot is to use odometry or ***path integration***
- Because of accumulation error, the robot will eventually need to recognize a landmark to reset the odometer
- This is localization relative to the start or reference point (i.e. GPS map)
- Localization is also treated as a ***state estimation*** problem
- State estimation is the process of estimating the state of a system from measurements

LOCALIZATION CATEGORIES

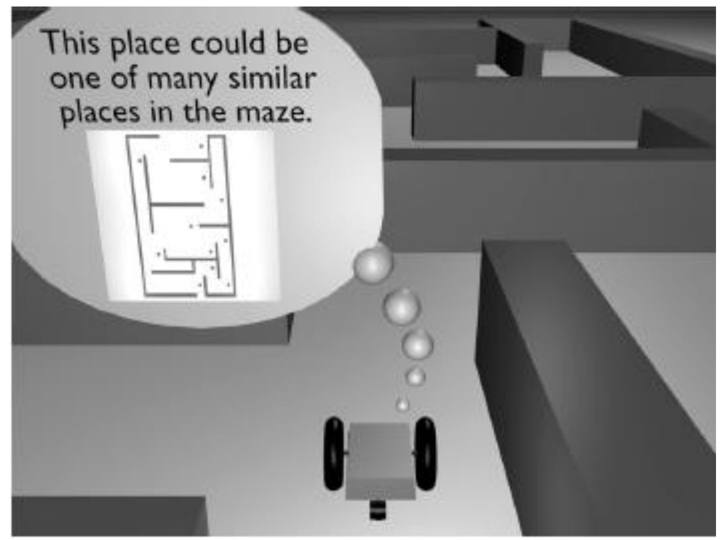
- Iconic-based
  - Use an occupancy grid (certainty and evidence grids)
  - Fuses sensor data into a world model or map
  - Fusion done by an algorithm provide by a formal theory of evidence, Bayesian or Dempster-Shafer or HIMM
  - Hybrid architectures use the occupancy grid as a virtual sensor
  - Suited for metric map building
- Feature-based
  - Suited for topological map building
  - Uses the Markov decision process (POMDP)

LOCALIZATION METHODS

- Odometry
- Using external sensors (beacons or landmarks)
- Probabilistic Map Based Localization

LOCALIZATION PROBLEMS

- The estimation process is indirect
- Measurements are noisy
- Measurements may not be available all the time



FRAME OF REFERENCE

- Frame of reference is important
  - Local/Relative: Where am I vs. where was I?
  - Global/Absolute: Where am I relative to the world frame?
- Location can be specified in two ways
  - Geometric: Distances and angles
  - Topological: Connections among landmarks

ABSOLUTE LOCALIZATION

- Proximity to reference
  - Landmarks/Beacons
- Angle to reference
  - Visual: manual triangulation from physical points
- Distance from reference
  - Time of Flight
    - Radio frequency (RF)
    - Global positioning system (GPS)
    - Acoustic
  - Signal Fading
    - Electromagnetic
    - Radio frequency
    - Acoustic

RELATIVE LOCALIZATION

- If you know your speed and direction, you can calculate where you are relative to where you were (integrate).
- Speed and direction might, themselves, be absolute (compass, speedometer), or integrated (gyroscope, accelerometer)
- Relative measurements are usually more accurate in the short term -- but suffer from accumulated error in the long term
- Most robotics research seems to focus on this

CHALLENGES OF LOCALIZATION

- Knowing the absolute position (e.g. GPS) is not sufficient
- ***Localization*** may also be required on a relative scale with respect to humans
- ***Cognition*** may require more than position, it may need to build an environmental model, ***map***, to plan a path to a goal

SENSOR NOISE

- Perception (sensors) and motion control (effectors) play an integral role in localization
  - Sensor noise
  - Sensor aliasing
  - Effector noise
  - Odometric position estimation

BELIEF REPRESENTATION

- The fundamental issue that differentiates map-based localization systems is ***representation***
  - ***Map representation***
    - Robot’s model of the environment, or a map
    - At what level of fidelity does the map represent the environment?
  - ***Belief representation***
    - Robot’s belief of its position on the map
    - Does the robot identify a single unique position?
    - Does the robot describe its position in terms of a set of possible positions?
    - How are multiple positions ranked

BAYESIAN

- The most popular evidential method for fusing evidence to translate sensor readings into probabilities using Bayes' rule.
- The conditional probability is $P(H|s)$ and two probabilities at the same time or two different times can be fused using Bayes' rule

DEMPSTER-SHAFER THEORY

- Bayes' relies on evidence being represented by *probability functions*.
- Dempster-Shafer theory represents evidence as *possibilistic belief* function. This means that the function represents *partial evidence*
- Dempster's rule of combination has a conflict metric that indicates when multiple observations disagree

LOCALIZATION METHODS

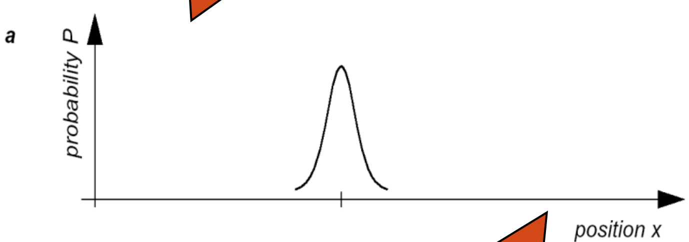
- Markov Localization:
  - Represent the robot's belief by a probability distribution over possible positions and uses Bayes' rule and convolution to update the belief whenever the robot senses or moves
- Gaussian
  - Represents the continuous hypothesis belief as a normal distribution

BELIEF REPRESENTATION CHARACTERISTICS

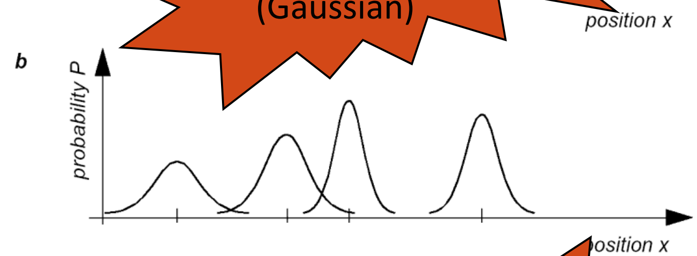
- Continuous
  - Precision bound by sensor data
  - Typically single hypothesis pose estimate
  - Lost when diverging (for single hypothesis)
  - Compact representation and typically reasonable in processing power.
- Discrete
  - Precision bound by resolution of discretization
  - Typically multiple hypothesis pose estimate
  - Never lost (when diverges converges to another cell)
  - Important memory and processing power needed. (not the case for topological maps)

TYPES OF BELIEF REPRESENTATION

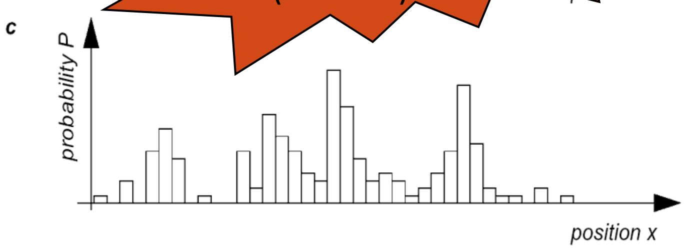
Continuous
Single hypothesis belief
(Gaussian)



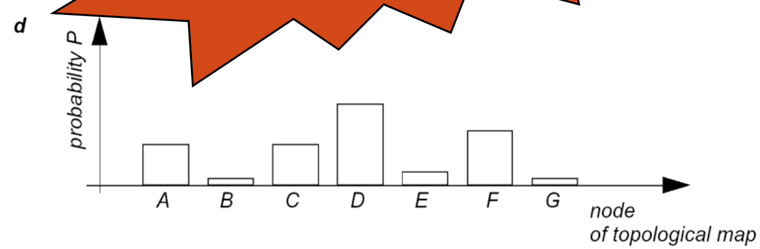
Continuous
Multiple hypothesis
belief
(Gaussian)



Discretized grid map
with probability values
for all possible robot
positions
(Markov)



Discretized topological map
with probability values
for all possible robot nodes
(Markov)



SINGLE HYPOTHESIS BELIEF

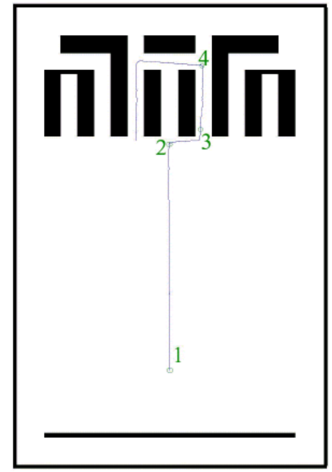
- Advantages:
  - Given a unique belief, there is no position ambiguity
  - Facilitates decision-making at robot's cognitive level (e.g. path planning)
- Disadvantages:
  - Robot motion induces uncertainty due to effector and sensor noise
  - Forcing the position update to always generate a single hypothesis of position is challenging

MULTIPLE HYPOTHESIS BELIEF

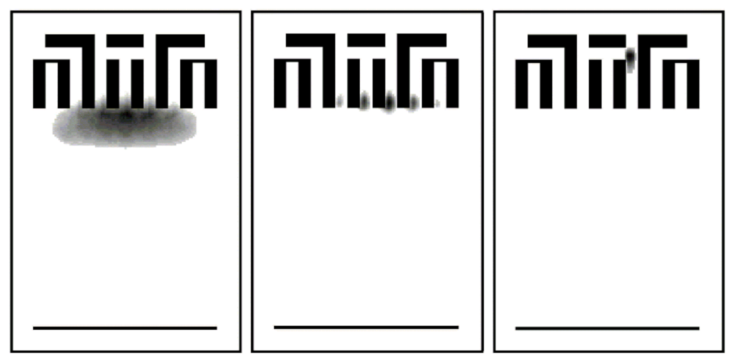
- The robot tracks an infinite set of possible positions
- This set can be described geometrically as a convex polygon positioned on a 2D map (continuous or discrete)
- In this method, the possible robot positions are not ranked
- To rank the positions requires a model of the beliefs as a mathematical distribution (Gaussian probability density function)

MULTIPLE HYPOTHESIS GRID-BASED REPRESENTATION

- There are discrete markers for each possible position
- Each position is noted along with a confidence or probability parameter
- Thousands of possible positions for a highly tessellated map



Path of the robot



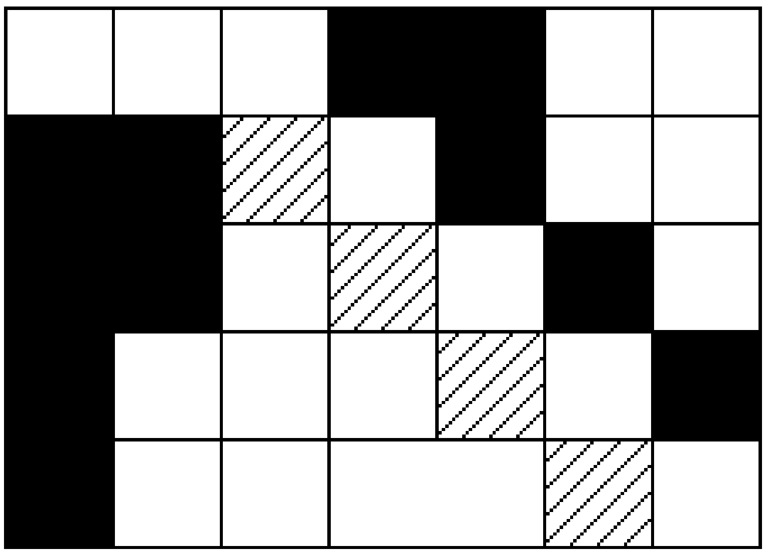
Belief states at positions 2, 3 and 4

LOCALIZATION (GRID-BASED)

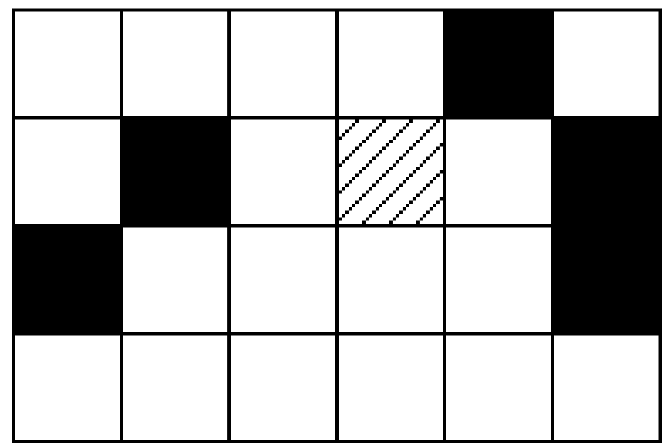
WORLD MAP

SENSOR DATA

Compare current and past reading



a.



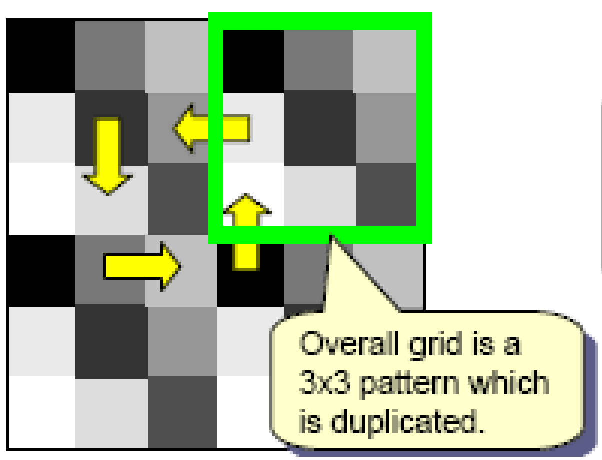
b.

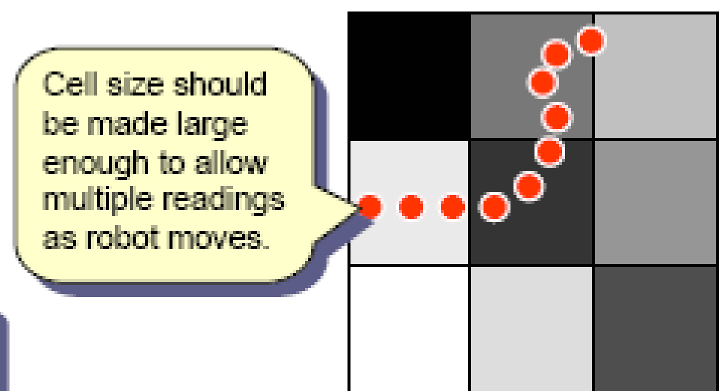
GRID-BASED LOCALIZATION

- Another strategy for position estimation is to do grid tracking
- Place a grid on the floor with clearly identifiable cells
- The robot senses change from one cell to another

GRID DESIGN

- A robot is equipped with a light sensor
- Grid must be designed to distinguish changes from one cell to another
- Must maximize the contrast between adjacent cells
- Grid cells must be larger when the robot moves faster





GRID TRACKING

- *Advantages*
  - Can re-confirm location after short distances, eliminate errors within 1 cell range
  - Simple to implement
- *Disadvantages*
  - Cell size limits accuracy
  - Requires many sensor readings and large cells for truly reliable estimations
  - Requires modification of the environment
  - Result depends on print quality and sensor calibration

MULTIPLE HYPOTHESIS GRID-BASED ADVANTAGES AND DISADVANTAGES

- Advantages:
  - Robot maintains a sense of position while explicitly annotating its own uncertainty about the position
  - Partial information from sensors and effectors can update the belief
  - Robot is able to explicitly measure its own degree of uncertainty regarding position
- Disadvantages:
  - In decision making, how does the robot decide what to do next?
  - Each position must have an associated probability
  - Computationally expensive