Lecture 20
Motion Planning II

Katie DC
Modern Robotics Ch 10.2-10.5
Administrivia

• Upcoming homework due dates:
  • HW6 due 11/14 at 8pm
  • HW7 due 11/19 at 8pm
  • HW8 (bonus) due 12/10 at 8pm
    • Note that it will likely be a good review for the exam!

• Last few lectures:
  • 11/16 will be a guest lecture – attendance is required!
  • 11/18 will be a review session
  • 11/30 and 12/2 will be project presentations

• Exam 2 is on 12/7 during lecture
all deadlines and submission instructions are on the website

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<tr>
<th>Assignment</th>
<th>Deadline</th>
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<tr>
<td>Project Video Presentations</td>
<td>11/29 at midnight</td>
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<td>Submit via Google Form</td>
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<td>Participation Self-Assessment</td>
<td>12/8 at midnight</td>
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<td>Submit via Google Form</td>
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<td>Participation Bonus Submissions</td>
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<td>Submit via Google Form</td>
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<td>Extra Credit Videos</td>
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<td>Team Assessment</td>
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<td>Project Report</td>
<td>12/17 at 8pm</td>
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Who is Nancy Amato?

- Head of the CS department and expert in motion planning
- Her paper on probabilistic planning is one of the most important papers in PRM, the first to not use uniform sampling in the configuration space
- She and her team wrote a seminal paper that shows how robot planning can be applied to protein motions (folding)
  → This line of work started a new research area in comp. biology
Motion Planning Overview
Graphs and Trees

• Motion planners often represent C-space as a graph.
• A graph is a collection of nodes $\mathcal{N}$ and edges $\mathcal{E}$, where edge $e$ connects two nodes.

• A tree is a directed graph with no cycles and each node has at least one parent.
Graphs and Trees
Grid-World Example
Graph Search Methods

A* search algorithm.

Dijkstra’s algorithm.

Credit: Subh83 on Wikipedia
A simple roadmap: visibility graph
A simple roadmap: visibility graph
Sampling Based Planners: Probabilistic Roadmaps
Reachability Tree for Dubin’s Car

Credit: Steven LaValle, Planning Algorithms
Rapidly Exploring Random Trees (RRT)

**Algorithm 10.3** RRT algorithm.

1: initialize search tree $T$ with $x_{\text{start}}$
2: while $T$ is less than the maximum tree size do
3: 
4: 
5: employ a local planner to find a motion from $x_{\text{nearest}}$ to $x_{\text{new}}$ in the direction of $x_{\text{samp}}$
6: if the motion is collision-free then
7: 
8: if $x_{\text{new}}$ is in $X_{\text{goal}}$ then
9: 
10: end if
11: end if
12: end while
13: return FAILURE
Rapidly Exploring Random Trees (RRT)

**Algorithm 10.3** RRT algorithm.

1: initialize search tree $T$ with $x_{\text{start}}$
2: while $T$ is less than the maximum tree size do
3: \hspace{1em} $x_{\text{samp}} \leftarrow$ sample from $\mathcal{X}$
4: \hspace{1em} $x_{\text{nearest}} \leftarrow$ nearest node in $T$ to $x_{\text{samp}}$
5: \hspace{1em} employ a local planner to find a motion from $x_{\text{nearest}}$ to $x_{\text{new}}$ in
6: \hspace{2em} the direction of $x_{\text{samp}}$
7: \hspace{1em} if the motion is collision-free then
8: \hspace{2em} add $x_{\text{new}}$ to $T$ with an edge from $x_{\text{nearest}}$ to $x_{\text{new}}$
9: \hspace{2em} if $x_{\text{new}}$ is in $\mathcal{X}_{\text{goal}}$ then
10: \hspace{3em} return SUCCESS and the motion to $x_{\text{new}}$
11: \hspace{2em} end if
12: \hspace{1em} end if
13: end while
14: return FAILURE
RRT: Lunar Lander

Check out Steven Lavalle’s RRT Gallery: [http://msl.cs.uiuc.edu/rrt/gallery.html](http://msl.cs.uiuc.edu/rrt/gallery.html)
Summary

• Given an initial state and a desired final state, motion planning provides us with tools to find a time horizon and a sequence of actions to find a trajectory that reaches the goal without collisions.

• A roadmap path planner uses a graph representation of free space, which can then provide a trajectory using search algorithms.

• The basic RRT algorithm is a sampling-based method that grows a single search tree from start to find a motion to goal:
  • Uses a local planner to find a motion from the nearest node to the sampled node.
A few things that might be useful to know

• What are some key properties of planners?
• Think about what applications some properties or types of planners might be needed.
• If given a very simple graph, can you find the shortest path?
• Be somewhat familiar with the pros and cons of the planners we just discussed.
Course Recap

1. Linear algebra and diff. eq. review
2. DoF, configuration space
3. Rigid body motion & transformations
4. Screw theory
5. Forward Kinematics
6. Velocity Kinematics
7. Inverse Kinematics
8. Dynamics
9. Motion Planning
Environment & Agent Models

Sensors

Perception

Decision-Making

Trajectory Planning

Low-level Control

Compute Platform

Simulation & Validation
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<th>If you liked...</th>
<th>Try this!</th>
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<tr>
<td>Everything!</td>
<td>ABE 424 Principles of Mobile Robotics</td>
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<tr>
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<td>ECE 484 Principles of Safe Autonomy</td>
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Graduate-Level Topics Courses

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<tr>
<td>ECE 598SG Learning</td>
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<td>ECE 598HCR Human</td>
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| **Everything!** | ABE 424 Principles of Mobile Robotics  
ECE 484 Principles of Safe Autonomy |
| Linear Algebra  | MATH 415 Applied Linear Algebra  
ECE 515 / ME 540 Control System Theory and Design |
| Sensing and State Estimation | ECE 310 / 417 Signal Processing  
ECE 437 Sensors and Instrumentation  
ABE 424 Principles of Mobile Robotics |
| Robot Kinematics | ECE 489 / ME 446 / SE 422 Robot Dynamics and Control  
CS 498 Robot Manipulation and Planning |
| Rigid Body Motion | SE 598 Soft Robotics  
ECE 549 Computer Vision |
| Control | ECE 486 Control Systems (or equivalent in your department)  
ECE 515 / ME 540 Control System Theory and Design |
| Decision-Making | ECE 448 Introduction to AI  
CS 446 Machine Learning |
| Planning | CS 498 Robot Manipulation and Planning |
| Labs | SE 423 Introduction to Mechatronics |
| Graduate-Level Topics Courses | ECE 598SG Learning-Based Robotics  
ECE 598HCR Human-Robot Interaction  
ECE 598JK Humanoid Robotics  
CS 598 Advanced Computational Robotics |