CMPE 185 Autonomous Mobile Robots

Perception, Sensor Characteristics and Uncertainty

Dr. Wencen Wu
Computer Engineering Department
San Jose State University

Group Project

- Reminder: check the group project assignments on Canvas

What is Perception of Mobile Robots?

Places / Situations
A specific room, a meeting situation, …

Servicing / Reasoning

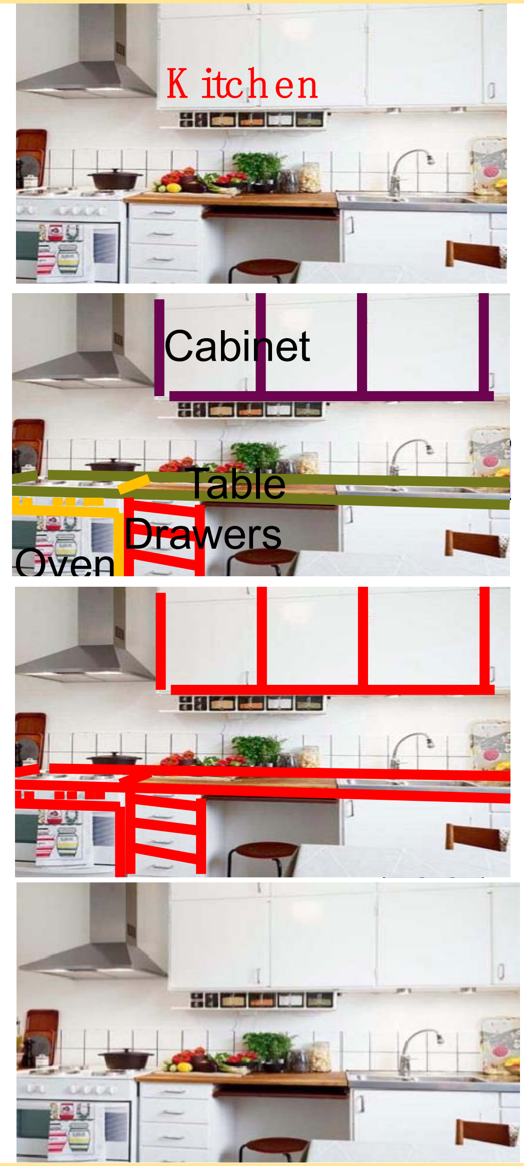
Objects
Doors, Humans, Coke bottle, car , …

Interaction

Features
Corners, Lines, Colors, Phonemes, …

Navigation

Raw Data
Vision, Laser, Sound, Smell, …



Perception is Hard!

- **Understanding = raw data + (probabilistic) models + context**
  - Intelligent systems interpret raw data according to probabilistic models and using contextual information that gives meaning to the data.
- Dealing with real-world situations
- Reasoning about a situation

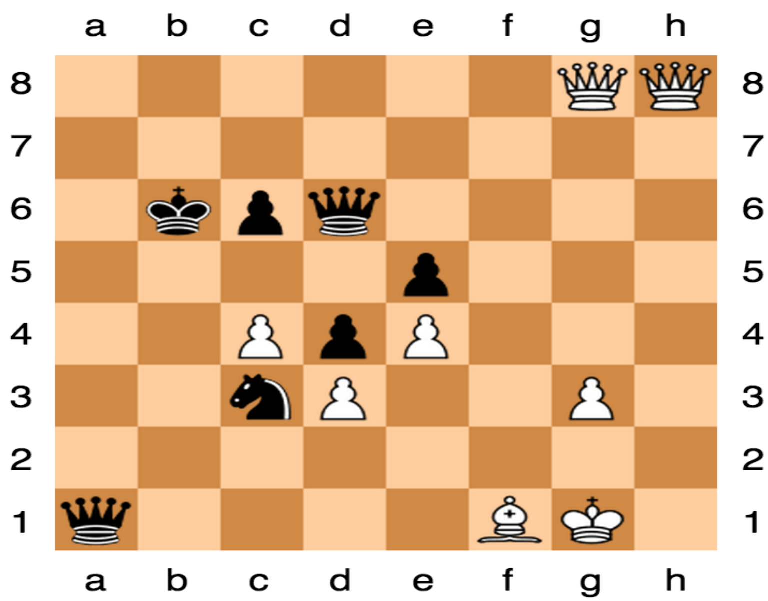
- Cognitive systems have to interpret situations based on uncertain and only partially available information

- They need ways to learn functional and contextual information (semantics / understanding)

Perception is Hard!

- "In robotics, the easy problems are hard and the hard problems are easy"
  - S. Pinker. The Language Instinct. New York: Harper Perennial Modern Classics, 1994

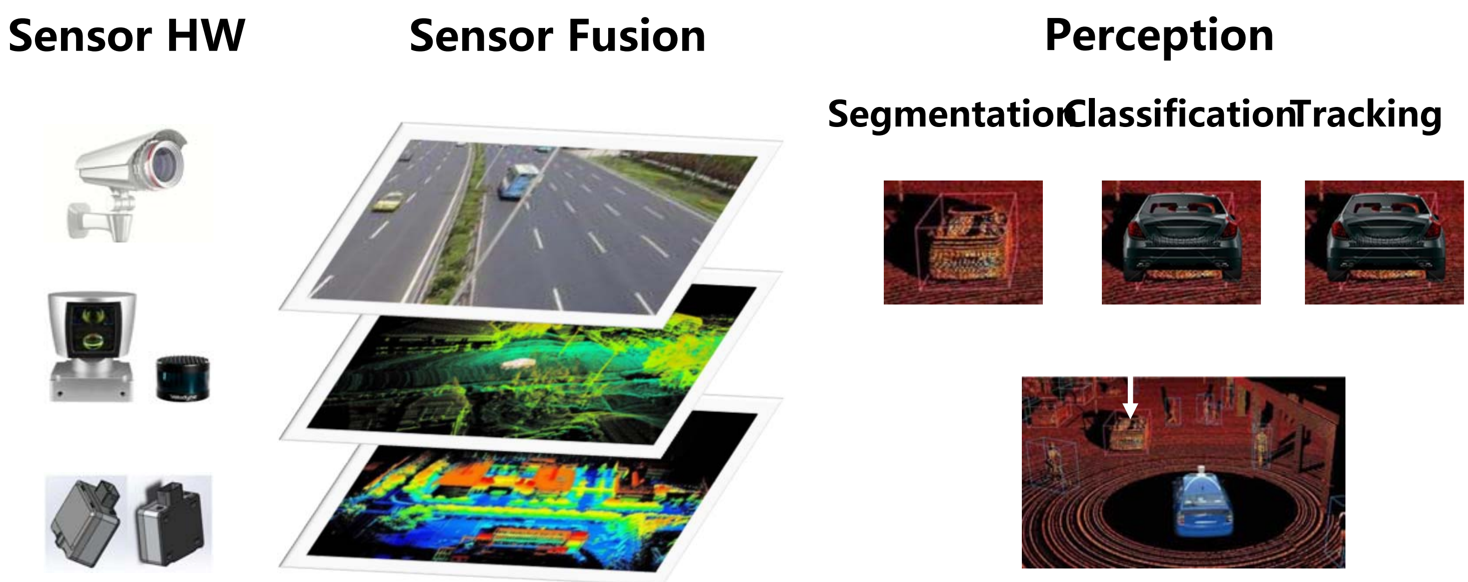
beating the world's chess master: EASY



create a machine with some "common sense": very HARD

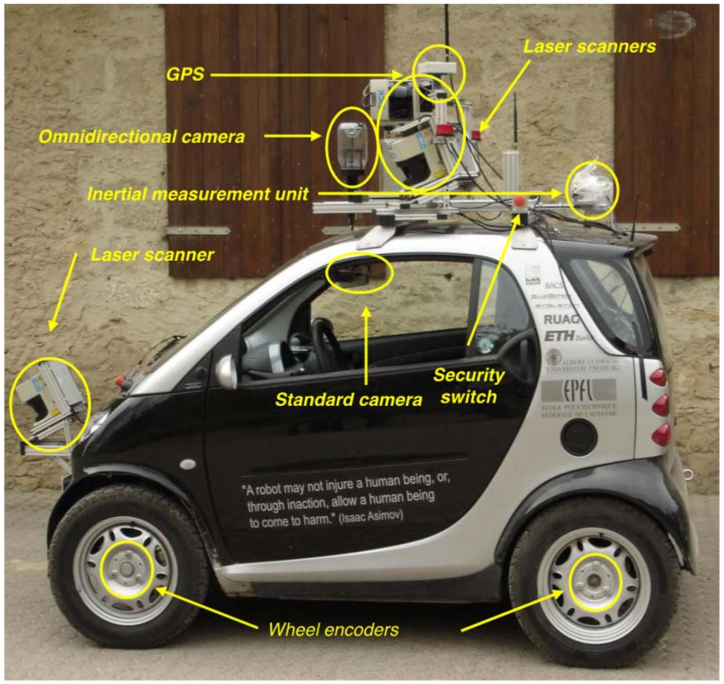
Example: Perception for a Self-driving Car

- Any information a self-driving car collects about itself or its environment requires sensing
- The self-driving cars that want to learn, map and/or navigate need to collect information about their surroundings
- All sensors have some degree of uncertainty
- Uncertainty can be reduced by multiple measurements.



Common Sensors for Mobile Robots

- Wheel encoders
  - Local motion estimation (odometry)
- GPS
  - Global localization and navigation
- Inertial Measurement Unit (IMU)
  - Orientation and acceleration of the robot
- Laser scanners, Radar, Ultrasonic sensors
  - Obstacle avoidance, motion estimation, scene interpretation (road detection, pedestrians)
- Cameras
  - Texture information, motion estimation, scene interpretation
- Bumper
- …



Classification of Sensors

- Robot = sensors + actuators
- Sensors are the key components for perceiving the environment

What:

- **Proprioceptive sensors**
  - measure values internally to the system (robot)
  - e.g. motor speed, wheel load, heading of the robot, battery status
- **Exteroceptive sensors**
  - information from the robots environment
  - distances to objects, intensity of the ambient light, unique features.

How:

- **Passive sensors**
  - Measure energy coming from the environment; very much influenced by the environment
- **Active sensors**
  - emit their proper energy and measure the reaction
  - better performance, but some influence on environment

Classification of Sensors

Sensor type	Sensor System	Proprioceptive (PC) or Exteroceptive (EC)	Active or Passive
Tacticle sensors	Bumbers	EC	P
Wheel/motor sensors	Brush encoders	PC	P
	Optical encoders	PC	A
Heading sensors	Compass	EC	P
	Gyroscope	PC	P
	Inclinometer	EC	A/P
Acceleration sensors	Accelerometer	PC	P
Beacons	GPS	EC	A
	Radio, ultrasonic, reflective beacons	EC	A
Motion/speed sensors	Doppler: radar or sound	EC	A
Range sensors	Ultrasound, laser rangefinder, structured light, time of flight	EC	A
Vision sensors	CCD/CMOS cameras	EC	P

Sensors

- Sensor Characteristics

- Sensor Uncertainty

- Different Sensors

Sensors: Basic Characteristics

- Range
  - Lower and upper limits
  - E.g., IR range sensor measures distance between 10 and 80cm

- Resolution
  - Minimum difference between two measurements
  - For digital sensors, it is usually the A/D resolution

$$\text{e.g.}\ \frac{5V}{255(8\ bit)} = 0.02V$$

Sensors: Basic Characteristics

- Dynamic range
  - Used to measure spread between lower and upper limits of sensor inputs
  - Formally, it is the ratio between the maximum and minimum measurable input, usually in decibels (dB)

$$Dynamic\ Range = 10\log[\frac{UpperLimit}{LowerLimit}]$$

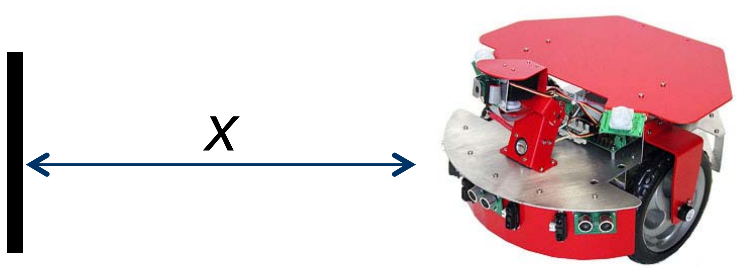
  - E.g., A sonar range sensor measures up to a max distance of 3m, with smallest measurement of 1cm

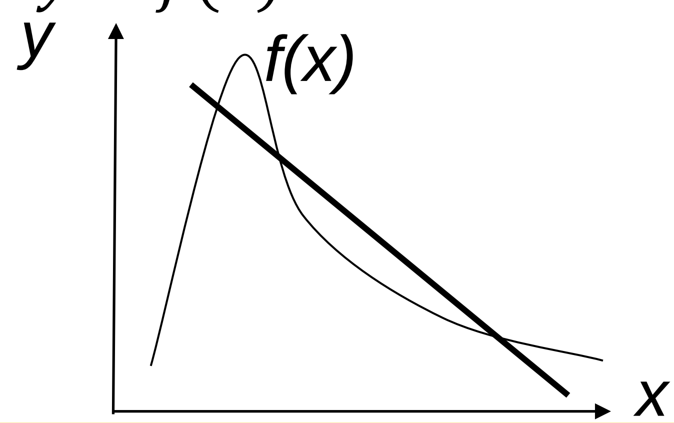
$$Dynamic\ Range = 10\log[\frac{3}{0.01}]$$

$$= 24.8dB$$

Sensors: Basic Characteristics

- Linearity
  - A measure of how linear the relationship between the sensor's output signal and input signal
  - Linearity is less important when signal is treated after with a computer
- Linearity example
  - Consider the range measurement from an IR range sensor
  - Let x be the actual measurement in meters, let y be the output from the sensor in volts, and $y = f(x)$





Sensors: Basic Characteristics

- Bandwidth or Frequency
  - The speed with when a sensor can provide a stream of readings
  - Usually there is an upper limit depending on the sensor and the sampling rate
    - e.g., sonar takes a long time to get a return signal
  - Higher frequencies are desired for autonomous control
    - e.g., if a GPS measurement occurs at 1 Hz and the autonomous vehicle uses this to avoid other vehicles that are 1 meter away
- Sensitivity
  - Ratio of output change to input change
    - E.g., range sensor will increase voltage output 0.1 V for every cm distance measured

Sensors: Basic Characteristics

- Accuracy
  - The difference between the sensor's output and the true value (i.e., $error = m - v$)

$$accuracy = 1 - \frac{|m - v|}{v}$$

m = measured value

v = true value

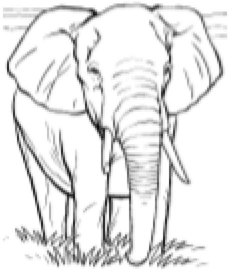
- Precision
  - The reproducibility of sensor results

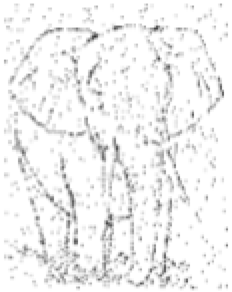
$$precision = \frac{range}{\sigma}$$

σ = standard deviation

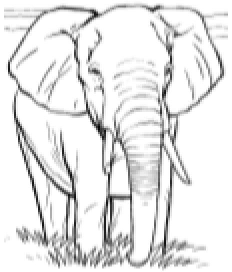
Sensors: In Situ Characteristics

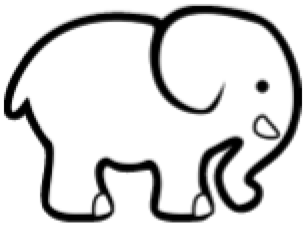
- Random Error
  - Non-deterministic
  - Not predictable
  - Usually described probabilistically





- Systematic Error
  - Deterministic
  - Caused by factors that can be modeled, e.g., optical distortion in camera





Sensors: In Situ Characteristics

- Measurements in the real-world are dynamically changing and error-prone
  - Changing illuminations
  - Light or sound absorbing surfaces

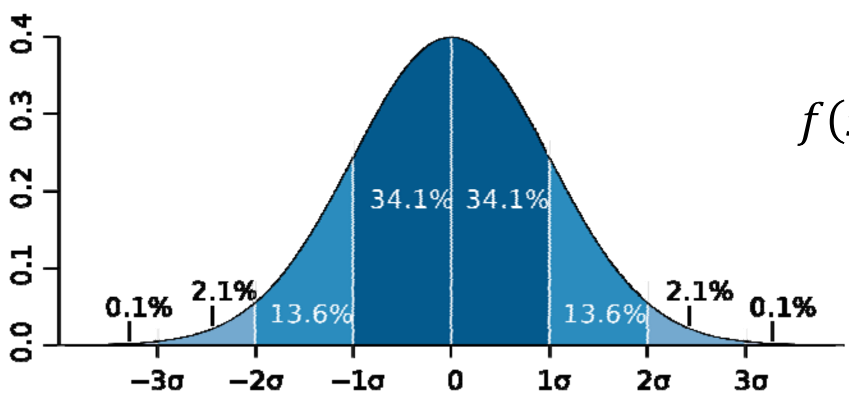
- Systematic versus random errors are not well-defined for mobile robots
  - There is a cross-sensitivity of robot sensor to robot pose and environment dynamics
  - Difficult to model, appear to be random

Sensors

- Sensor Characteristics
- Sensor Uncertainty
- Different Sensors

Sensor Uncertainty

- How can it be represented?
  - With probability distributions
- Representation
  - Describe measurement as a random variable *X*
  - Given a set of *n* measurements with values ρ_I
  - Characterize statistical properties of *X* with a probability density function *f(x)*



$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{-(x-\mu)^2}{2\sigma^2}\right]$$

Sensor Uncertainty

1m → true distance

- Expected value of X is the mean μ

X → measurement

→ take measurement 10 times

→ $x_1 = 1.1m$, x_2 1.05m, 0.95m, 0.9m, 0.85m, 1.12m, ...

$$\mu = E[X] = \int_{-\infty}^{\infty} x f(x)\, dx \quad \Rightarrow \quad \mu = E[X] = \frac{\sum^n x}{n}$$

$$\frac{\sum_1^n x_i}{n}$$

→ 1

→ 1

- The variance of X is σ^2

$$\sigma^2 = Var(X) = \int_{-\infty}^{\infty} (x-\mu)^2 f(x)\, dx \quad \Rightarrow \quad \sigma^2 = Var(X) = \frac{\sum^n (x-\mu)^2}{n}$$

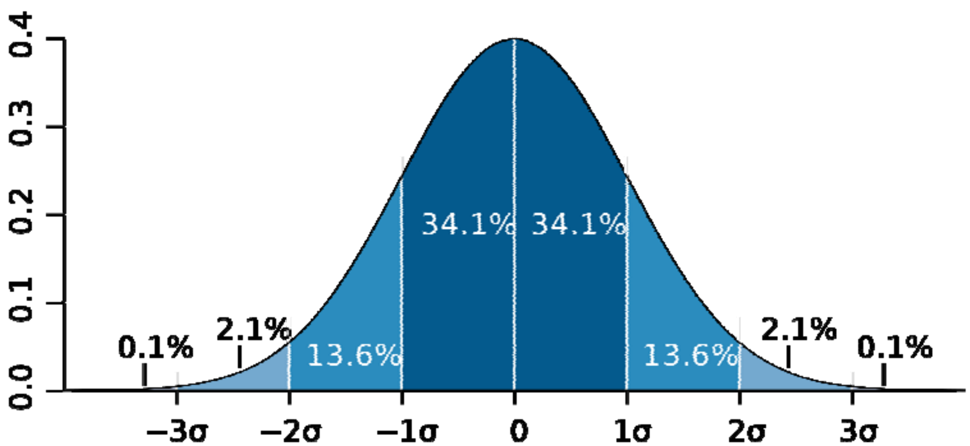
10

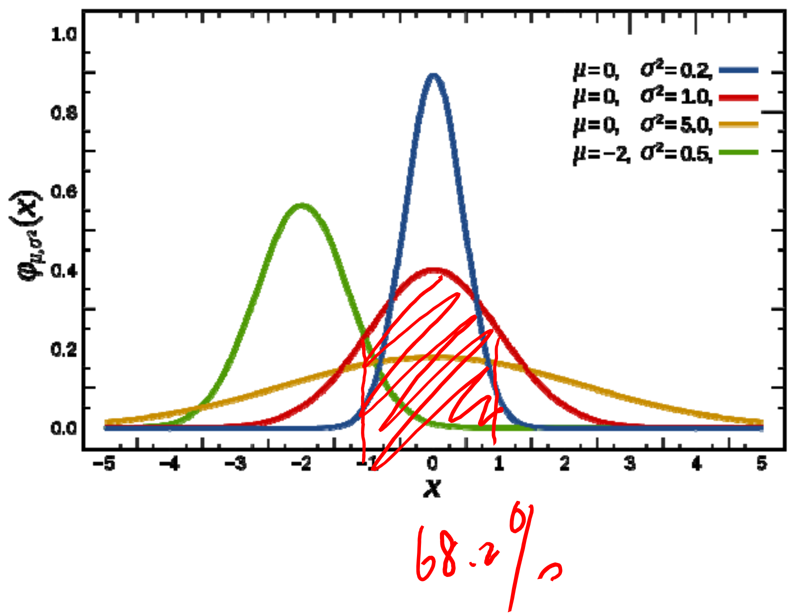
$$\frac{1}{10}\left((1.1-1)^2 + (1.05-1)^2 + (0.95-1)^2 + \ldots\right)$$

Sensor Uncertainty

- Use a Gaussian Distribution

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp[\frac{-(x-\mu)^2}{2\sigma^2}]$$



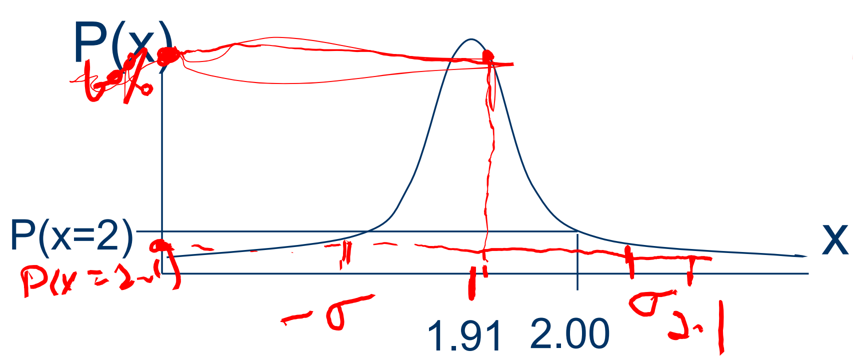


Sensor Uncertainty

- How do we use the Gaussian?

  $\sigma^2 \rightarrow \sigma$
  - Learn the variance of sensor measurements ahead of time
  - Assume mean measurement is equal to actual measurement

    μ
- Example:
  - If a robot is 1.91 meters from a wall, what is the probability of getting a measurement of 2 meters?
  - Answer: if the sensor error is modeled as a Gaussian, we can assume the sensor has the following probability distribution



68.2% time, get the measure $-\sigma < x < \sigma$

  - Then, use the distribution to determine $\mathrm{P}(x = 2)$

- Thank you!