CS 460/560
Introduction to Computational Robotics
Fall 2019, Rutgers University

Course Logistics

Instructor: Jingjin Yu (jingjin.yu@cs.rutgers.edu)

Logistics, etc. – General

Lectures: Wed 12-1:20pm, Fri 1:40-3pm, SEC 111

Instructor: Jingjin Yu (https://arc.cs.rutgers.edu)

Email: jingjin.yu@cs.rutgers.edu

Email subject line should include 460 or 560 to reach my inbox; otherwise your email may go to in spam/junk.

Office: Hill 277 (may change, always check the webpage below)

Office hours: 2-4pm Wednesdays

TAs (office hours TBD):

Siwei Feng (siwei.feng@rutgers.edu)

Baichuan Huang (baichuan.huang@rutgers.edu)

Static page: https://arc.cs.rutgers.edu/courses/f19/460.html

Logistics, etc. – Reference Texts - Downloadable

[IAMR] Introduction to Autonomous Mobile Robots, 2nd Edition

Roland Siegwart, Illah Reza Nourbakhsh, Davide Scaramuzza

[MR] Modern Robotics: Mechanics, Planning, and Control

Kevin M Lynch and Frank C. Park

[PA] Planning Algorithms

Steve LaValle

[PRMTAI] Principles of Robot Motion:Theory, Algorithms, and Implementations

Howie Choset, Kevin M. Lynch, Seth Hutchinson, George A. Kantor, Wolfram Burgard, Lydia E. Kavraki, Sebastian Thrun

Logistics, etc. – Course Work and Grading

HW + MP: 6-8 sets total, every set carries equal weight (total 55%)

MPs will use mainly **python**; we may have minor hardware project(s), depending on class progress and hardware readiness

Late HW/MP is accepted with 20% daily late penalty

HW and MP can be done by **groups of size of up to 2**

Midterm: time TBD, likely on 10/11 or 11/06 (20%)

Final: Thursday, December 19, 8am-11am (20%)

Participation: class (5%)

For 560, PhD students may choose to do a research project instead of doing exams. Interested students should inform me by 09/15. Must decide (choose one) before 10/01. By default, I assume exams

Logistics, etc. – Ways to do Well

460 and 560 will have different curves

460: A – 85%, B+ – 80%, B – 75%, C+ – 70%, C – 60%

560: A – 87.5%, B+ – 82.5%, B – 77.5%, C+ – 70%, C – 60%

These cutoffs may be adjusted lower but not higher

For 460, the top 10% students by exam score in either the midterm or the final will automatically receive an A, regardless of HW/MP/participation. Top 20% will automatically get at least a B+. Note that I will not disclose where you place in the midterm; I will only disclose quartile cutoff lines (e.g., 25%, 50%, 75%).

This "exam exception" is to encourage students to actually do the HW/MPs by themselves to truly understand the material. You **will do well in the exams** if you work out the detail in HW and MPs. I hope you all get As!

Logistics, etc. – Recitations

10-12 sessions on course materials, robotics software and (possibly some) hardware.

Some selected topics other than course materials:

- ⇨Python intro
- ⇨3D-printing get started (we will print a small item for you)
- ⇨Robotic operating systems (ROS) intro
- ⇨ROS simulation intro

Will begin in the 2nd week (python intro)

Participation is optional, but

⇨Attendance counts toward the 5% participation credit

⇨Some materials may appear in exams

Logistics, etc. – Placement of CS 460/560

Placement of CS 460/560 with respect to other robotics courses (in preparation)

CS 460/560: Computational Foundations of Robotics, Fall

- ⇨Introductory, mobile robotics focus
- ⇨With some experimental exposure

CS (561?): Algorithmic Foundations of Robotics, Spring

- ⇨Advanced, algorithmic focus with more theory coverage
- ⇨Covers mobile robots and kinematic chains (e.g., manipulators & humanoids)
- ⇨I expect to teach one seminar course similar to this in the Spring

CS (562?): Bio-Inspired Robotics, Spring

- ⇨With a focus on bio-mechanisms, neuroscience, and learning

Logistics, etc. – Course Outline

Expected core material (12-13 weeks excluding exam and travel)

- ⇨~1 week on logistics/introductory material
- ⇨~1.5 weeks on background material (mathematical foundations)
- ⇨~2 weeks on sensing and perception
- ⇨~6 weeks on planning and decision making
- ⇨~2 weeks on actuation and control

I expect to travel on 10/09, 10/11, 11/06, and 12/06

- ⇨10/11 or 11/06 will be midterm
- ⇨Hopefully, I will have someone fill in for me

Questions?

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Lecture 00
Summary of Topics

Instructor: Jingjin Yu (jingjin.yu@cs.rutgers.edu)

Introduction

Why study robotics? What is a robot?

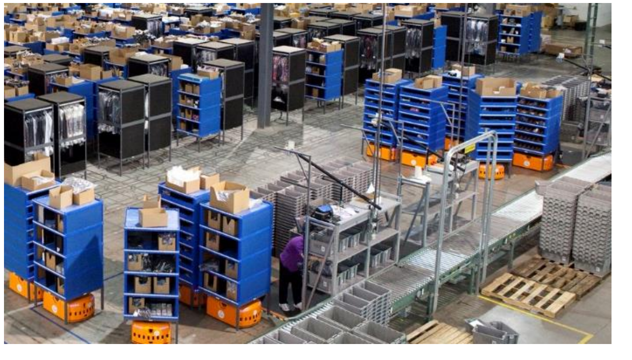
Brief history of robots

Types of robots and their applications

- ⇨Industrial
- ⇨Transportation
- ⇨Home
- ⇨Medical
- ⇨Agriculture
- ⇨Social and entertainment
- ⇨...

The main components of robots

- ⇨Sensing
- ⇨Computation
- ⇨Actuation



Mathematical Foundations

Quick review of sets, functions, etc.

Transformations

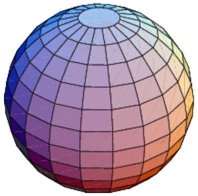
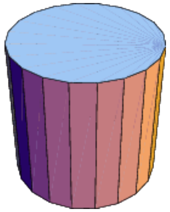
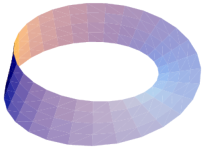
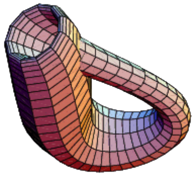
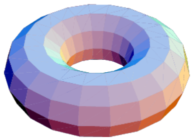
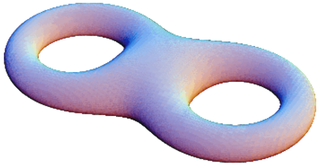
Group concepts

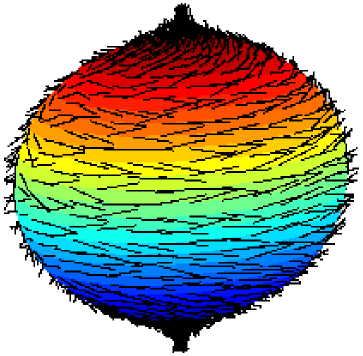
Fun topological concepts

- ⇨Topological spaces
- ⇨Fixed-point theorems (continuous, discrete)
- ⇨Hairy ball theorem

Manifolds

Metric spaces

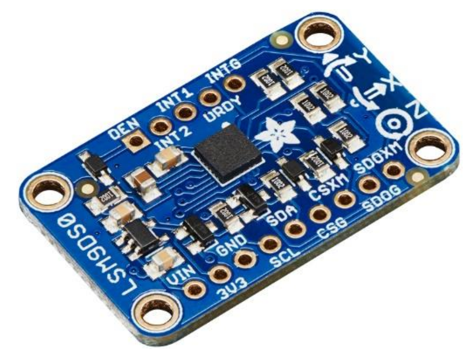









Sensors

Real sensors and their mechanism

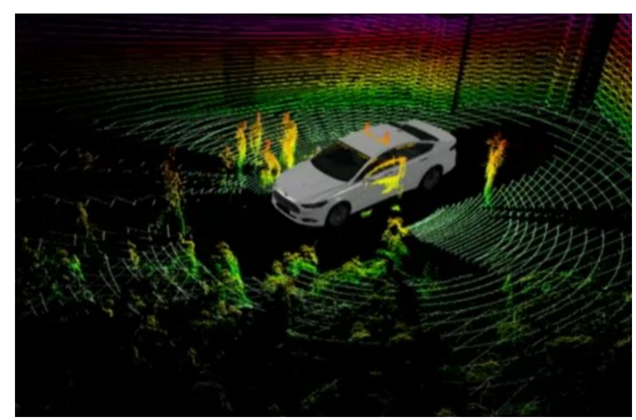
- ⇨Compass
- ⇨Encoders
- ⇨Accelerometers, gyroscope, magnetic field sensor, IMU
- ⇨IR sensors, active and passive
- ⇨Laser scanners
- ⇨Cameras



Virtual and abstract sensors

- ⇨Heading sensors
- ⇨Distance sensors
- ⇨Object counters
- ⇨….

Sensor mapping



State Estimation

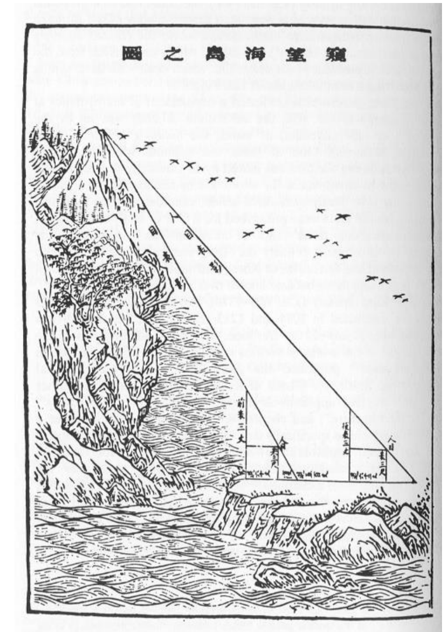
Localization techniques

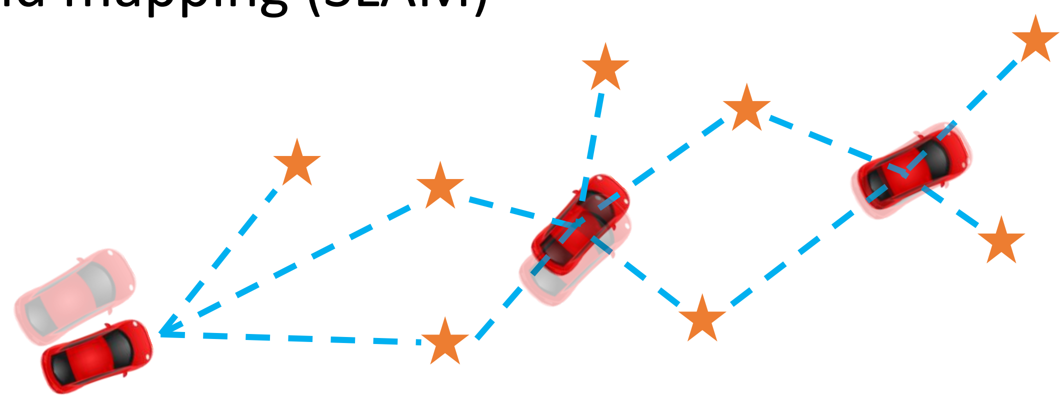
- ➪Triangulation, trilateration, etc
- ➪GPS mechanisms
- ➪Other localization methods

State estimation

- ➪Kalman filters
- ➪Extended Kalman filters (EKF)
- ➪Particle filters
- ➪Combinatorial filters

Simultaneous localization and mapping (SLAM)

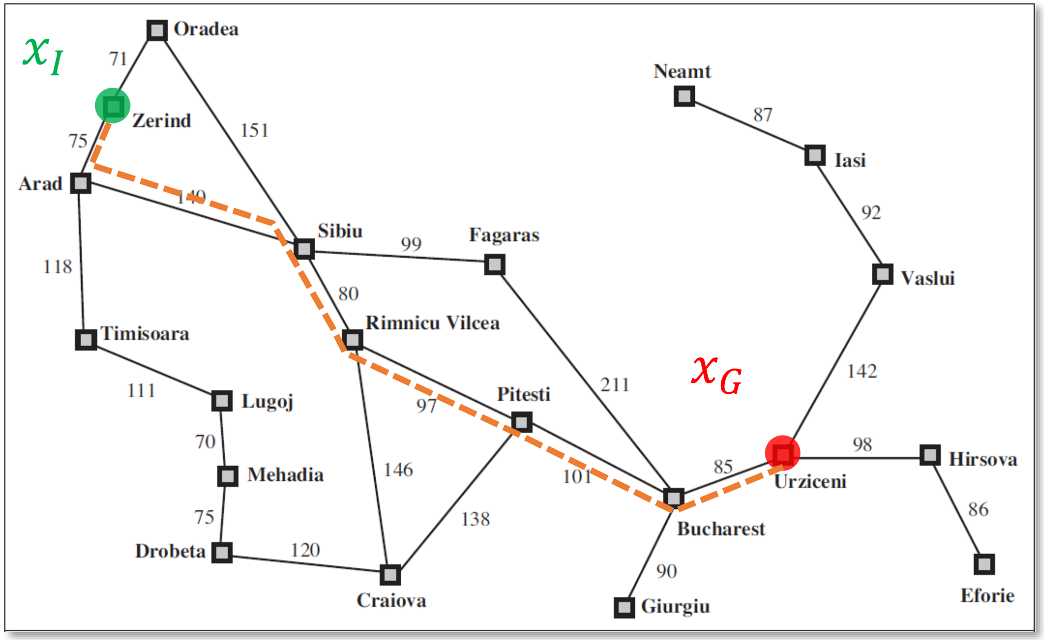




Discrete Planning Review and Extensions

Review of classical graph search algorithms

- ⇨DFS, BFS, uniform-cost, A*
- ⇨All pairs shortest path
- ⇨D* and D*-lite
- ⇨Dynamic programming



Combinatorial Motion Planning

The configuration space

⇨Minkowski sum

Combinatorial planning methods

⇨Visibility graph and 2D shortest path

⇨Vertical cell decomposition

⇨Cylindrical algebraic decomposition

⇨Canny’s algorithm

⇨Complexity of motion planning

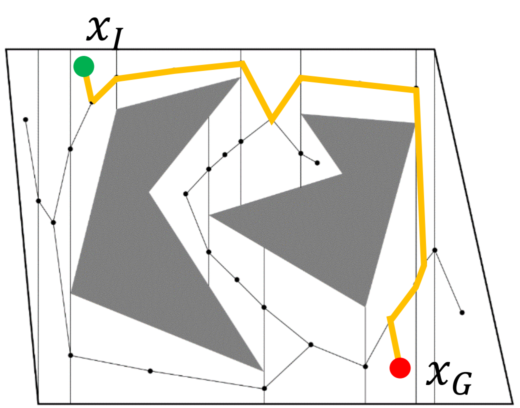
Extensions

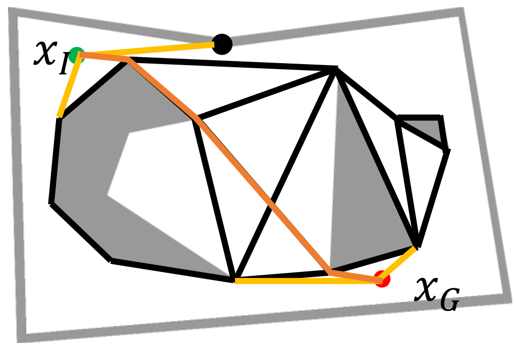
⇨Time varying obstacles

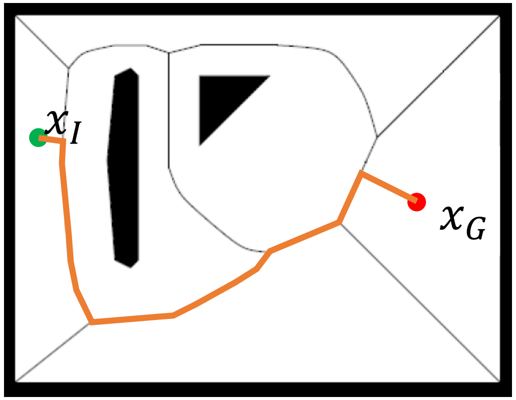
⇨Hybrid domain (discrete and continuous)

⇨Manipulation planning

⇨Coverage planning







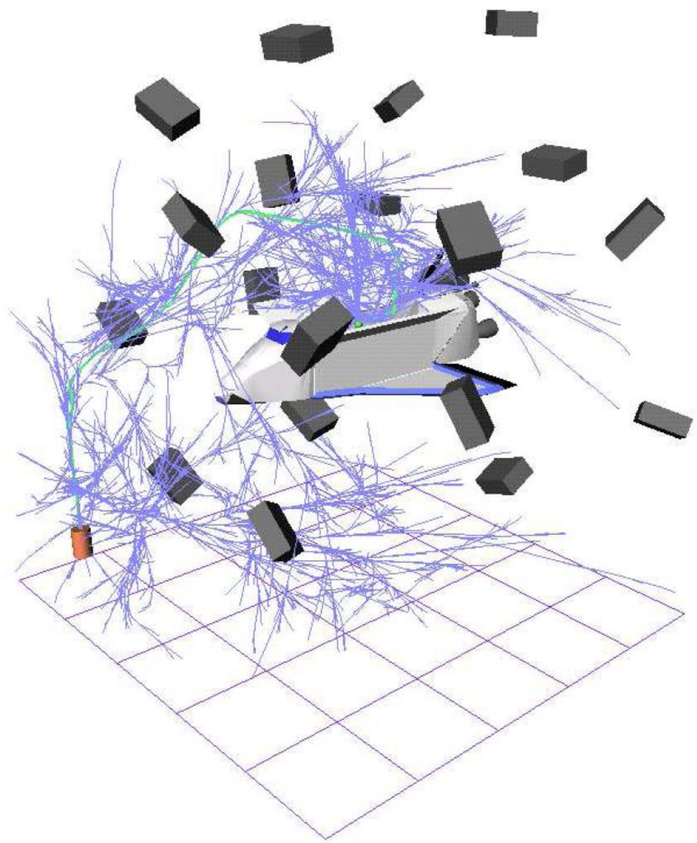
Probabilistic Motion Planning Methods

Sampling theory

Collision detector

Sampling-based planning methods

- ⇨Probabilistic road maps (PRM)
- ⇨Rapidly-exploring random trees (RRT)
- ⇨Optimal version (RRT*, SST)



Multi-Robot Path Planning

Feasibility

Optimal solutions for the discrete case

- ⇨Distinguishable robots
  - ⇨ Complexity
  - ⇨ A*-based methods
  - ⇨ Integer linear programming methods
- ⇨ Indistinguishable robots
  - ⇨ Network flow

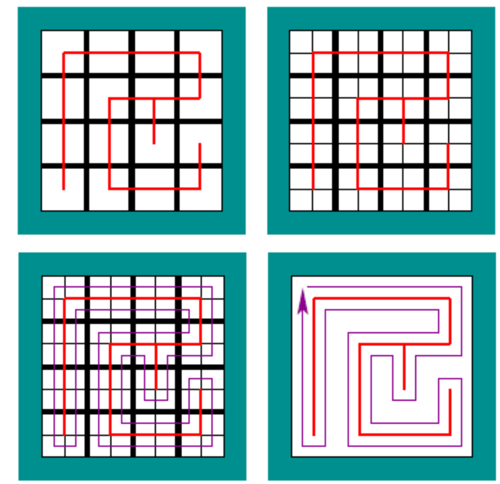
Continuous domains

Other Planning Methods

Feedback based planner, artificial potential field

Planning under differential constraints

- ➩Combinatorial methods
- ➩Sampling based methods

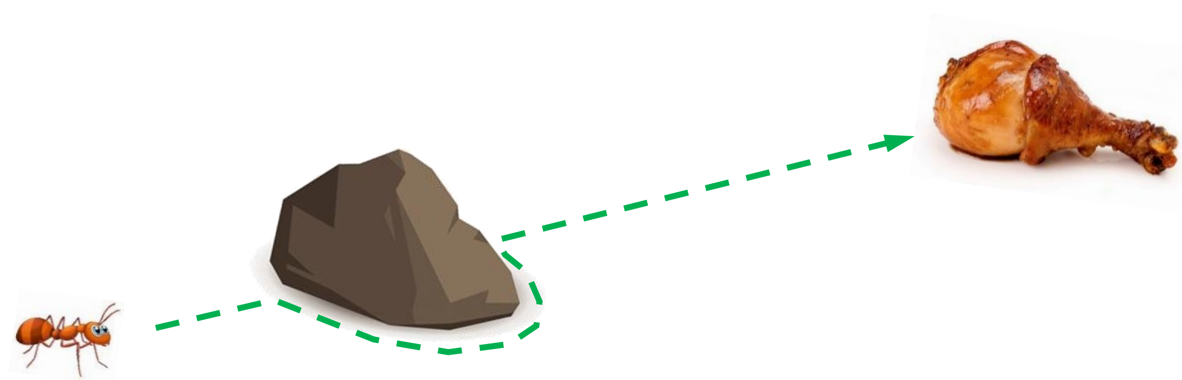


Minimalistic planning methods

- ➩Bug algorithms
- ➩Gap navigation trees
- ➩Nonprehensile manipulation

Planning under uncertainty

- ➩Discrete MDP
- ➩POMDPs



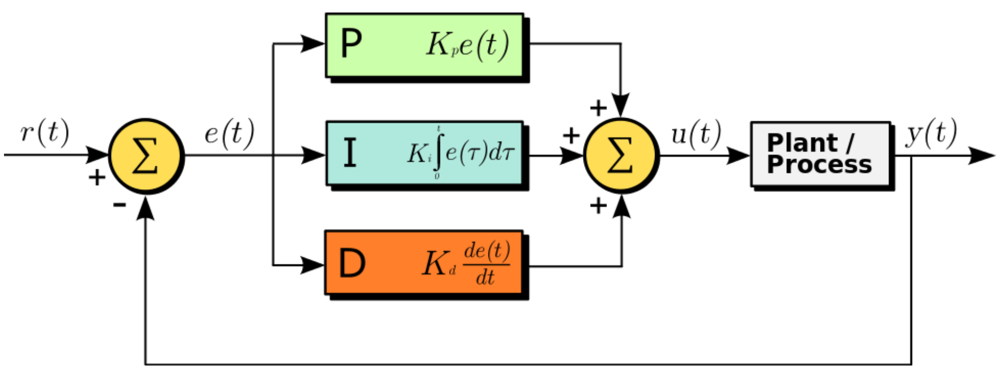
Control

Trajectory tracking, pure pursuit

PID control

Advanced topics (if we have time)

- ⇨Euler-Lagrange
- ⇨Dynamic programming and the maximum principle
- ⇨Controllability



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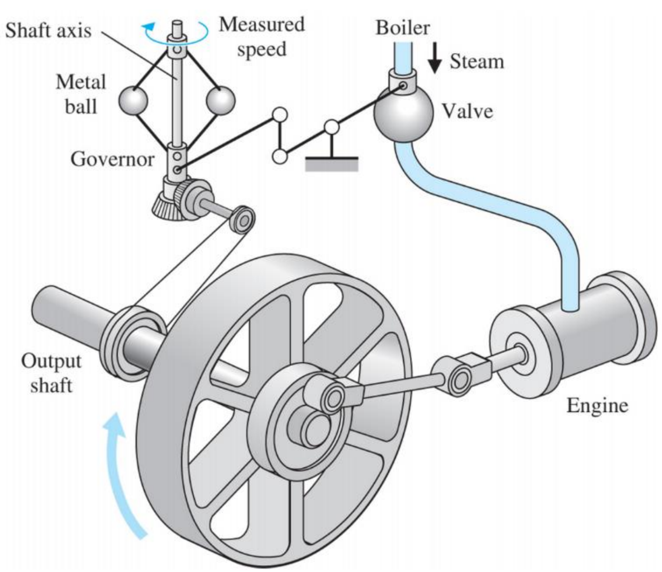

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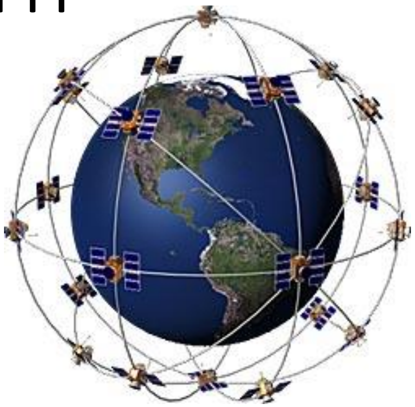
Computational Methods You Will Learn

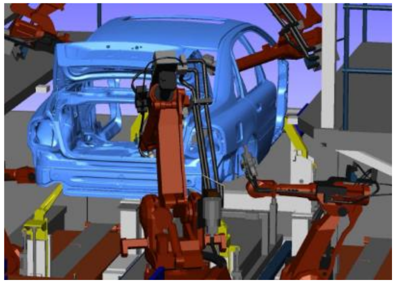
Example 1: How does GPS navigation work?

- ➩GPS hardware basics
- ➩Trilateration-based localization
  - ➩ One of your assignments…
- ➩Route planning



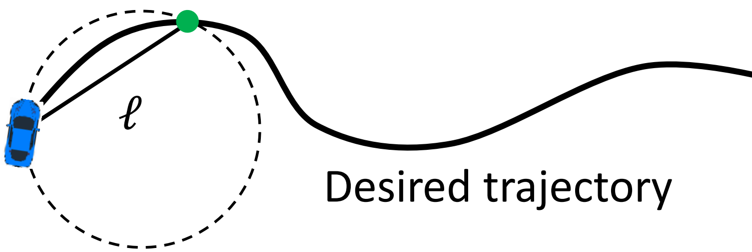
Example 2: How to move robots?

- ➩How to model rigid body motion
- ➩Algorithms for solving them



Example 3: How to actually control robots?

- ➩Autonomously moving a car?



A Word About Easy/Hard

Questions on robots
and robotics?