

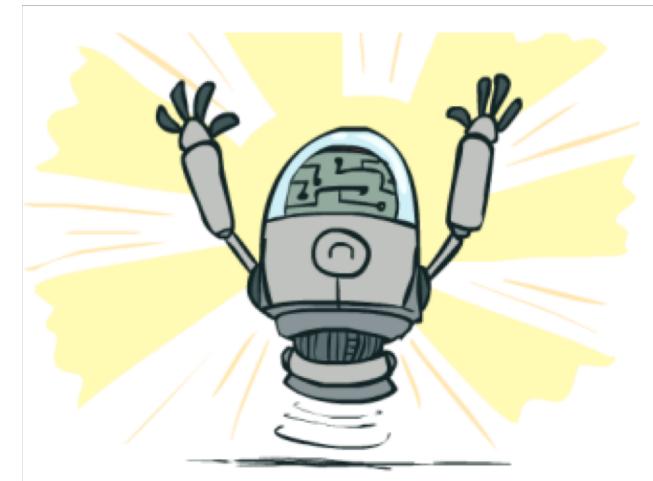
CS 1501: Intro to Robotics

Autonomy, AI, and Applications

The Last Lecture



Rohan Raval
Monday 1-1:50pm, MEC 213



Roadmap: Today's Lecture...

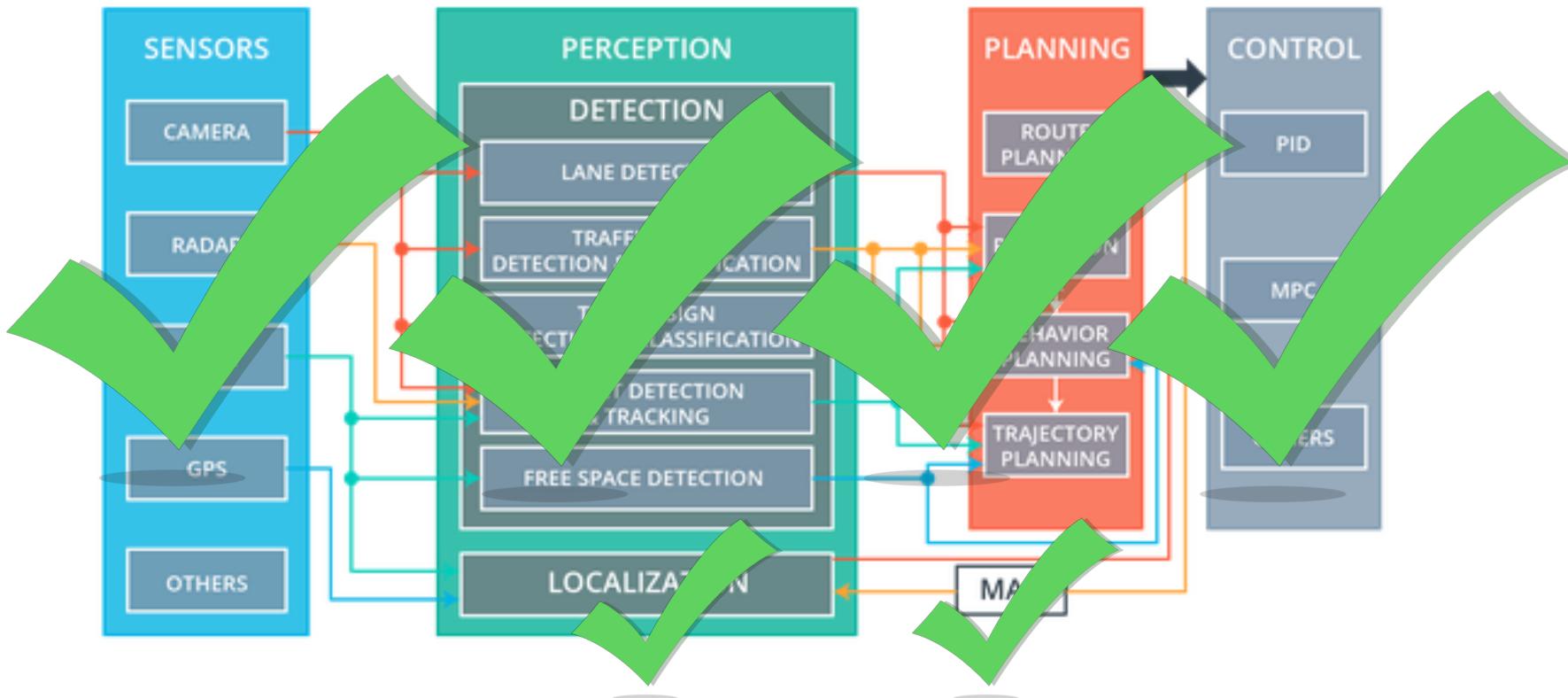
Goal: Where to go from here?

Topics:

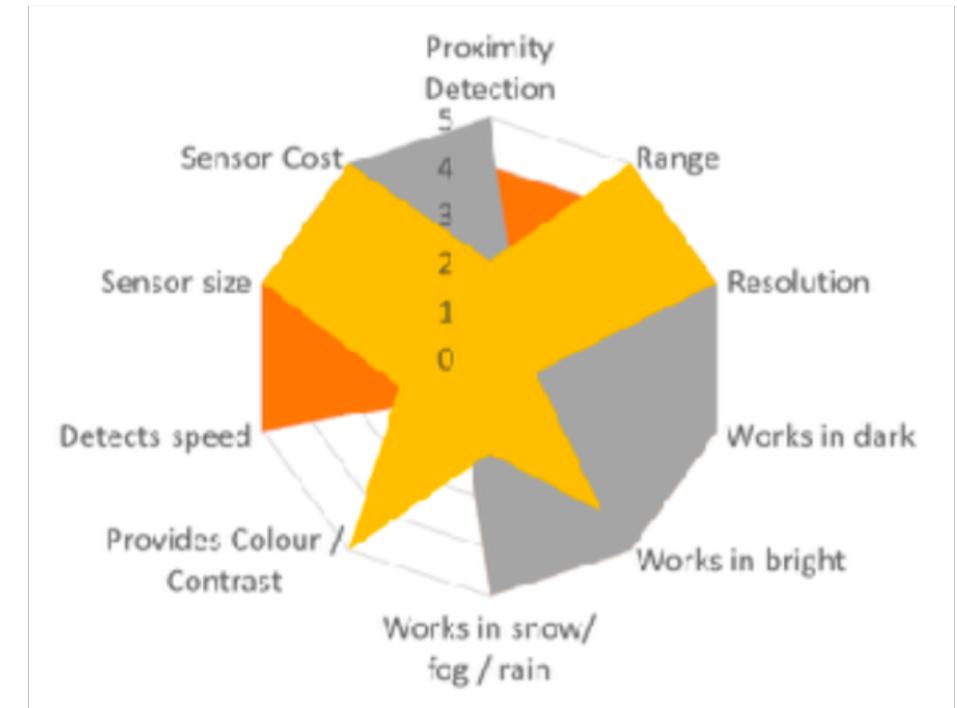
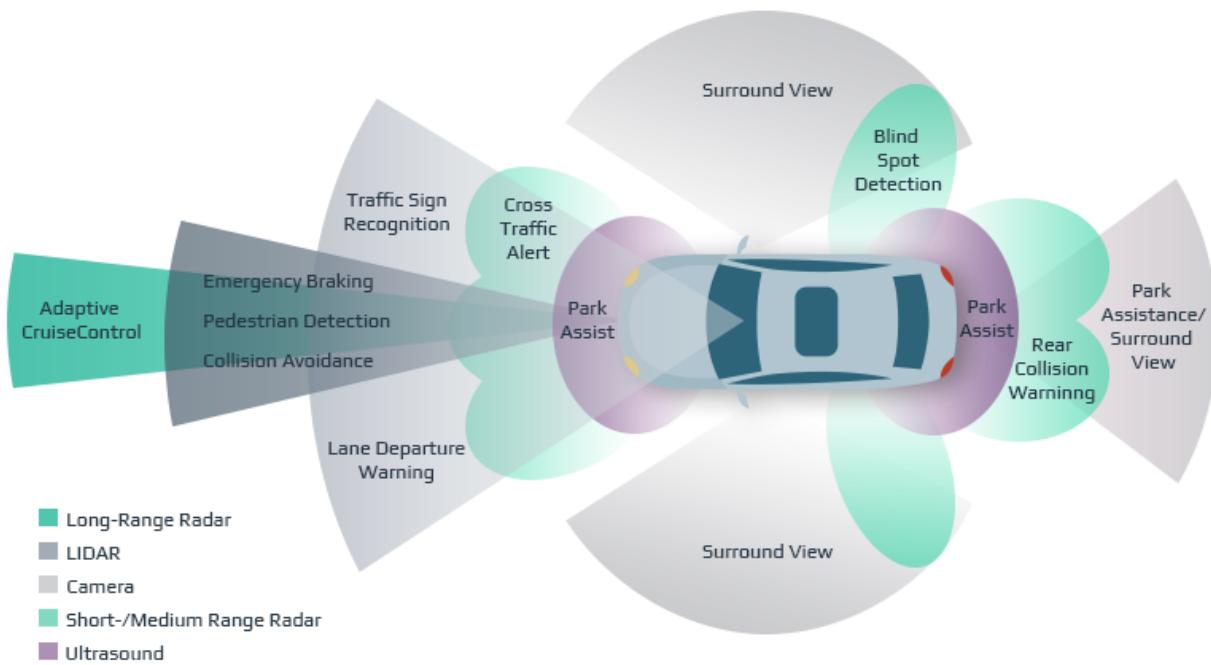
- The Past: Highlight Reel
- The Present: Today's Industry!
- The Future...
- Where do I go from here?
 - Software & Programming Languages
 - Classes and Higher Education
 - Other Resources
 - How to get a job...
- Closing Words

Recap: See-Think-Act

“a robot is a goal-oriented machine that can sense, plan and act”



Recap: Sensor Fusion



Recap: Camera vs LiDAR

Camera

- Better / more available data
- Better Computer Vision algorithms (active area of research)

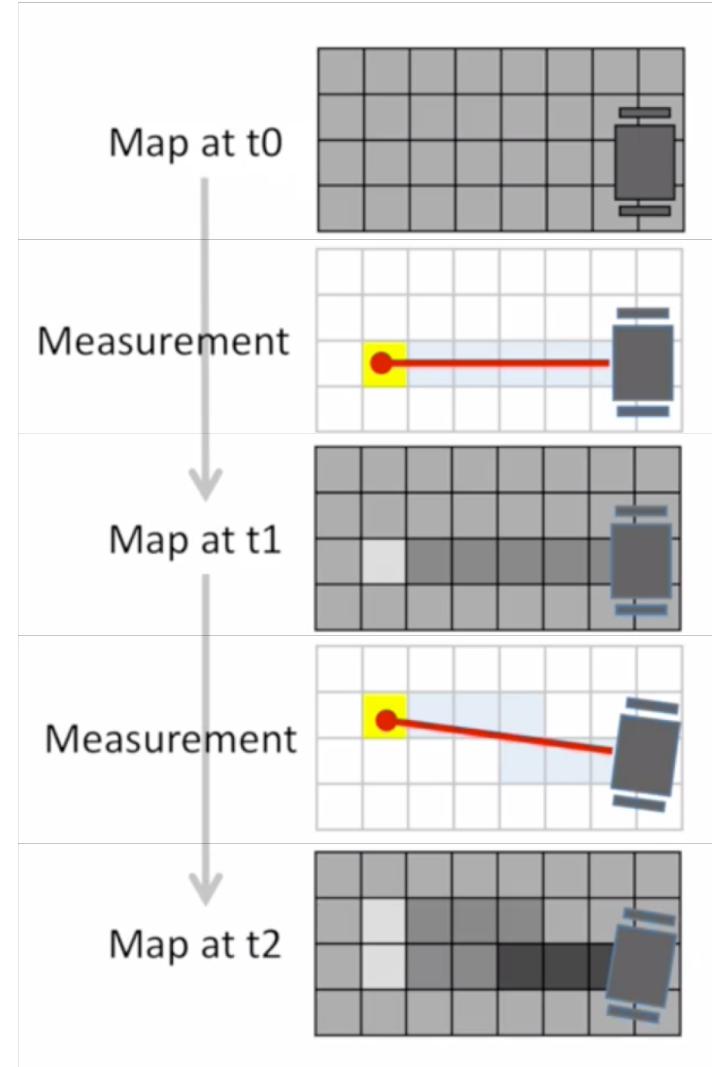
LiDAR

- Cheaper
- Increased range
- Upcoming... *Solid-State Lidar??*

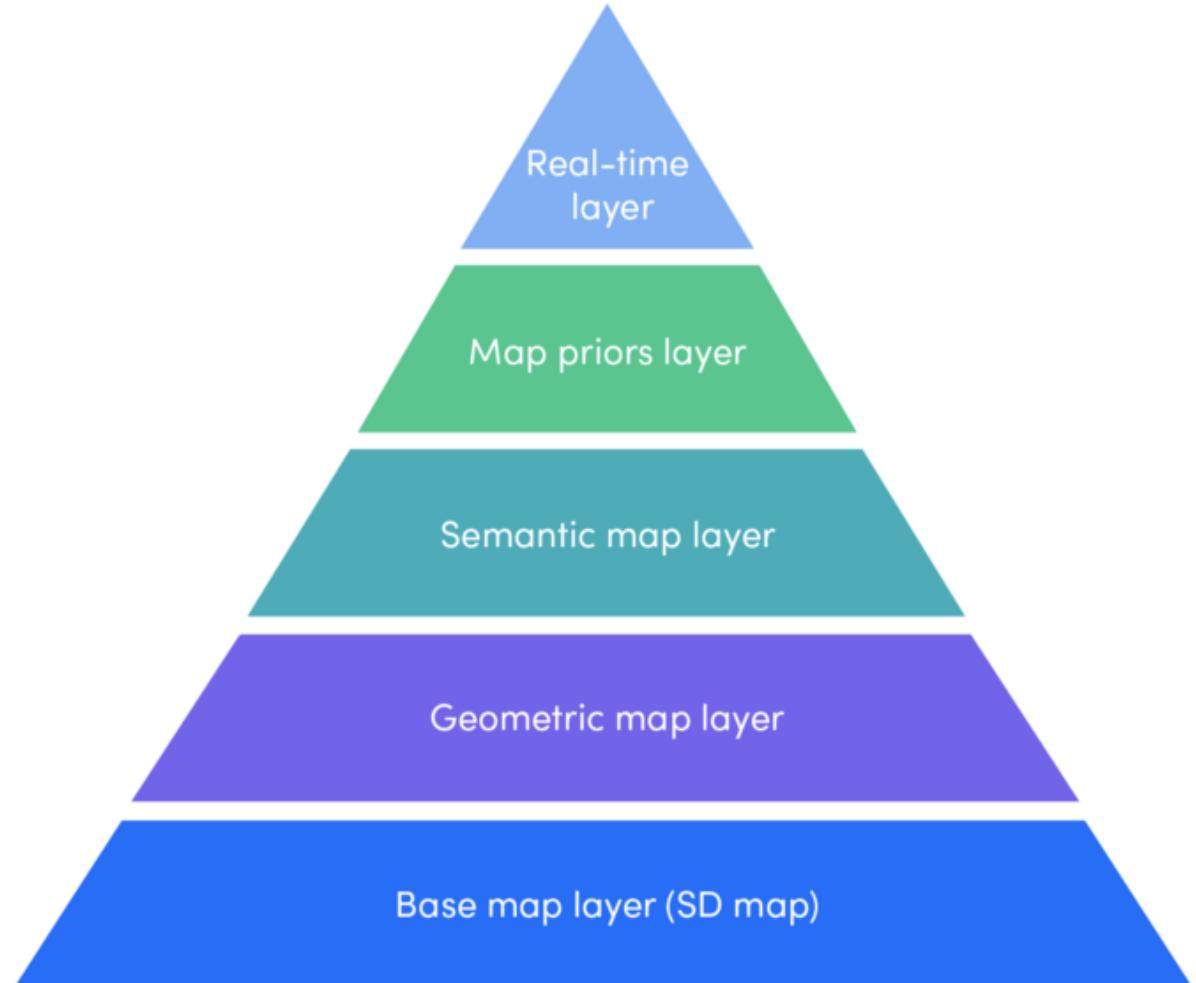
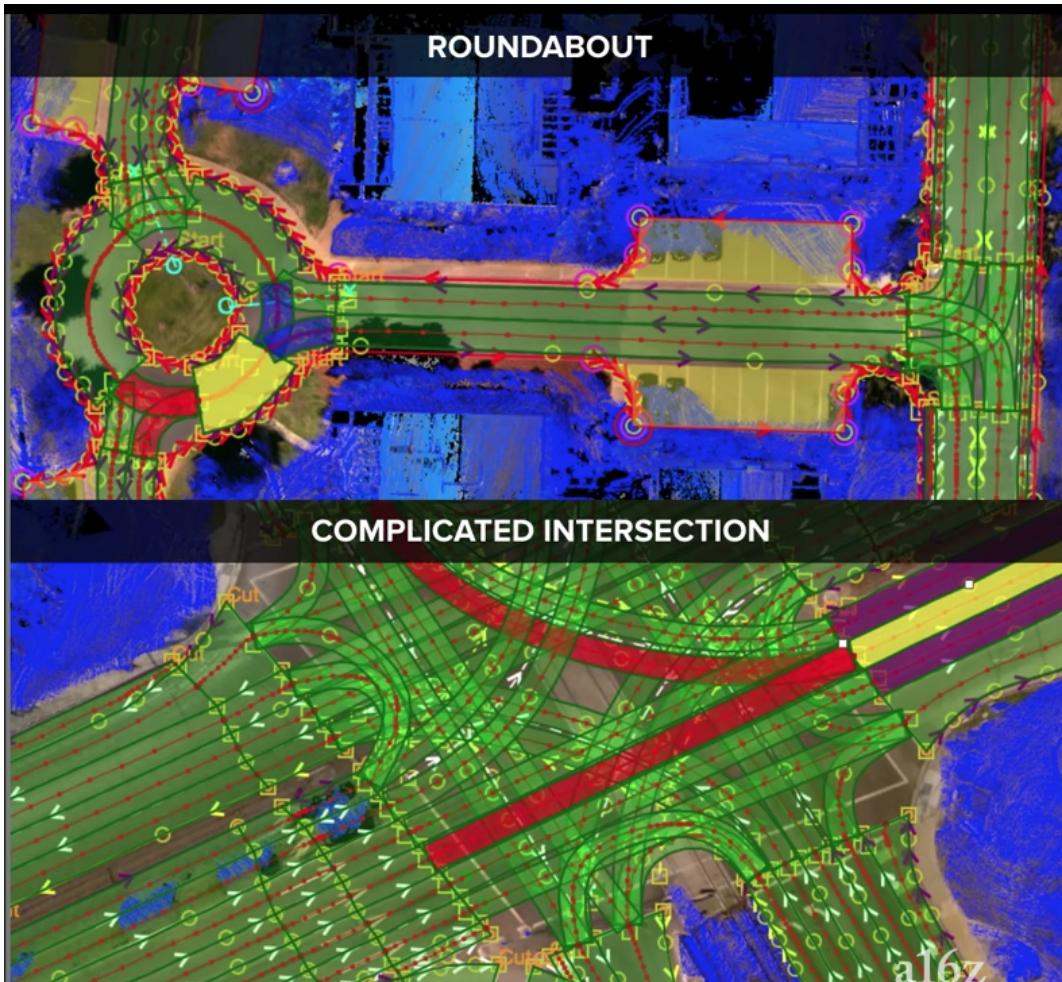


Recap: Maps

- Challenges of Maps
 - Dynamic Environment
 - Motion
 - Reference Frames: Robot to Global
- Occupancy Grid Mapping
 1. Prior Map
 2. Measurement
 3. Update (Posterior)
 4. Measurement
 5. Update (Posterior)
- HD Maps
 - Layered Maps
 - Storage and Retrieval

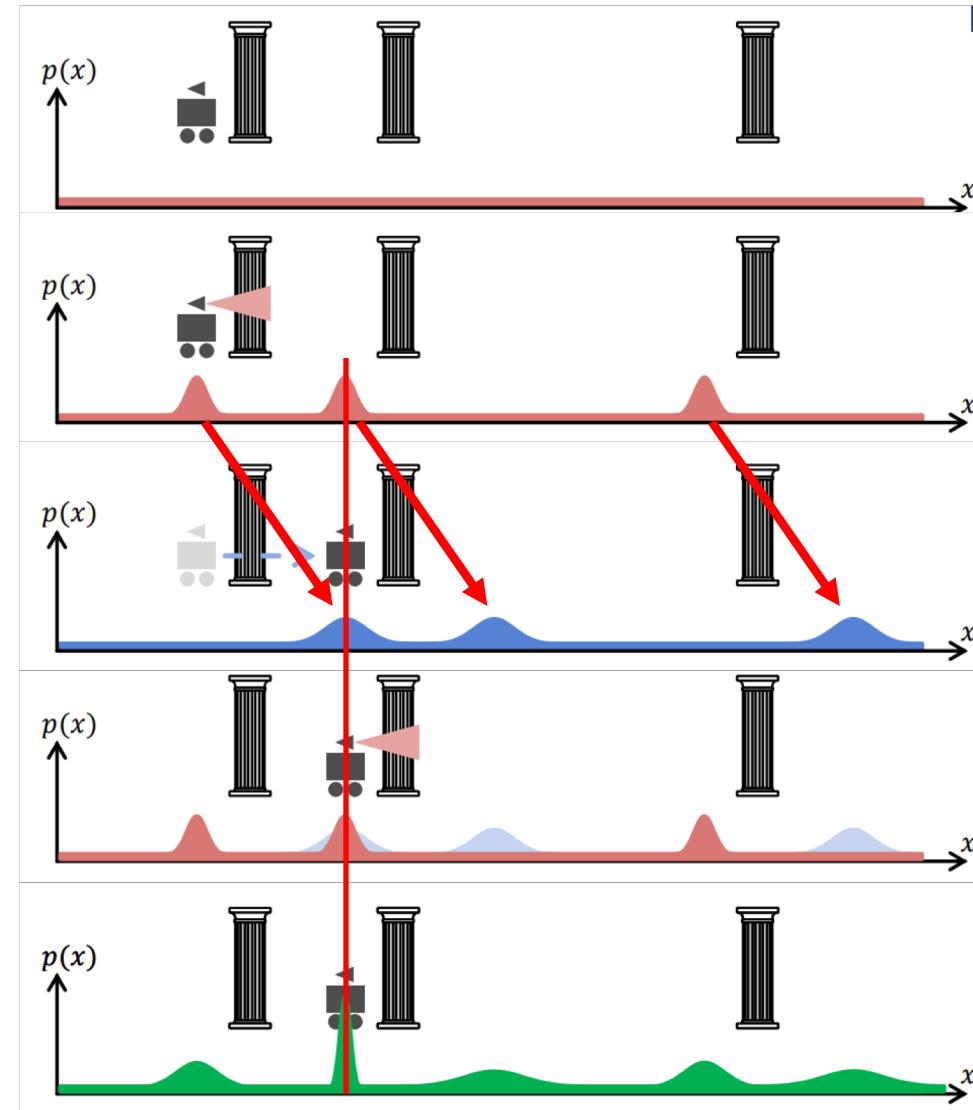


Recap: HD Maps

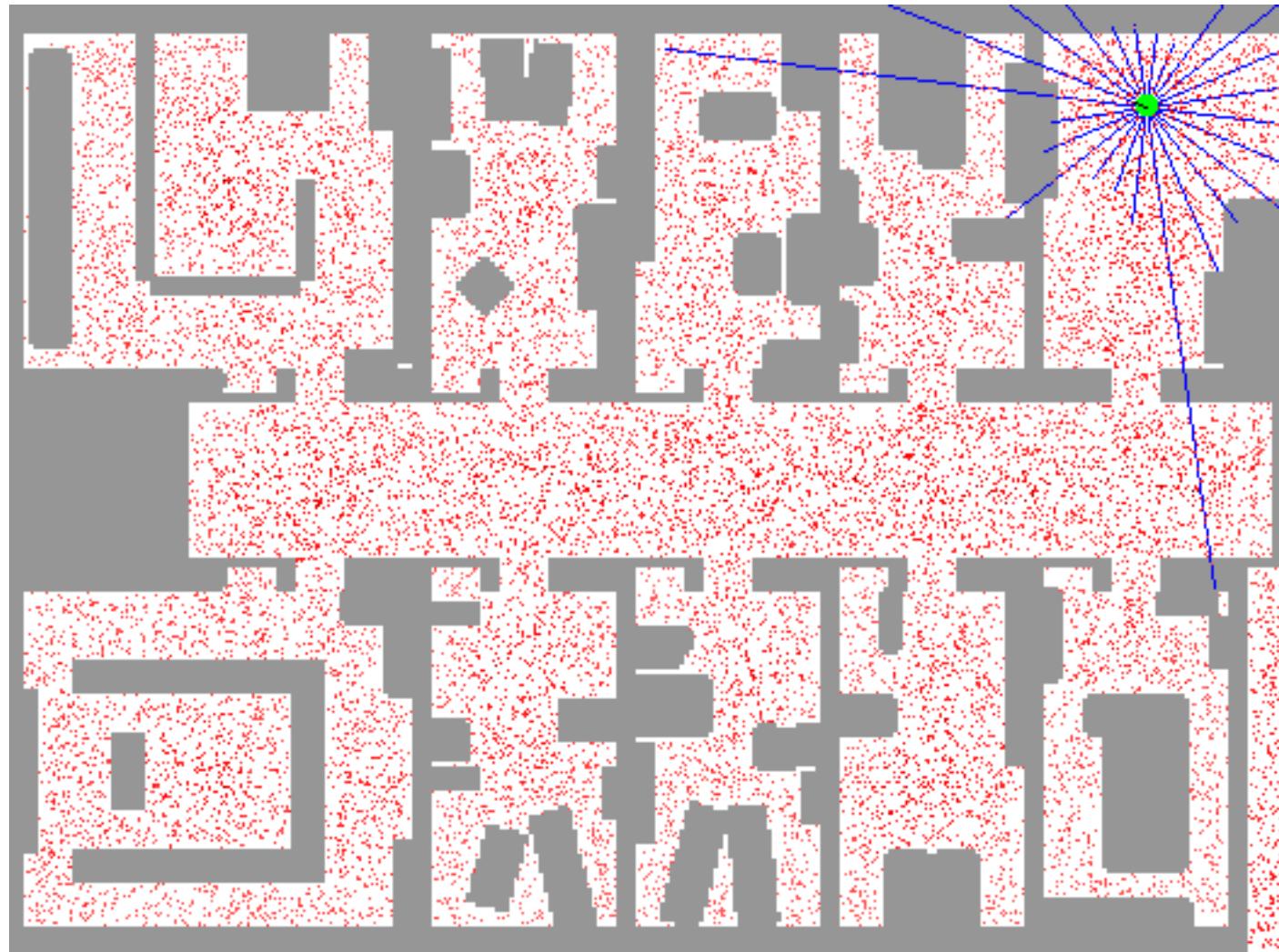


Recap: Probabilistic Localization

1. Initial Belief (Prior)
2. Measurement → Update
3. Move → Predict
4. Measurement → Update
5. Final Belief (Posterior)

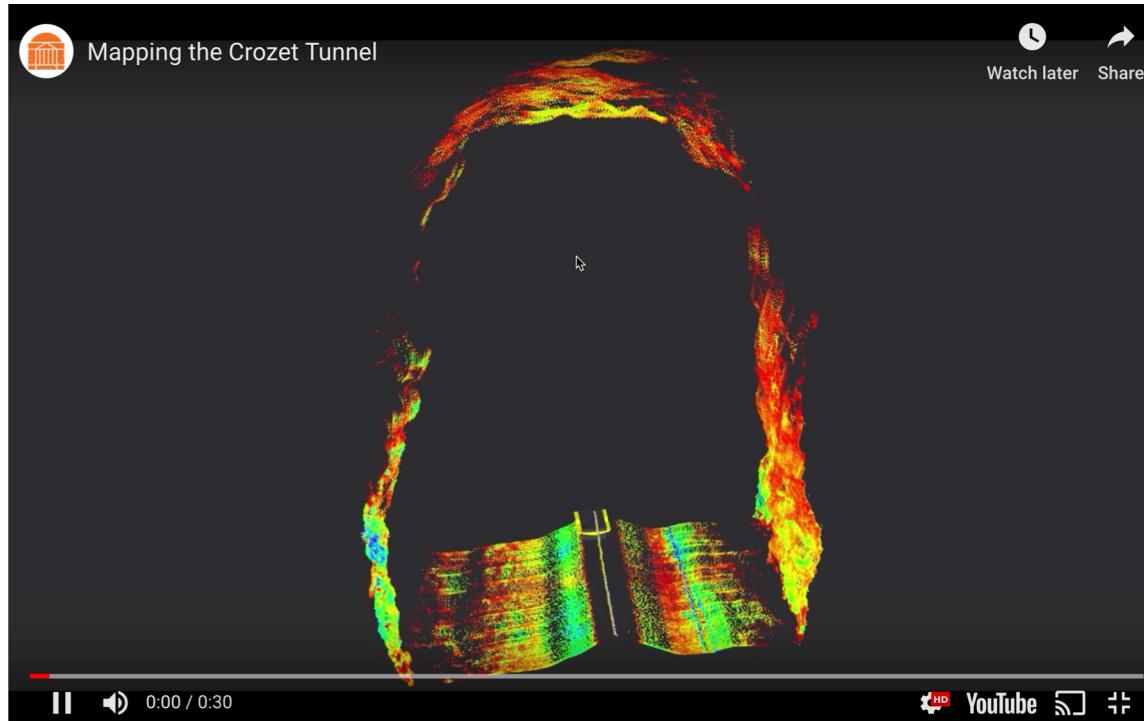


Recap: Particle Filter



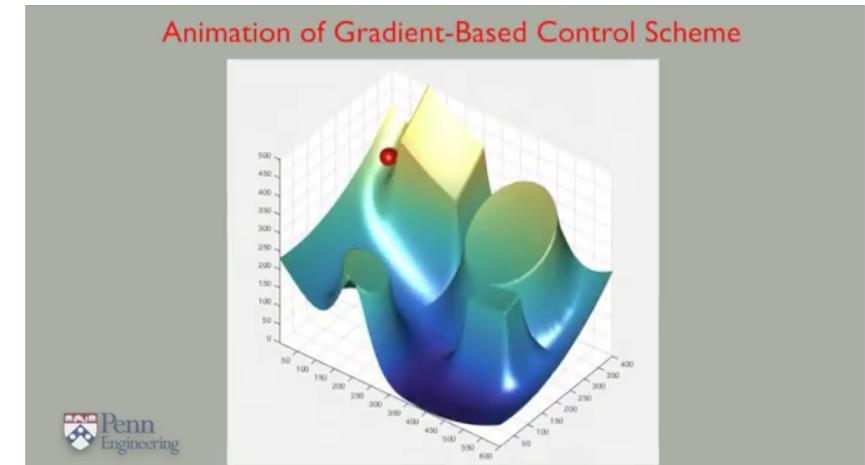
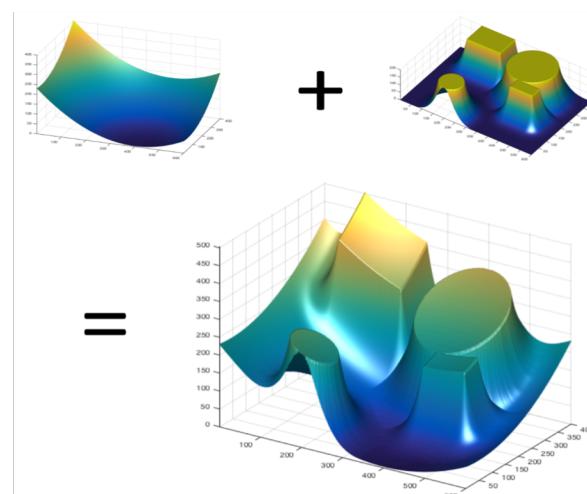
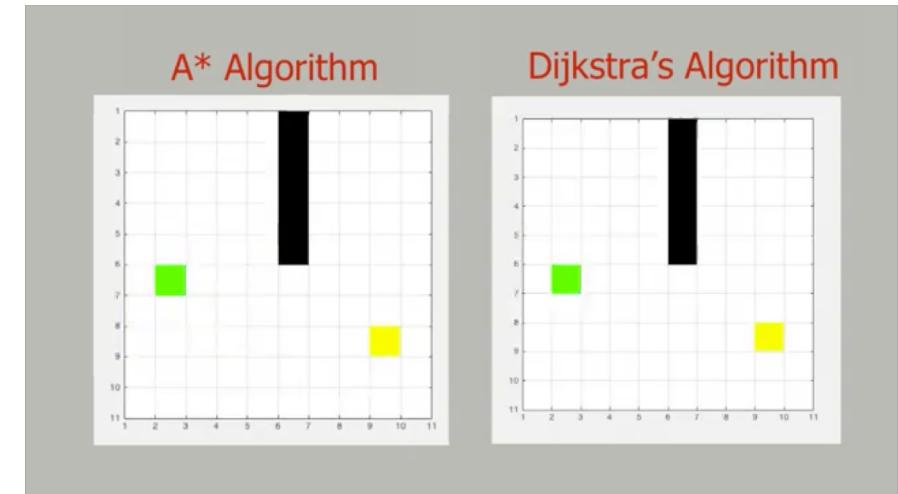
Recap: SLAM

SLAM = Simultaneous Localization and Mapping



Recap: Motion Planning

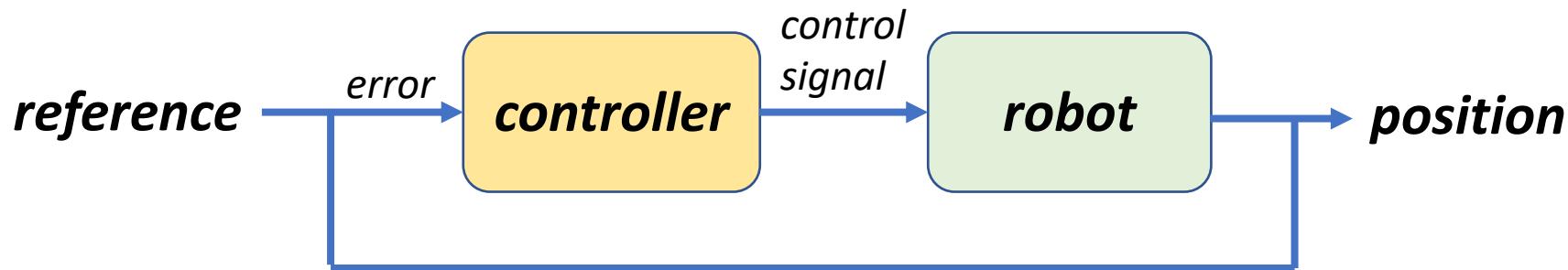
- Basics: BFS and DFS
- Dijkstra's Shortest Path Algorithm
- Heuristics
- A* Algorithm
 - Is it optimal? YES*
- Artificial Potential Fields!
 - Gradient Descent
 - Local Minima
 - Is it optimal?



Recap: Control Theory

Closed-Loop (Feedback) Control

Controller = creates a command (control signal u) to be sent to robot, calculated according to the error (e) deviation from the desired trajectory (r)

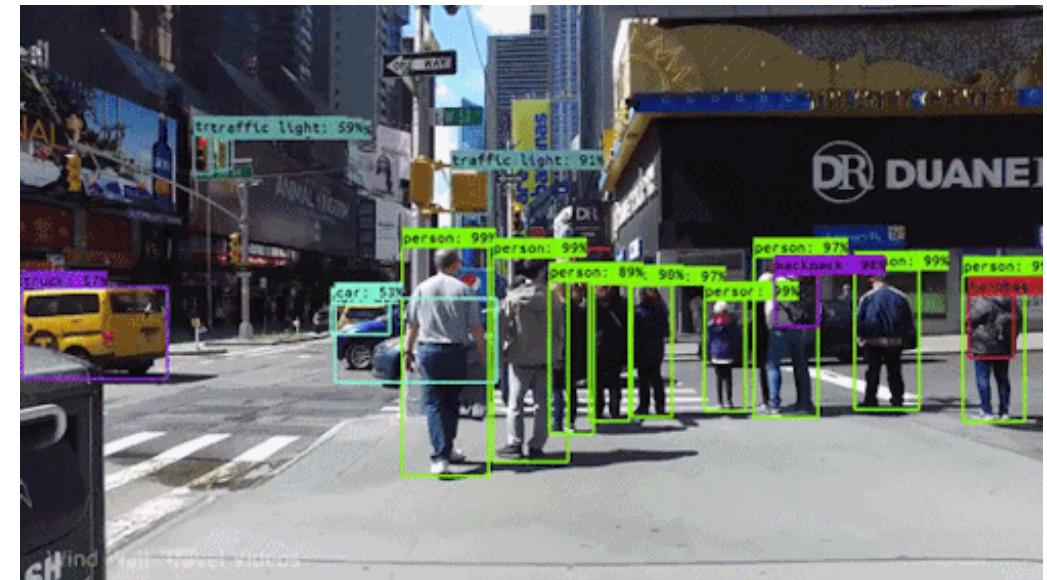
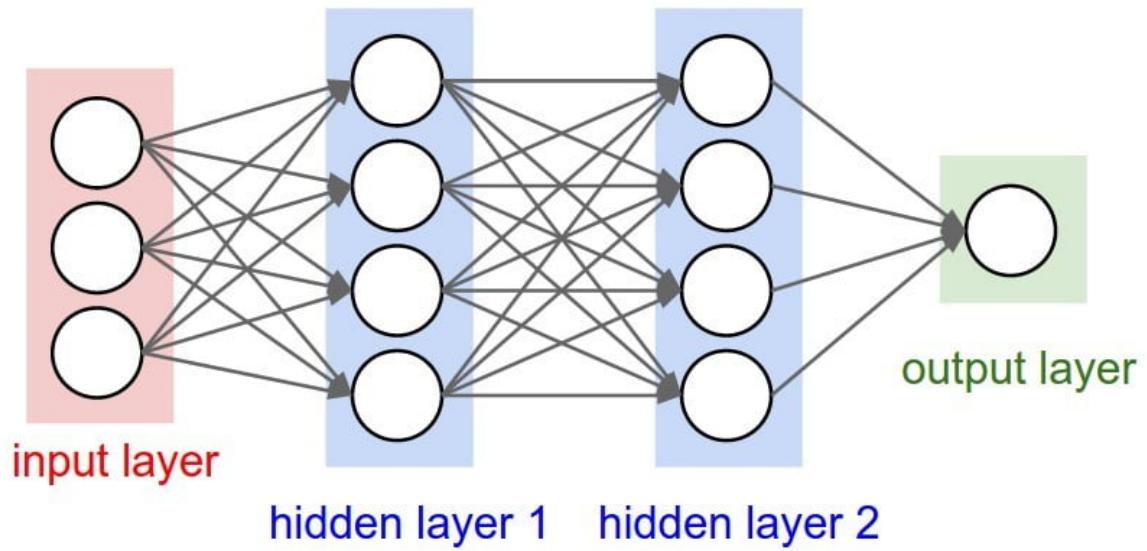


PID Controller

$$u(t) = k_P e(t) + k_I \int_0^t e(\tau) d\tau + k_D \frac{de(t)}{dt}$$

Recap: Perception

~ ~ ~ ~ *D e e p* ~ ~ ~ ~ Learning



The Real World: Self-Driving Cars

Big Tech

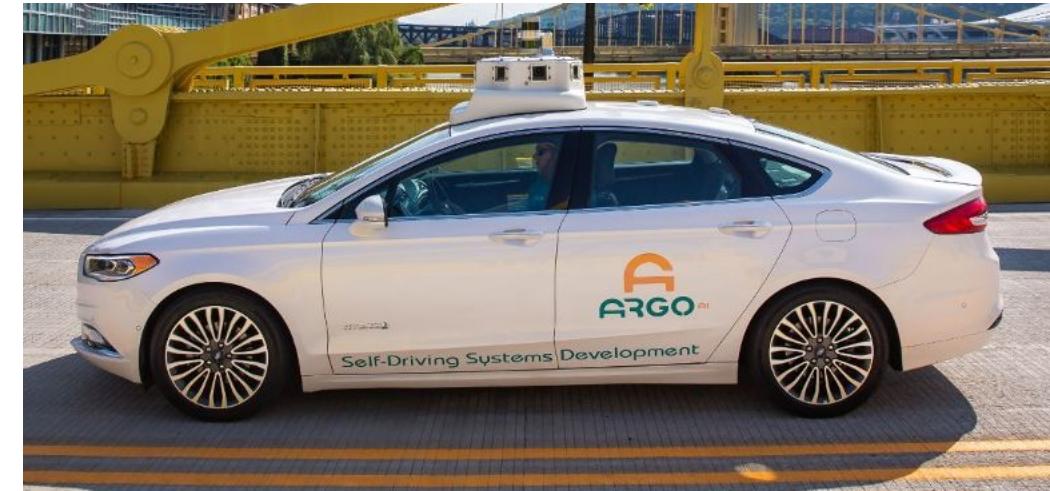
- Big Hitters:
 - Google (Waymo)
 - Uber (ATG)
- Honorable Mentions:
 - Lyft (Level 5)
 - Apple (Project Titan?)
 - Baidu
 - More to come...



The Real World: Self-Driving Cars

Automakers (OEMs)

- Big Hitters:
 - Tesla... “Full Self-Driving” HA!
 - GM (Cruise)
- Honorable Mentions:
 - Ford ([Argo.ai](#))
 - Daimler (Torc Robotics), Daimler-Bosch
 - Renault-Nissan-Mitsubishi
 - Toyota (TRI)



The Real World: Self-Driving Cars

Tech Startups (Vertical)

- Big Hitters:
 - Aurora (Amazon) – A+ team!
 - Zoox
- Promising
 - Voyage – retirement communities
 - Comma.ai – OPEN SOURCE!!!
 - Drive.ai
- Honorable Mentions:
 - Pony.ai, nuTonomy



The Real World: Self-Driving Cars

Tech Startups (Horizontal)

- Mapping
 - DeepMap
 - Carmera
 - LVL5.ai – crowdsourcing!
- Perception
 - DeepScale
- Simulation
 - Applied Intuition
- Other dimensions...

DEEPMAP



DEEPSCALE

 **CARMERA**

 **Applied Intuition**

The Real World: Other Awesome Projects

Self-Driving Trucks

- Daimler, Tesla...
- Embark, Starsky Labs, Pronto.ai, etc...



Delivery Robots

- Nuro
- Kiwibots, Starship Robotics – campus delivery
- Amazon (formerly Scout)



Drones

- Zipline – blood delivery, Skydio – camera, DJI, others...



The Real World: But Where?

San Francisco (Bay Area)

- Tech Capital of the World
- eNtrEpReNooorSherp
- Network Effects are important!



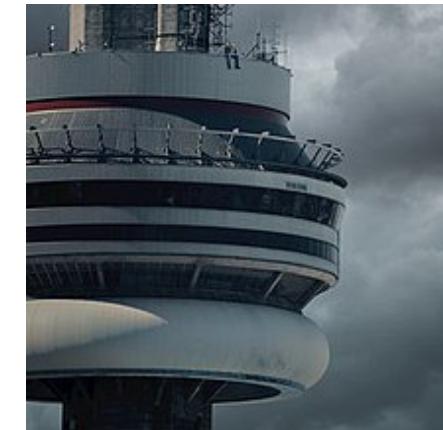
Pittsburgh, PA

- Research, R&D
- Where it all began...



Detroit, Toronto, Beijing, Munich, Bengaluru, others...

- Global, distributed teams with different strengths



The Future

Safety

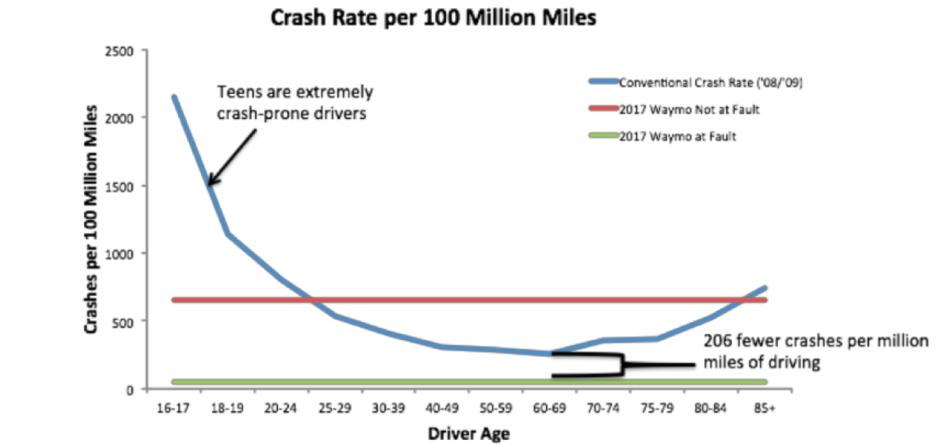
- Every 23 seconds... 😞

Accessibility

- Who's left out? How can we bring them in?

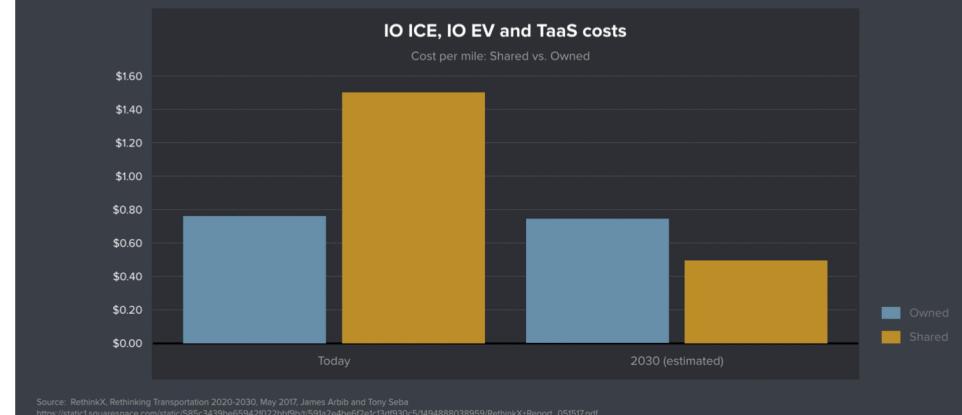
Electric + Ridesharing

human health, energy, and human productivity. In the United States alone 42,000 people die annually in nearly 6 million traffic accidents.⁹ Traffic jams account for 3.7 billion wasted hours of human time and 2.3 billion wasted gallons of fuel.⁹ And because of our strong emphasis on individual car ownership, cars are utilized less than 4% of their lifetime, wasting precious natural resources and space when not in use.



Electric + Self Driving = Travel as a Service

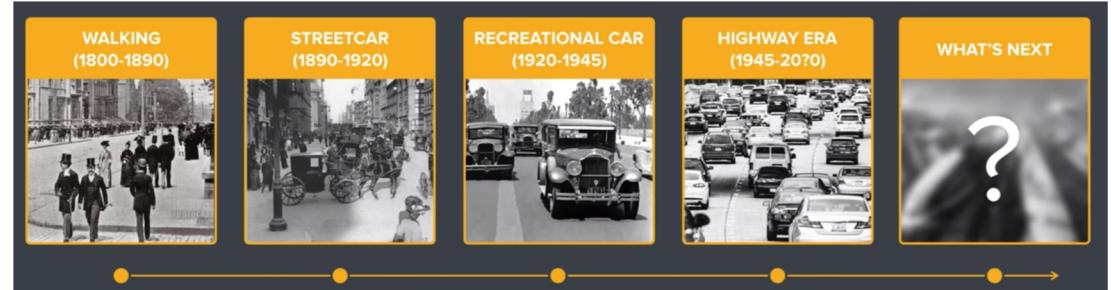
Costs drive us to electric, self-driving



The Future

Public Infrastructure

- Parking Lots... 14%
- Micro-mobility Solutions!



Form Factors

Business Models

- Proprietary vs Open Source?
- Incumbent vs Startup?
- Full-Stack vs Modular?
- LiDAR vs Camera?



“There’s been very few times in history...”

The Future: Big Questions

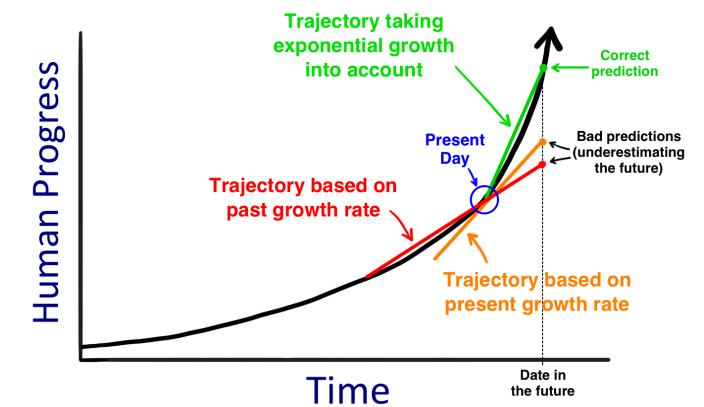
Will Self-Driving Cars take away our jobs??

- Yes and no
- What happened to all the typists?
- Long tail of adoption... jobs created
- Tradeoffs
- Increase technical/semi-technical roles



When will they be here?

- Kurzweil's Law
- "It took cars 50 years to replace horses so it will take AVs 50 years to replace cars"
- Cautious Optimism... we want to do it *right*
- Bubble?



What to Learn: Programming Languages

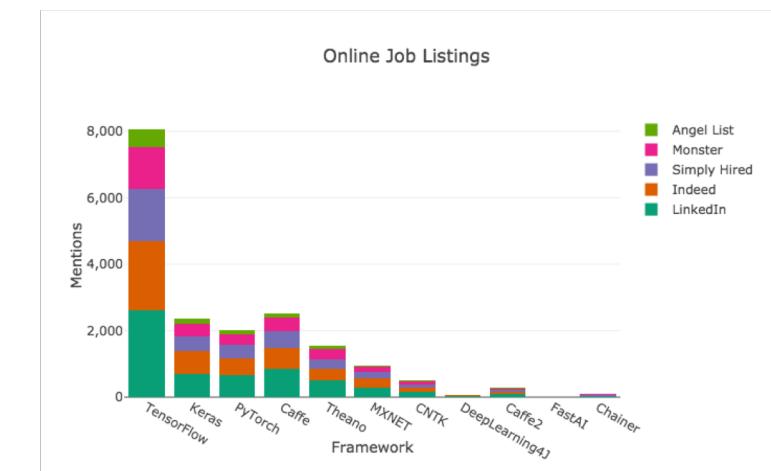
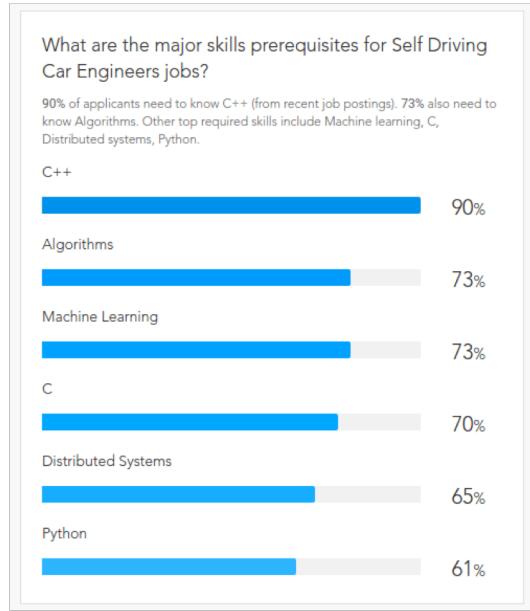
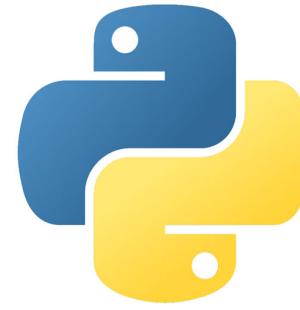
C++

- Highly optimized, super fast, low-level control
- Almost all AV companies use this...



Python

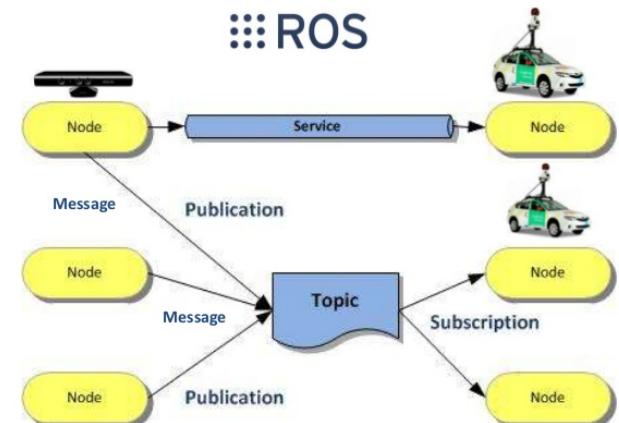
- Machine Learning
 - numpy, scikit-learn, pandas
- Deep Learning
 - TensorFlow, Pytorch, Keras, Caffe, ...



What to Learn: Frameworks and Tools

ROS (Robot Operating System)

- Peer-to-peer Communication
- Coordination, Time Sync, Shared Memory
- In-built Support and Libraries for Hardware Integration

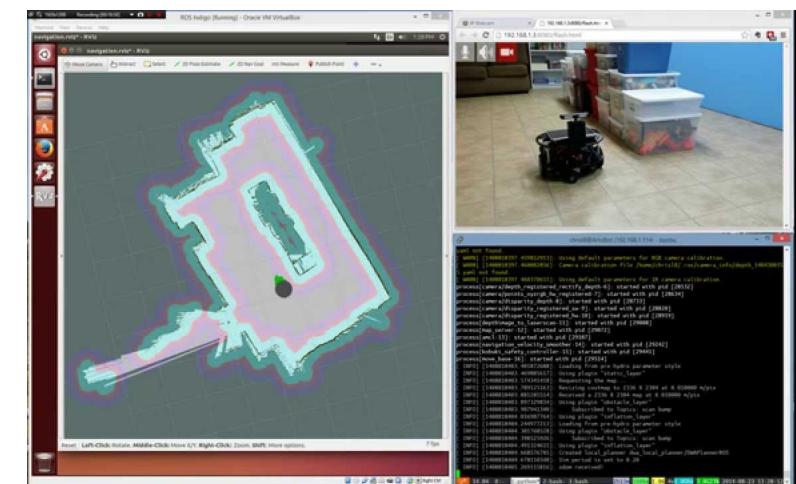
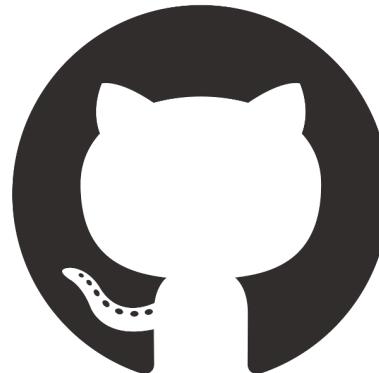


Linux Command Line

Git(hub)

MATLAB/Simulink

Cloud Tools – AWS, Hadoop/Spark, etc



How to Learn: Classes at UVa

CS/ECE/SYS 6501: Autonomous Mobile Robots

CS 4501: F1/10th Autonomous Racing

CS 4xx: Machine Learning, and Artificial Intelligence

CS 4xx: Internet Scale Applications

CS 4xx: Computer Vision

others in the future?

World is moving way toooo fast...

How to Learn: DIY

Coursera

- UPenn Robotics, UToronto Self-Driving Cars, ML (Ng)... all FREE!

Udacity

- Self-Driving Car Nanodegree, Robotics Nanodegree, C++ Nanodegree, ...
- Lots of Free Options!

YouTube

“you don’t pay for the education... you pay for the degree”

“never let schooling interfere with your education” – Twain

Orienting Yourself

Learn & Do

- Coding and Classes
- Projects – get your hands dirty!
- Twitter – “LinkedIn, except better”
- Podcasts

Talk to people!

Interview

- Numbers game... attrition
- Resume
- Technical Interviews
- Ask Questions!!!!

Where to go next?

- The Conformity Conundrum, and College SNR
- College = Particle Filter
- “I took the one less traveled by,... and that has made all the difference”
 - Self-Driving Cars, Robotics, Machine Learning, Computer Vision, Blockchain, Graphics and Gaming, FinTech, Cloud, IoT, Cybersecurity, ... GET HYPEEE
- What do *you* want to optimize for?
- ABC -- Always Be Coding
- Long-term bets

Aaand... that's a wrap!

Thank you 😊

rohanraval@virginia.edu