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<th>Std Dev</th>
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**Midterm Grade Distribution**

- <79.99: 3
- 80-84.99: 4
- 85-89.99: 4
- 90-94.99: 7
- >=95: 4

**Grade**: 88.28 7.22
1. What do you think of the balance of theoretical vs. applied work?
2. What’s been most useful to you (and why)?
3. What’s been least useful (and why)?
4. What could students do to improve the class?
5. What could Matt do to improve the class?

<table>
<thead>
<tr>
<th>Rating</th>
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<tr>
<td>Reasonable</td>
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<td>Good</td>
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<tr>
<td>Perfect</td>
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<table>
<thead>
<tr>
<th>Online slides/lectures: 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory/Kinematics: 2</td>
</tr>
<tr>
<td>Aligning labs/hw with lecture</td>
</tr>
<tr>
<td>Labs: 4</td>
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</tbody>
</table>
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Guest lecture / when Matt's gone: 3

Math: (3) Why not use built in software for kinematics calculations?

HW 1

Using ROS

Intro to sensors

Locomotion

Piazza: rarely follow through
1. What do you think of the balance of theoretical vs. applied work?
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| Piazza: 4 |
| Review online lectures: 1 |
| Come to lecture & Participate |
| Start earlier / work together more: 6 |
1. What do you think of the balance of theoretical vs. applied work?
2. What’s been most useful to you (and why)?
3. What’s been least useful (and why)?
4. What could students do to improve the class?
5. What could Matt do to improve the class?

| Faster grading: 1 |
| More examples/demos: 6 |
| Keep starting labs in class: 2 |
| More theory rather than ROS stuff |
| Baby us more through more more stuff |
Continuous Localization and Mapping

Sensor data → Construct local map → Pose estimation

Encoder data → Construct local map → Pose estimation

Local map → Match and score → k possible poses

Best pose → Register → Global map
Matching

Where am I on the global map?

Examine different possible robot positions.
• General approach:

A: action
S: pose
O: observation

Position at time $t$ depends on position previous position and action, and current observation.
• Pose at time $t$ determines the observation at time $t$
• If we know the pose, we can say what the observation is
• But, this is *backwards*...
• Hello Bayes!
Quiz!

• If events a and b are independent,
  • $p(a, b) =$

• If events a and b are not independent,
  • $p(a, b) =$

• $p(c \mid d) =$ ?
Quiz!

• If events a and b are independent,
  
  • \( p(a, b) = p(a) \times p(b) \)

• If events a and b are not independent,
  
  • \( p(a, b) = p(a) \times p(b|a) = p(b) \times p(a|b) \)

• \( p(c|d) = p(c, d) / p(d) = p((d|c) p(c)) / p(d) \)
Bayes Filtering

• Want to have a way of representing uncertainty
• Probability Distribution
  – Could be discrete or continuous
  – Prob. of each pose in set of all possible poses

• Belief
• Prior
• Posterior
Models of Belief

- Single hypothesis, continuous distribution
- Multiple hypothesis, continuous distribution
- Multiple hypothesis, discrete distribution
- Topological map, discrete distribution
1. Uniform Prior

2. Observation: see pillar

3. Action: move right

4. Observation: see pillar
Modeling objects in the environment

http://www.cs.washington.edu/research/rse-lab/projects/mcl
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Simple Example of State Estimation

• Suppose a robot obtains measurement $z$
• What is $P(open|z)$?
Causal vs. Diagnostic Reasoning

- \( P(\text{open}|z) \) is **diagnostic**.
- \( P(z|\text{open}) \) is **causal**.
- Often **causal** knowledge is easier to obtain.

Bayes rule allows us to use causal knowledge:

\[
P(\text{open} \mid z) = \frac{P(z \mid \text{open})P(\text{open})}{P(z)}
\]

Comes from sensor model.
Bayes Formula

\[ P(x, y) = P(x \mid y)P(y) = P(y \mid x)P(x) \]

\[ \Rightarrow \]

\[ P(x \mid y) = \frac{P(y \mid x) P(x)}{P(y)} = \frac{\text{likelihood} \cdot \text{prior}}{\text{evidence}} \]

If \( y \) is a new sensor reading:

- \( p(x) \) ➔ Prior probability distribution
- \( p(x \mid y) \) ➔ Posterior (conditional) probability distribution
- \( p(y \mid x) \) ➔ Model of the characteristics of the sensor
- \( p(y) \) ➔ Does not depend on \( x \)
Bayes Formula

\[ P(x, y) = P(x \mid y)P(y) = P(y \mid x)P(x) \]

\[ \Rightarrow \quad P(x \mid y) = \frac{P(y \mid x) P(x)}{P(y)} = \frac{\text{likelihood} \cdot \text{prior}}{\text{evidence}} \]

\[ \Rightarrow \quad P(x \mid y) = \frac{P(y \mid x) P(x)}{\sum_x P(y \mid x)P(x)} \]
Example

- \( P(z|\text{open}) = 0.6 \) \( P(z|\neg\text{open}) = 0.3 \)
- \( P(\text{open}) = P(\neg\text{open}) = 0.5 \)

\[ P(\text{open} \mid z) = ? \]
Example

\[ P(\text{open} \mid z) = \frac{P(z \mid \text{open})P(\text{open})}{P(z)} \]

\[ P(\text{open}) = \frac{P(z \mid \neg \text{open})P(\neg \text{open})}{P(z \mid \text{open})P(\text{open})} \]

- \( P(z \mid \text{open}) = 0.6 \)
- \( P(z \mid \neg \text{open}) = 0.3 \)
- \( P(\text{open}) = P(\neg \text{open}) = 0.5 \)

\[ P(\text{open} \mid z) = \frac{0.6 \cdot 0.5}{0.6 \cdot 0.5 + 0.3 \cdot 0.5} = \frac{2}{3} = 0.67 \]

\( z \) raises the probability that the door is open.