Dr. Cengiz Günay, Emory Univ.
Robots As Killers?

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  1. A robot may not injure or cause indirect harm to a human.
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  2. It must obey orders except when in conflict with law #1.
Robots As Killers?

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- Isaac Asimov developed the concept of robotics and three laws:
  1. A robot may not injure or cause indirect harm to a human.
  2. It must obey orders except when in conflict with law #1.
  3. It must stay alive as long as not in conflict with laws #1 and #2.
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  1. A robot may not injure or cause indirect harm to a human.
  2. It must obey orders except when in conflict with law #1.
  3. It must stay alive as long as not in conflict with laws #1 and #2.
- Fiction always liked to depict robots taking over
In reality, first we need to *make* the robots

Dr. Thrun says we will soon
Or As Helpers?

- In reality, first we need to make the robots
- Dr. Thrun says we will soon
- They can help with?

- Disabled people
- Children
- Risky tasks
- Mundane tasks

We'll focus on the self-driving car in two lectures.
...Or As Helpers?

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- We’ll focus on the the **self-driving car** in two lectures
Exit survey: Computer Vision III – Structure from Motion

- What additional piece of information an SfM algorithm needs when the objects in the scene also moves?
- What parameters an SfM algorithm cannot recover?

Entry survey: Robotics I – Autonomous Robots (0.25 pts)

- What methods that we have previously seen in this class would be involved in robotics?
- Name a useful task that you think would be possible to assign to robots.
Self-Driving Cars and DARPA Challenge

1st DARPA challenge was a failure: cars completed at most 5%.
Undergrads like you made Stanley win!
1st DARPA challenge was a failure: cars completed at most 5%.
Undergrads like you made Stanley win!
Urban Challenge
Google car self-drove 100,000 miles already!

We will focus on machine learning, particle filters, and planning.
Robot as an Agent

Is it:
1. Part-observable?
2. Stochastic?
3. Adversarial?
4. Continuous?
5. Single/Multi?
Robot as an Agent

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1. Part.-observable?
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Is it:
1. Part.-observable
2. Stochastic
3. Adversarial?
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5. Single/Multi?
Perception to Estimate Internal State: Kinematic

Roomba is cleaning a room:

How many dimensions we need for kinematic state?

- \( x \)
- \( y \)
- heading angle

Total: 3
Perception to Estimate Internal State: Kinematic

**Kinematic state:** Where in the world are we??
Roomba is cleaning a room:

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- $x$, $y$, heading angle

**Total:** 3
Perception to Estimate Internal State: Kinematic

Kinematic state: Where in the world are we??

How about for Junior?

How many dimensions we need for kinematic state?
Perception to Estimate Internal State: Kinematic

Kinematic state: Where in the world are we??

How many dimensions we need for kinematic state?

- SAME: $x$, $y$, heading angle

Total: 3
Including Movement: Dynamic State

**Kinematic state:**

Where in the world are we??
Including Movement: Dynamic State

Kinematic state:
Where in the world are we??

Junior:

![Diagram of Kinematic State with 3 Dimensions]
Including Movement: Dynamic State

Kinematic state:
Where in the world are we??

Junior:

![Kinematic State Diagram]

3 Dimensions
Including Movement: Dynamic State

Kinematic state:  
Where in the world are we??

Dynamic state:  
Where are you going??

Junior:

[Image of a diagram with "Kinematic State" and "3 Dimensions" written on it]
Including Movement: Dynamic State

Kinematic state:
Where in the world are we??

Junior:

Dynamic state:
Where are you going??
(also includes the kinematic state).

How many dimensions in dynamic state of Junior?
3 from kinematic forward velocity, $v$
yaw rate: turning angle
Total: 5
Including Movement: Dynamic State

Kinematic state:
   Where in the world are we??

Junior:

Dynamic state:
   Where are you going??
   (also includes the kinematic state).

How many dimensions in dynamic state of Junior?

3 from kinematic forward velocity, \( v \), yaw rate, \( \gamma \); total: 5.
Including Movement: Dynamic State

Kinematic state:

Where in the world are we??

Junior:

Dynamic state:

Where are you going??
(also includes the kinematic state).

How many dimensions in dynamic state of Junior?

- 3 from kinematic
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Including Movement: Dynamic State

**Kinematic state:**

Where in the world are we??

Junior:

**Dynamic state:**

Where are you going??
(Also includes the kinematic state).

How many dimensions in dynamic state of Junior?

- 3 from kinematic
- Forward velocity, \(v\)
- **Yaw rate**: Turning angle

Total: 5
More Dimensions: Flying
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More quadcopter videos:

- Aggressive Maneuvers I: State estimation
- Aggressive Maneuvers II: Hoops!
- Aggressive Maneuvers III: Trajectory planning
- Fails!
Quadcopters:

Dimensions in **kinematic** state?
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Dimensions in **kinematic** state?

- 3D location: $x, y, z$
Quadcopters:

Dimensions in *kinematic* state?

- 3D location: $x, y, z$
- 3D angles: heading, incline, roll
Quadcopters:

Dimensions in **kinematic** state?

- 3D location: $x, y, z$
- 3D angles: heading, incline, roll

**Total:** 6
Quadcopters:

Dimensions in **kinematic** state?

- 3D location: $x, y, z$
- 3D angles: heading, incline, roll

Total: 6

Dimensions in **dynamic** state?

6 from kinematic
3 for each dimensional velocity
3 for each angular velocity

Total: 12

Unlike a car, this can go in all directions!
Quadcopters:

Dimensions in **kinematic** state?

- 3D location: $x, y, z$
- 3D angles: heading, incline, roll

Total: 6

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Total: 12

Unlike a car, this can go in all directions!
Honda’s Asimo: a humanoid bipedal robot
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Robotic arm:
Kinematic & Dynamic State of Jointed Robots

Honda’s Asimo: a humanoid bipedal robot

Robotic arm:

Kinematic dimensions:
Honda’s Asimo: a humanoid bipedal robot

Kinematic dimensions: 6?
Honda’s Asimo: a humanoid bipedal robot

Robotic arm:

**Kinematic dimensions:** 6?
- base angles (2)
- joint angles (2)
- arm rotation (1), grab (1)
Kinematic & Dynamic State of Jointed Robots

Honda’s Asimo: a humanoid bipedal robot

Robotic arm:

Kinematic dimensions: 6?
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Dynamic dimensions?
Kinematic & Dynamic State of Jointed Robots

Honda’s Asimo: a humanoid bipedal robot

Robotic arm:

- **Kinematic dimensions:** 6?
  - base angles (2)
  - joint angles (2)
  - arm rotation (1), grab (1)

- **Dynamic dimensions?** $2 \times 6$
Localization
Monte Carlo Localization: Particle Filter

Roomba:

Kinematic state variables:
- $x, y$: location
- $\theta$: heading angle
Monte Carlo Localization: Particle Filter

Roomba:

Kinematic state variables:
- $x, y$: location
- $\theta$: heading angle

Dynamic state variables:
- $v$: forward velocity
- $w$: angular velocity (yaw)

Each particle: $\begin{bmatrix} x \\ y \\ \theta \end{bmatrix}$
Monte Carlo Localization: Particle Filter

Roomba:

Each particle:

\[
\begin{pmatrix}
    x \\
y \\
\theta
\end{pmatrix}
\]

Remember: estimation and prediction?

Kinematic state variables:
- \( x, y \): location
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Monte Carlo Localization: Particle Filter

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Each particle:

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\begin{pmatrix}
    x \\
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    \theta
\end{pmatrix}
\]

Remember: estimation and prediction?
State estimation after \(\Delta t\):

\[
x' = x + 
\]

Kinematic state variables:
- \(x, y\): location
- \(\theta\): heading angle

Dynamic state variables:
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Monte Carlo Localization: Particle Filter

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Kinematic state variables:
- \(x, y\): location
- \(\theta\): heading angle

Dynamic state variables:
- \(v\): forward velocity
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State estimation after \(\Delta t\):

\[
x' = x + \Delta t \cdot v \cos \theta
\]
Monte Carlo Localization: Particle Filter

Roomba:

Kinematic state variables:
- $x, y$: location
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Each particle:

\[
\begin{pmatrix}
  x \\
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Remember: estimation and prediction?

State estimation after $\Delta t$:

\[
\begin{align*}
x' & = x + \Delta t \: v \: \cos \theta \\
y' & = y + \Delta t \: v \: \sin \theta
\end{align*}
\]
Monte Carlo Localization: Particle Filter

Roomba:

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State estimation after $\Delta t$:
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\begin{align*}
  x' &= x + \Delta t \, v \, \cos \theta \\
  y' &= y + \Delta t \, v \, \sin \theta \\
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\end{align*}
\]
Monte Carlo Localization: Particle Filter

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Kinematic state variables:

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Dynamic state variables:

- \( v \): forward velocity
- \( w \): angular velocity (yaw)

Remember: estimation and prediction?

State estimation after \( \Delta t \):

\[
\begin{align*}
  x' &= x + \Delta t \cdot v \cdot \cos \theta \\
  y' &= y + \Delta t \cdot v \cdot \sin \theta \\
  \theta' &= \theta + \Delta t \cdot w
\end{align*}
\]

1st approx., but works well.
Localization Question

Roomba:

Kinematic state variables:
- $x, y$: location
- $\theta$: heading angle

Dynamic state variables:
- $v$: forward velocity
- $w$: angular velocity (yaw)

State estimation after $\Delta t$:

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Localization Question

Roomba:

State estimation after $\Delta t$:

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    y' &= y + \Delta t \, v \sin \theta \\
    \theta' &= \theta + \Delta t \, w
\end{align*}
\]

Initial state:
\[
\begin{align*}
    x &= 24, \quad y = 18, \quad \theta = 0 \\
    v &= 5/\text{sec}, \quad w = \frac{\pi}{8 \text{sec}}
\end{align*}
\]

Kinematic state variables:
- $x, y$: location
- $\theta$: heading angle

Dynamic state variables:
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- $w$: angular velocity (yaw)
Localization Question

Roomba:

---

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- $x, y$: location
- $\theta$: heading angle

Dynamic state variables:
- $v$: forward velocity
- $w$: angular velocity (yaw)

State estimation after $\Delta t$:

$$
\begin{align*}
x' &= x + \Delta t \cdot v \cdot \cos \theta \\
y' &= y + \Delta t \cdot v \cdot \sin \theta \\
\theta' &= \theta + \Delta t \cdot w
\end{align*}
$$

Initial state:
- $x = 24$, $y = 18$, $\theta = 0$
- $v = 5$/sec, $w = \frac{\pi}{8}$/sec

Estimate after $\Delta t = 1$ sec?
Localization Question

Roomba:

Kinematic state variables:
- $x, y$: location
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Dynamic state variables:
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- $w$: angular velocity (yaw)

State estimation after $\Delta t$:

\[
\begin{align*}
x' &= x + \Delta t \, v \, \cos \theta \\
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\end{align*}
\]

Initial state:
- $x = 24$, $y = 18$, $\theta = 0$
- $v = 5$ /sec, $w = \frac{\pi}{8}$ /sec

Estimate after $\Delta t = 1$ sec?

\[
\begin{align*}
x' &= 24 + 1 \times 5 \times 1 = 29 \\
y' &= 18 + 1 \times 5 \times 0 = 18 \\
\theta' &= 0 + 1 \times \frac{\pi}{8} = \frac{\pi}{8}
\end{align*}
\]