CS598 Fall: Advanced Topics in Robot Perception

Shenlong Wang

Aug 25, 2021

Many slides are adapted from Saurabh Gupta, Kris Hauser, Yuke Zhu, Frank Delleart, Shuran Song

Today’s Agenda

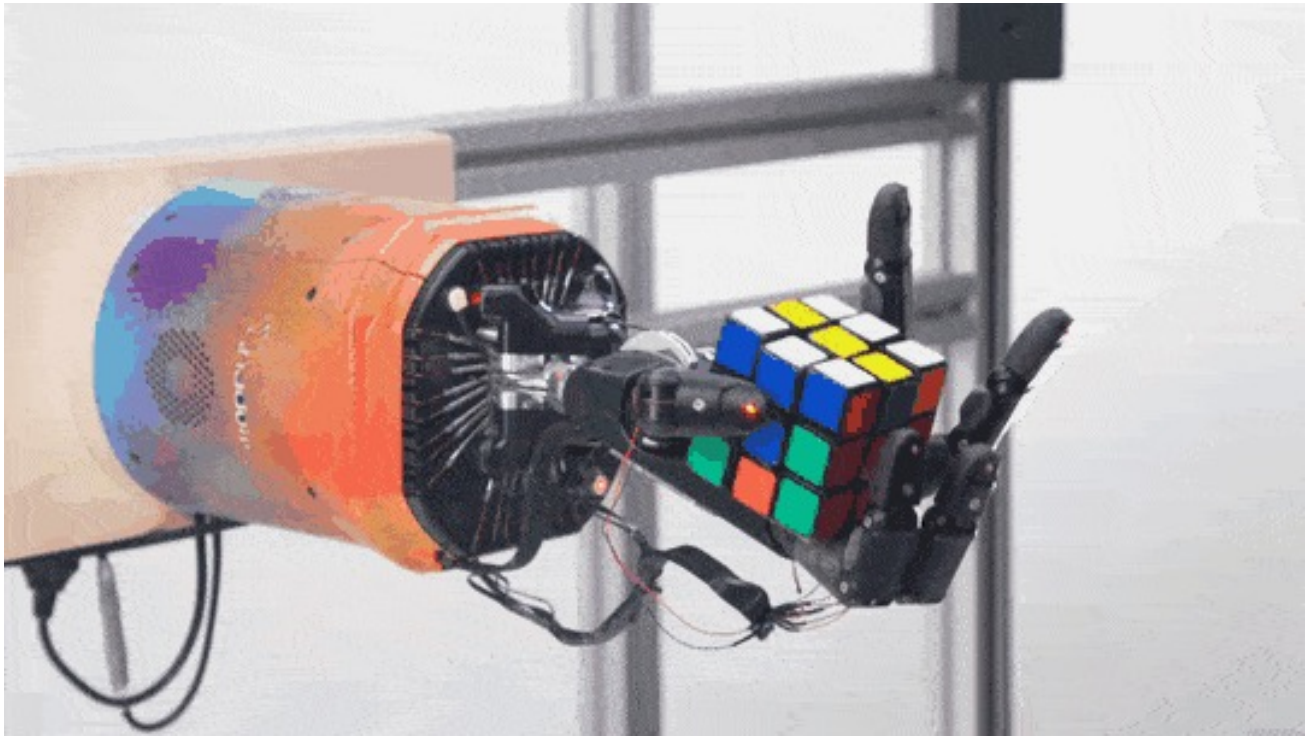
- Intro to Robot Perception
- Course Outline
- Logistics
- Get to Know Each Other

Why Should You Take This Course?

Robots are Cool!

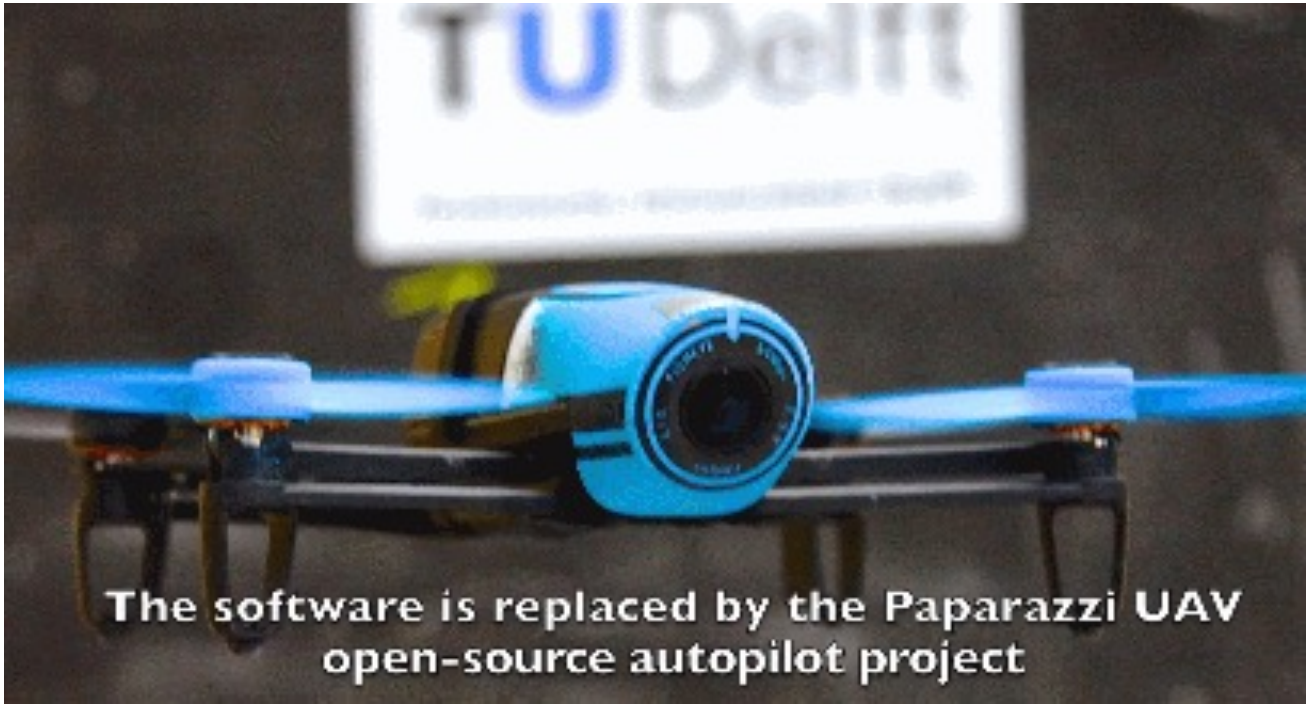
Boston Dynamics

Robots are Cool!



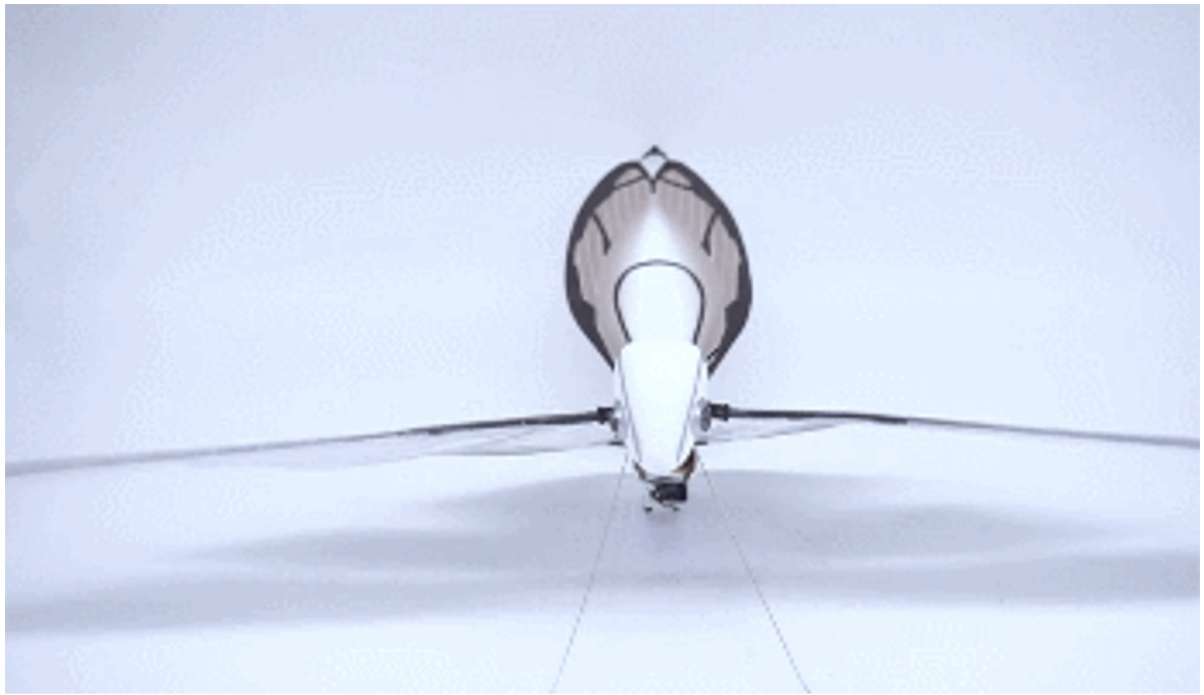
OpenAI

Robots are Cool!



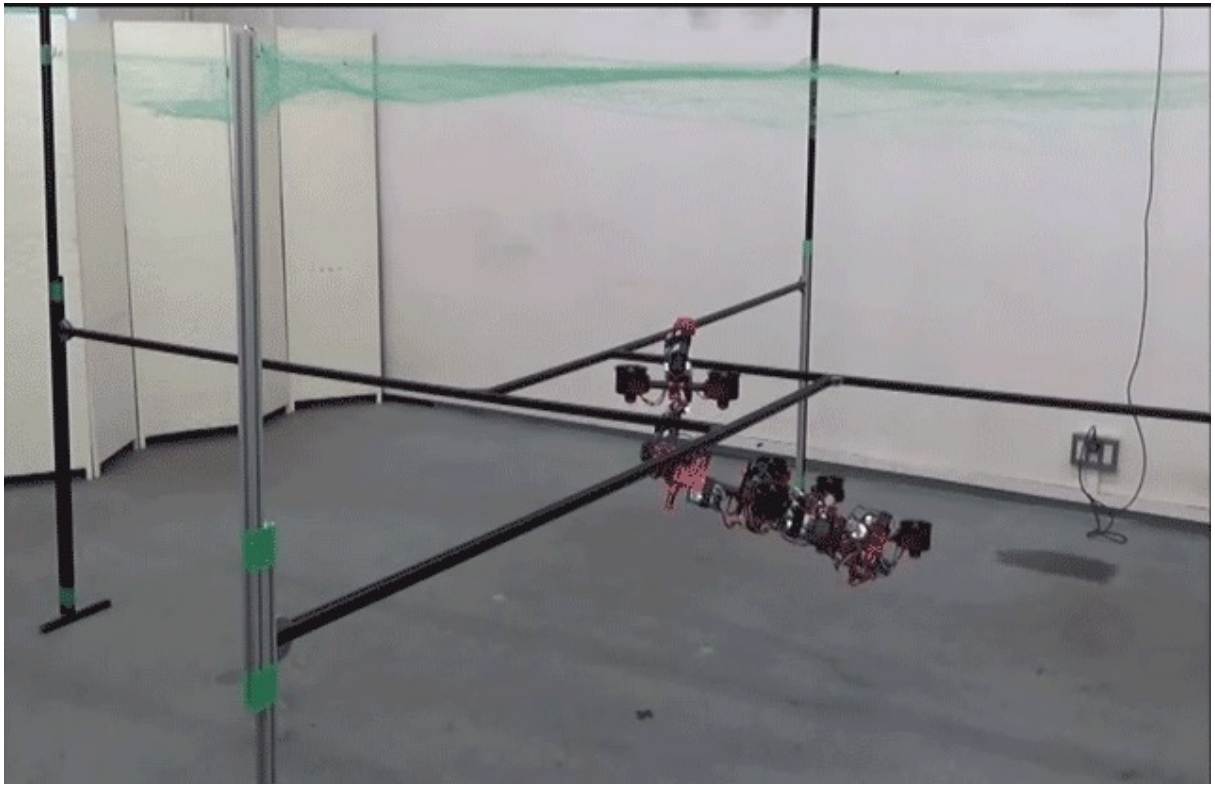
TUDeft

Robots are Cool!



BionicBird MetaFly

Robots are Cool!



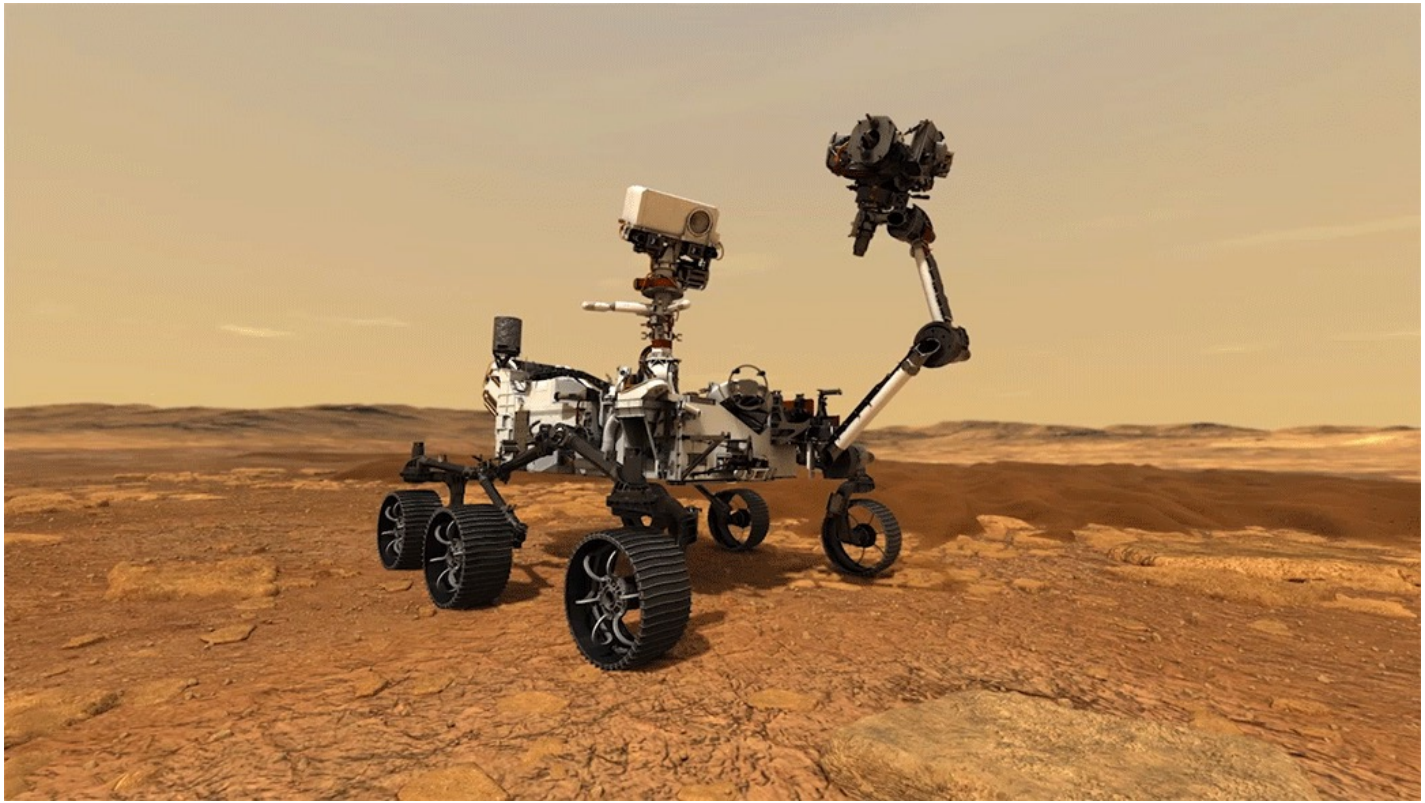
Dragon University of Tokyo

Robots are Cool!

Dash! Yonkuro

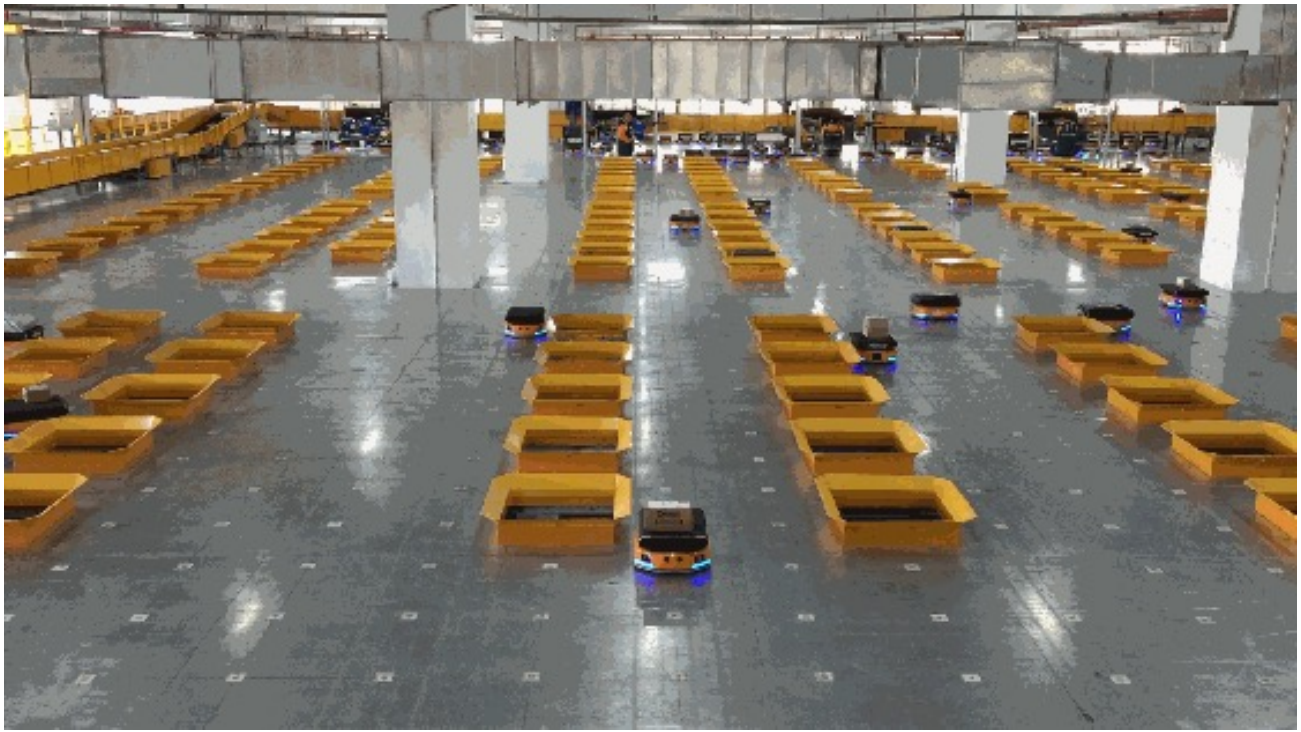
https://diyrobocars.com/diy-robocar-races-110th-and-116th/

Robots are Useful!



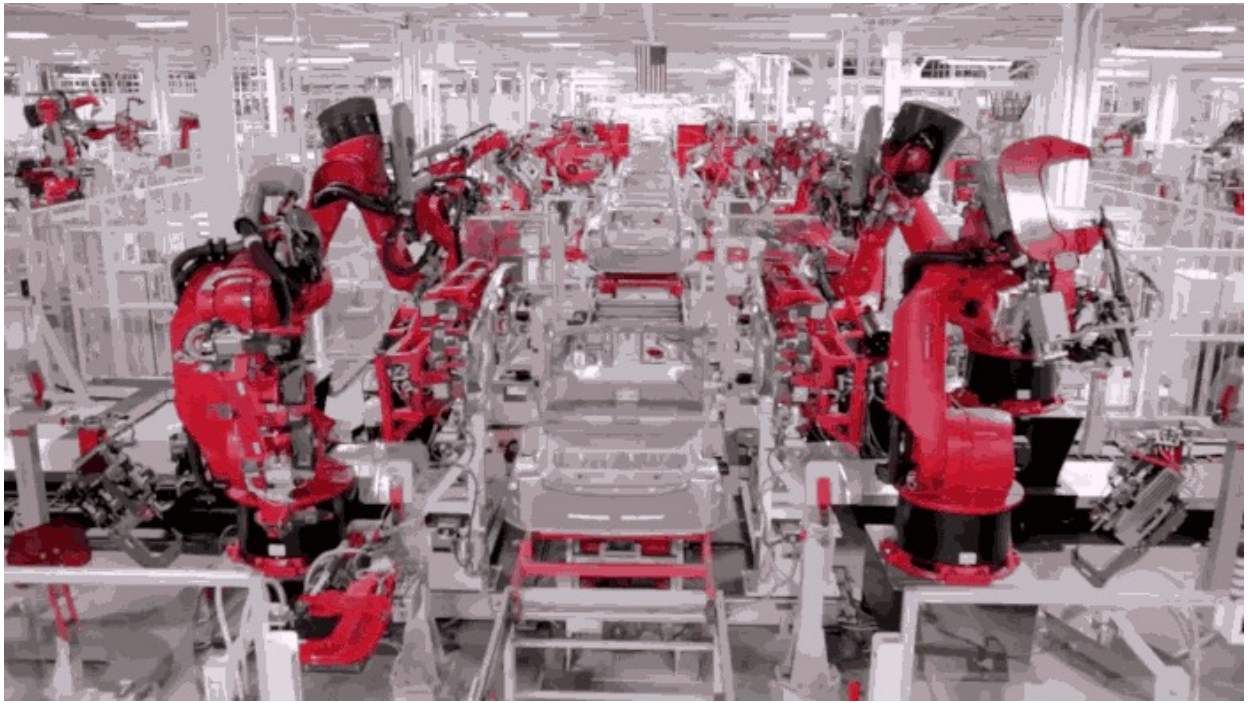
NASA

Robots are Useful!



Alibaba

Robots are Useful!



Tesla

Robots are Useful!

Tesla

Robot Tasks: Navigation

- Determine of the robot's current position.
- Determine the goal location and plan a trajectory
- Reach a goal location safely

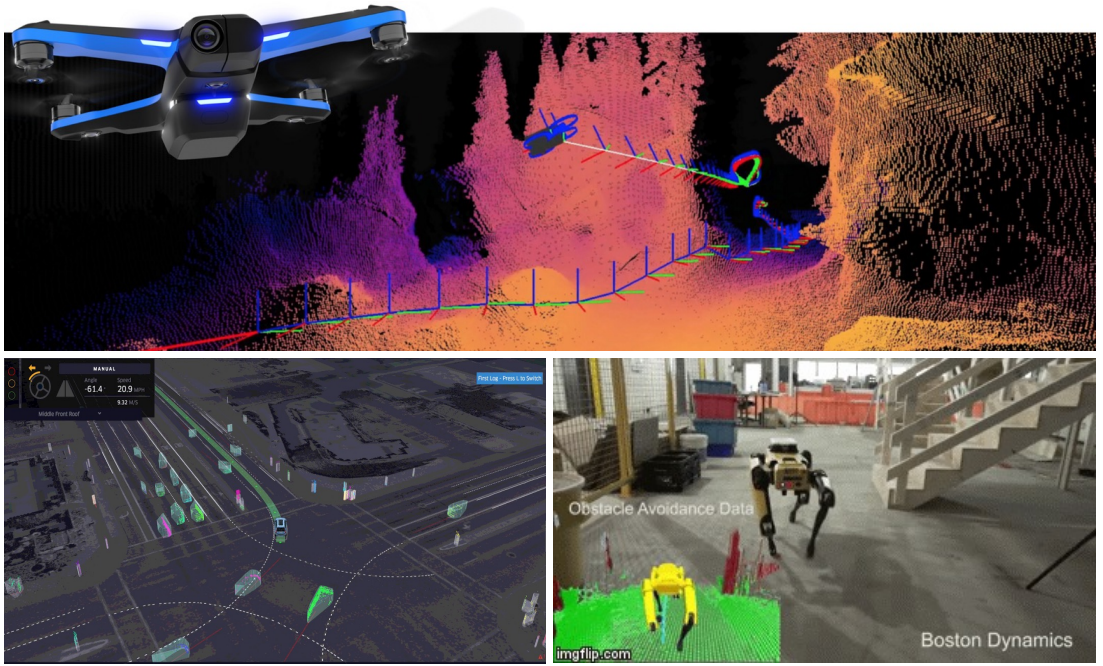
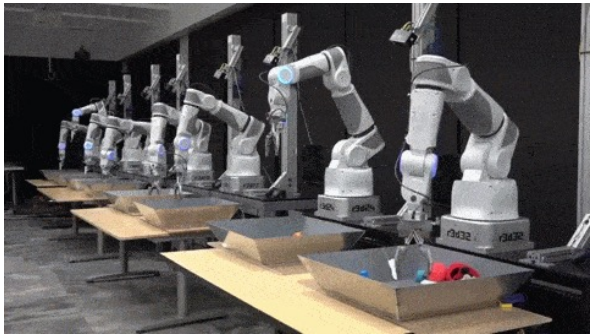
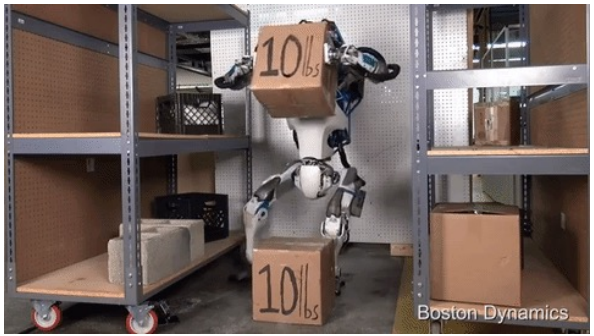


Image credit: Skydio, Uber, Boston Dynamics

Robot Tasks: Manipulation

- Determine of the other objects' pose.
- Determine a series of movement to reach the goal
- Execute the motion without breaking things





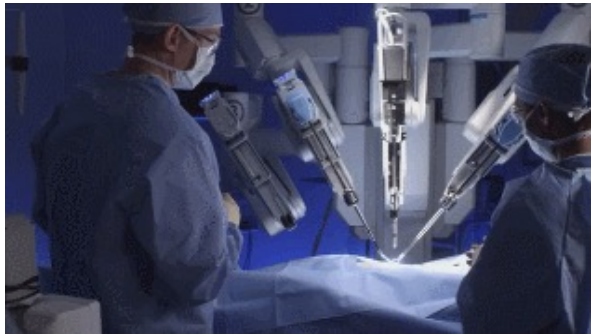
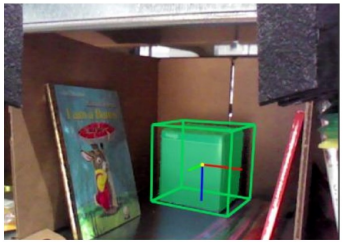


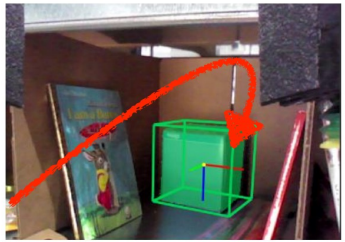
Image credit: Google, Nvidia, Boston Dynamics, da Vinci

Key Ingredients of a Robot

Observed Images



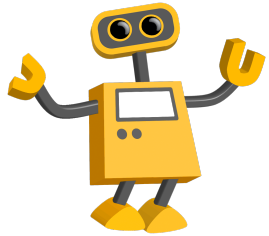
6DOF Pose

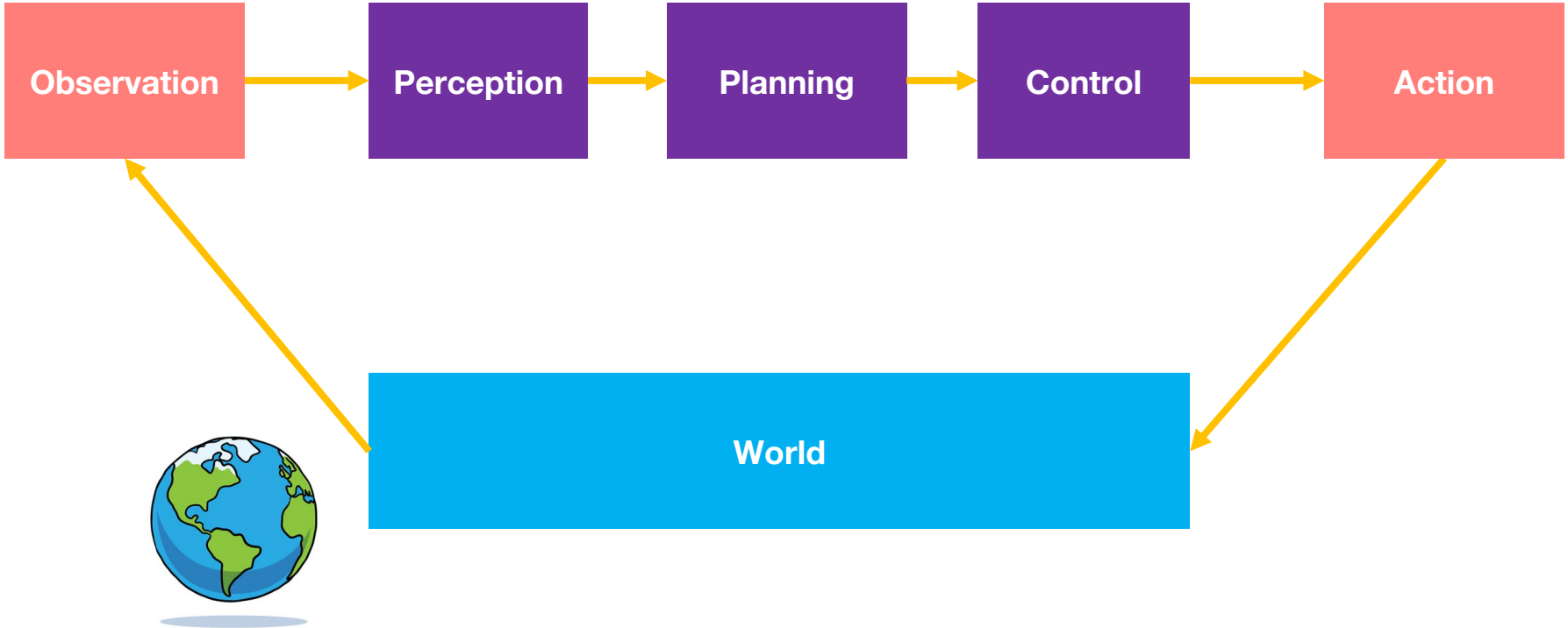


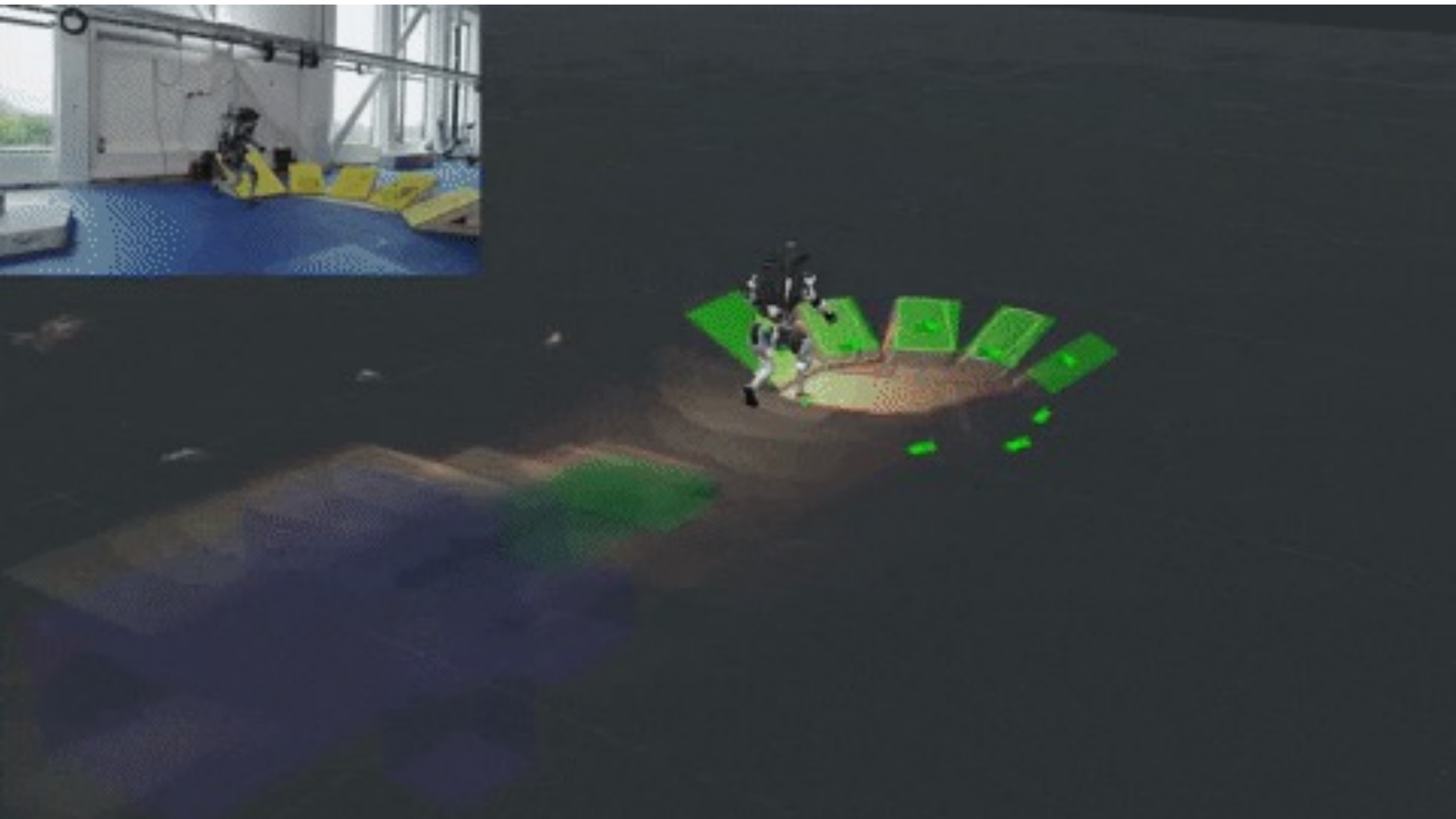
Grasp Motion Planning

Image credit: Saurabh Gupta

Key Ingredients of a Robot







Key Ingredients of a Robot

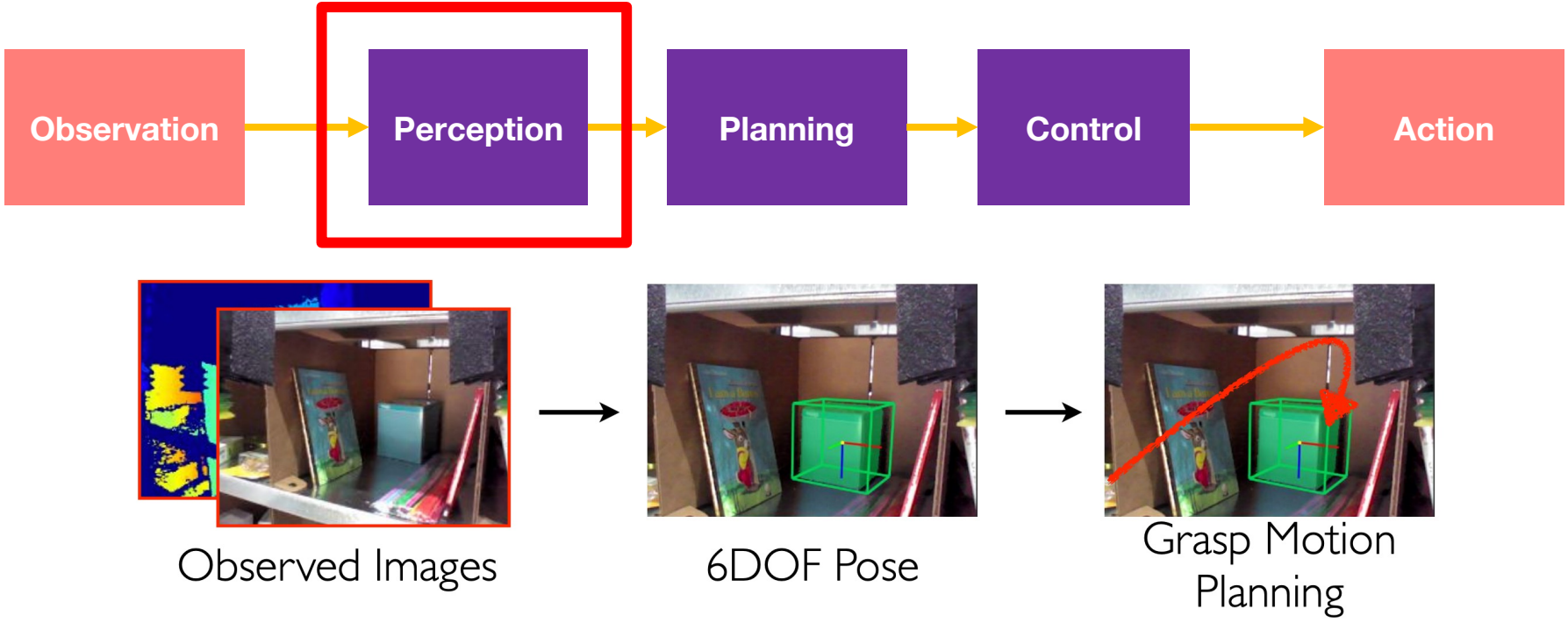
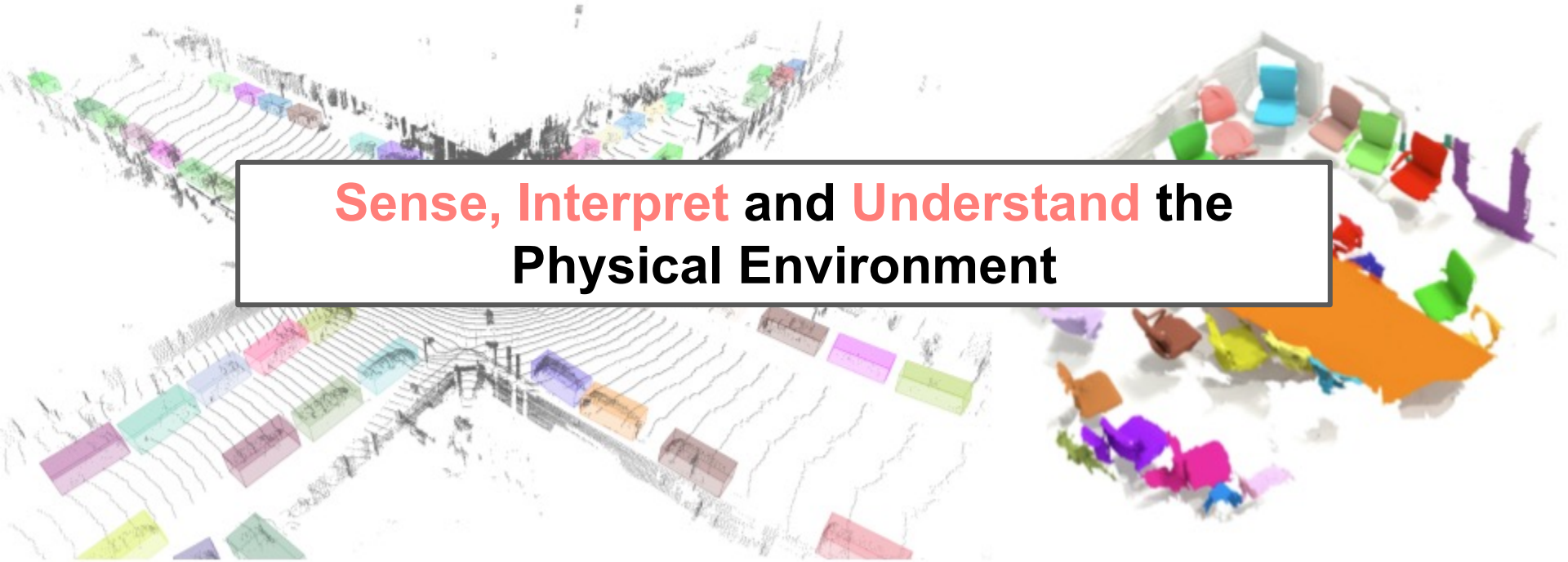


Image credit: Saurabh Gupta

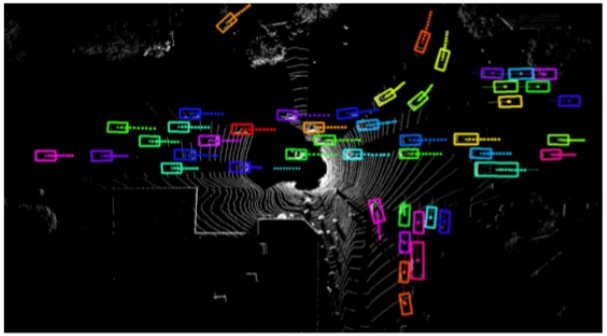
Robot Perception



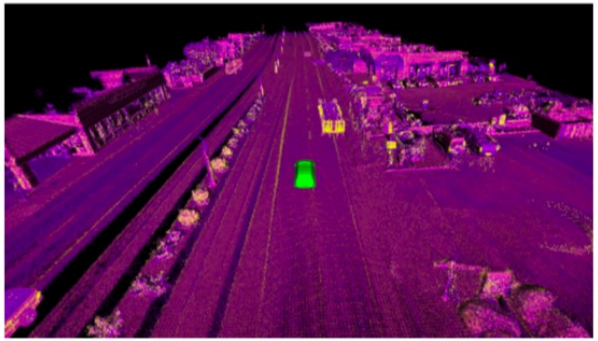
Sense, Interpret and Understand the Physical Environment

Image credit: Google, Waymo Open Dataset, ScanNet

Perception: Self-Driving



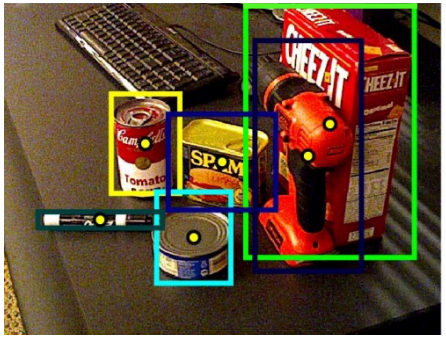
Perceive other objects



Localize itself

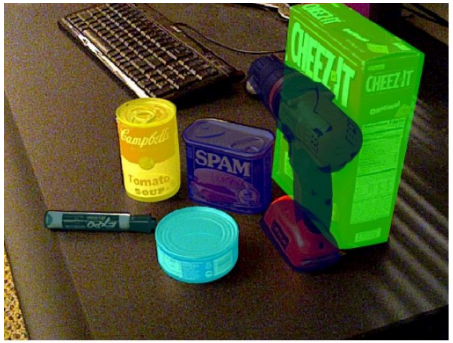
Perceive surrounding scene

Perception: Manipulation



Detect objects

Group instances



Reconstruct geometry

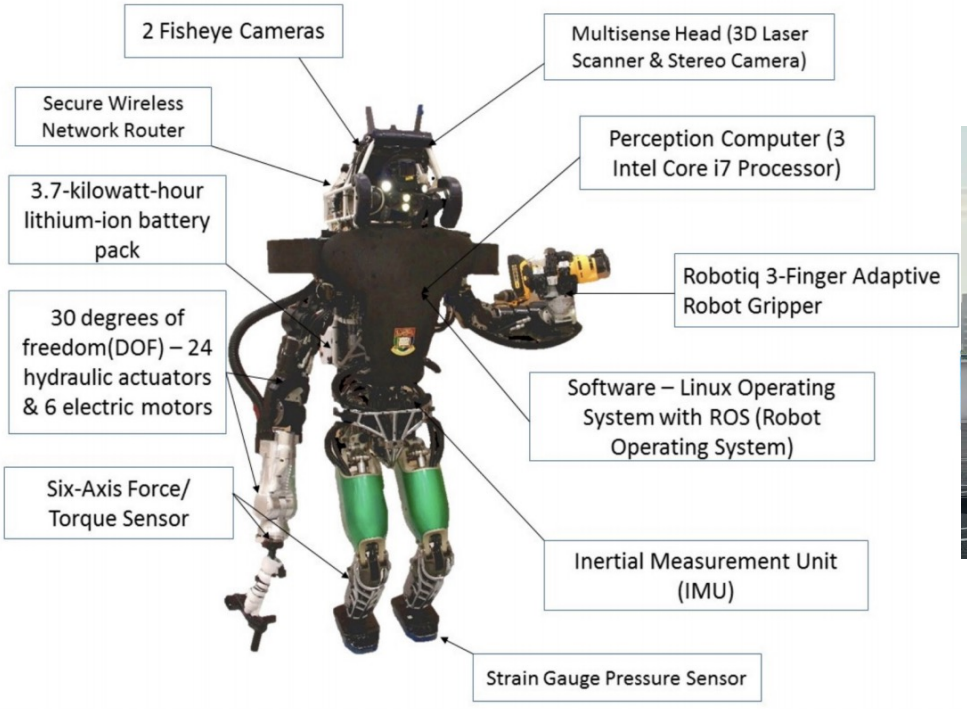
Image credit: PoseCNN Yu et al. 2018

What Makes Robot Perception Special?

- **Embodied**: Robots have physical bodies, situated in the physical world, and experience the world directly

- **Active** : Robots are active perceivers. It knows why it wishes to sense, and chooses what to perceive, and determines how, when and where to achieve that perception.

Sensors



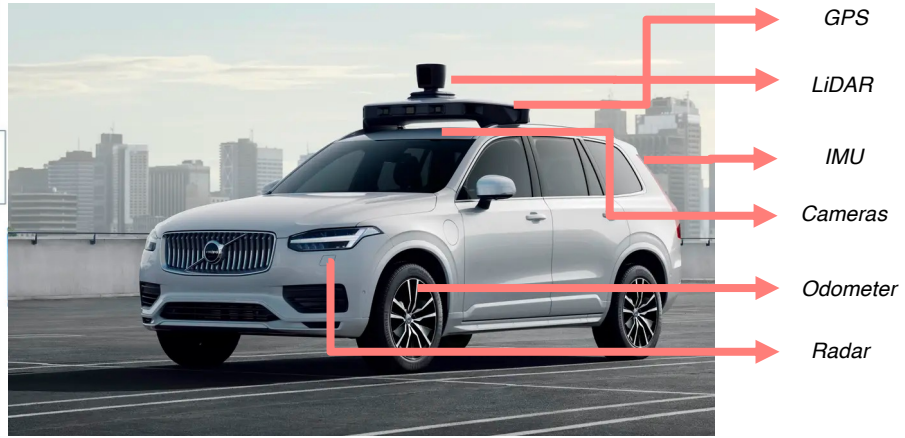


Image credit: HKU and Uber

Desiderata for Robot Perception

- **Robust**: handling unknowns and observation noises
- **Efficient**: runs in real-time on an embodied device
- **Active**: suitable towards action goal; able to move and see better
- **Verifiable**: have a form of guarantees; can tell when it failed / uncertain

Why Robot Perception is Not There Yet?

object variation

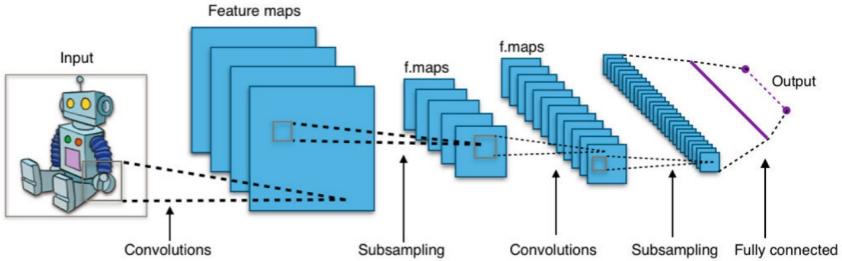
environment uncertainty

adaptation

Image credit: Yuke Zhu

Opportunities

Algorithms



Sensing

Dataset and Simulation

Hardware Support

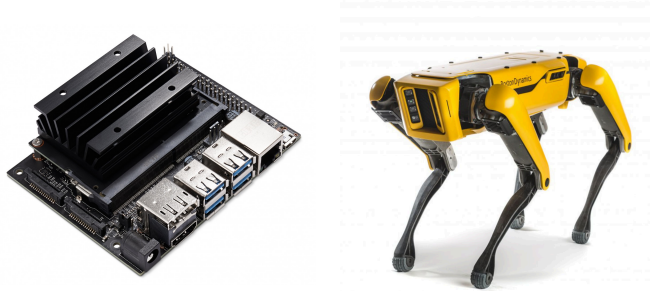


Image credit: Yuke Zhu, Nvidia, Carla, Boston Dynamics

Why You Should Take This Course?

- Robots are cool!
- Robots are useful!
- Robot perception needs your help to become better.
- And we have the tools!

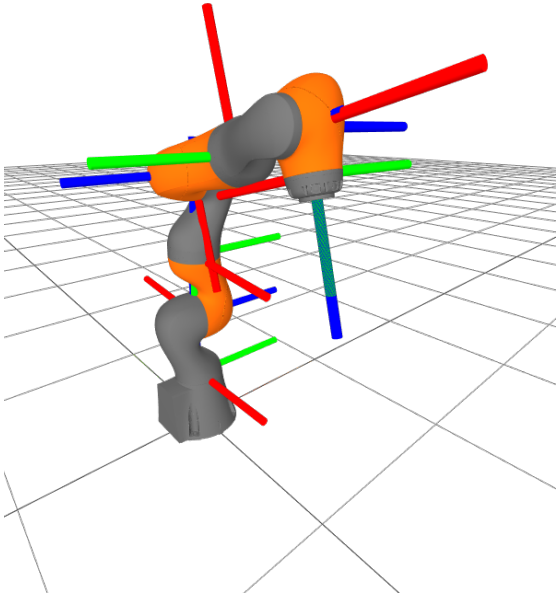
Learning Objectives

- Understand **technical challenges** arising from building perception algorithms. Understand the technical and societal impact of perception for building robust autonomy in the real world.
- Get familiar with **mathematical toolkits** and **state-of-the-art** robot perception algorithms.
- Be able to develop **potential novel solutions** in addressing these challenges and build perception algorithms for real-world systems.

Course Content

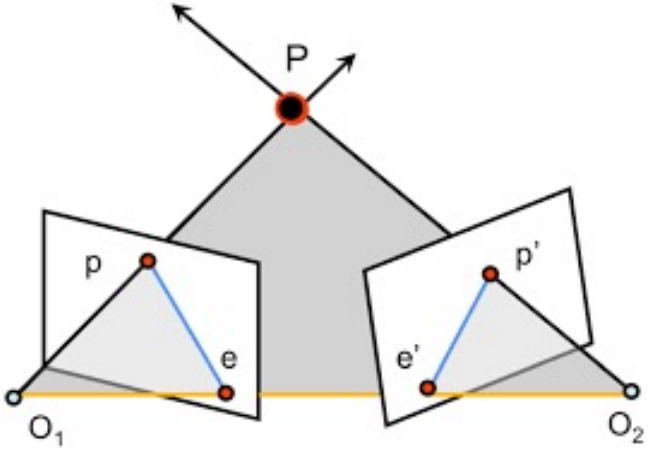
- **Chapter I Fundamentals**: basic knowledge and tools for perception
- **Chapter II Case Studies**: crucial robot perception tasks
- **Chapter III Frontiers**: unsolved challenges and state-of-the-art progresses

Fundamentals: Transforms and Sensing Models



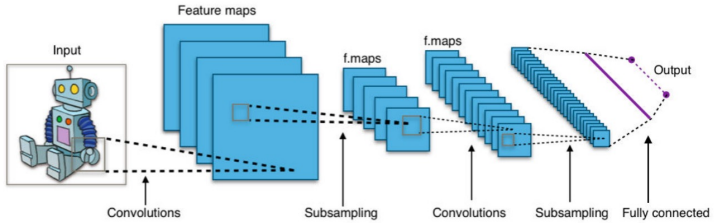
Lecture 2
Poses, Transforms, Kinematics

Lecture 3
Sensing I: LiDAR, Radar, GPS, IMU, Tactile, ... etc

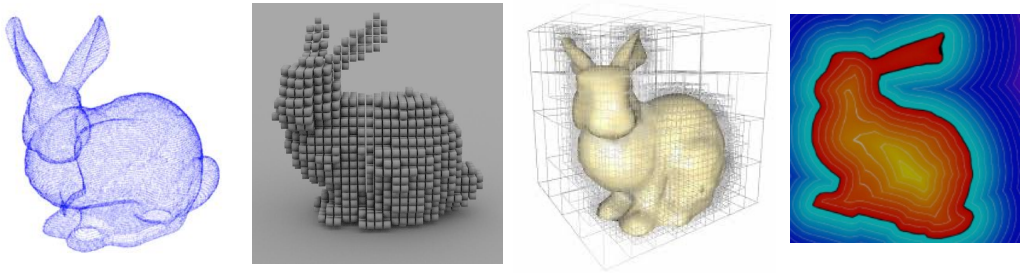


Lecture 4
Sensing II: Cameras, Stereo, Perspective Geometry, Epipolar Geometry

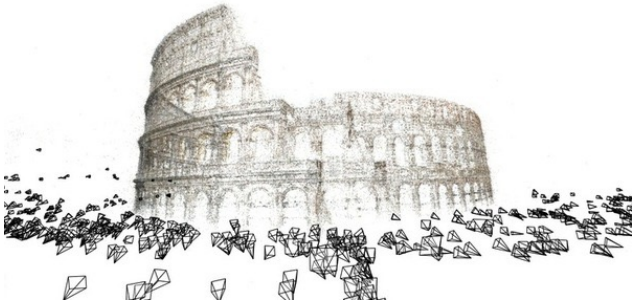
Fundamentals: Mathematical Toolkits



Lecture 5: Deep Learning



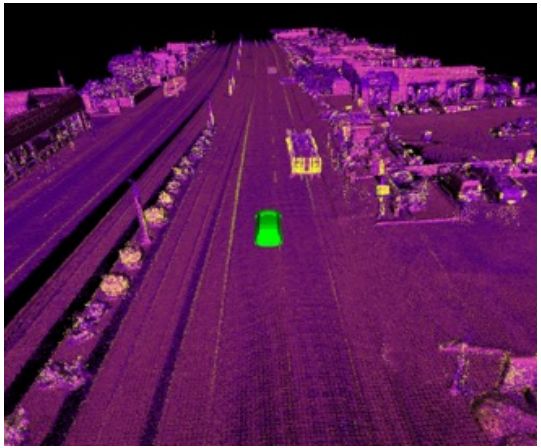
Lecture 6: 3D Representations



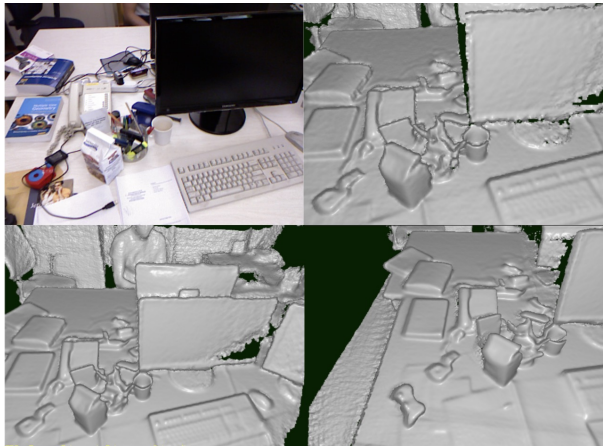
Lecture 7: Graphical Models and Nonlinear Optimization

Lecture 8: State Estimation and Bayes Filers

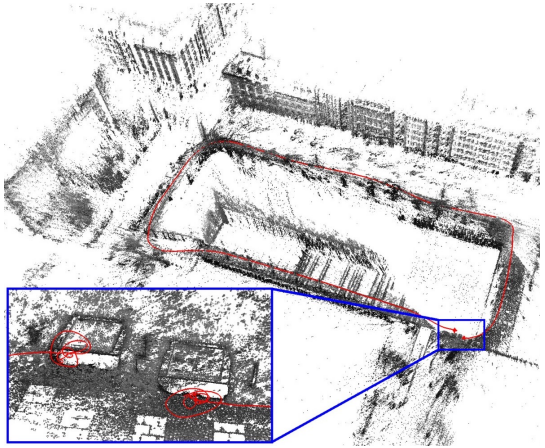
Case Studies: **Spatial** Perception



Lecture 9: Localization with a Map

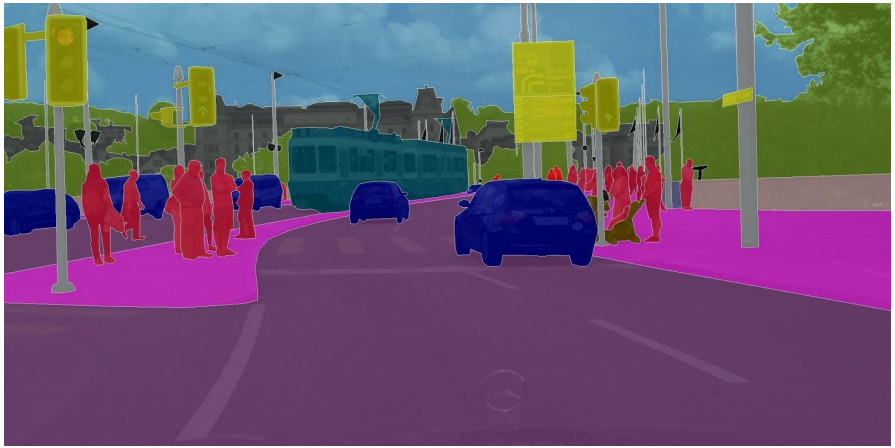


Lecture 10: Depth Sensor SLAM

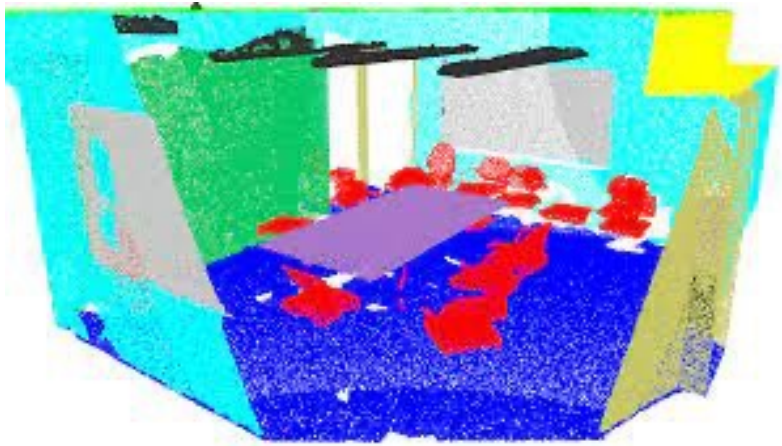


Lecture 11: Visual SLAM

Case Studies: **Scene** Understanding

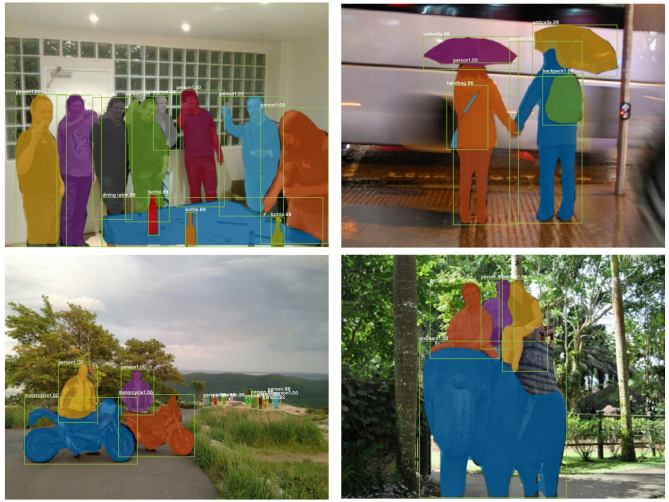


Lecture 12: Image Segmentation

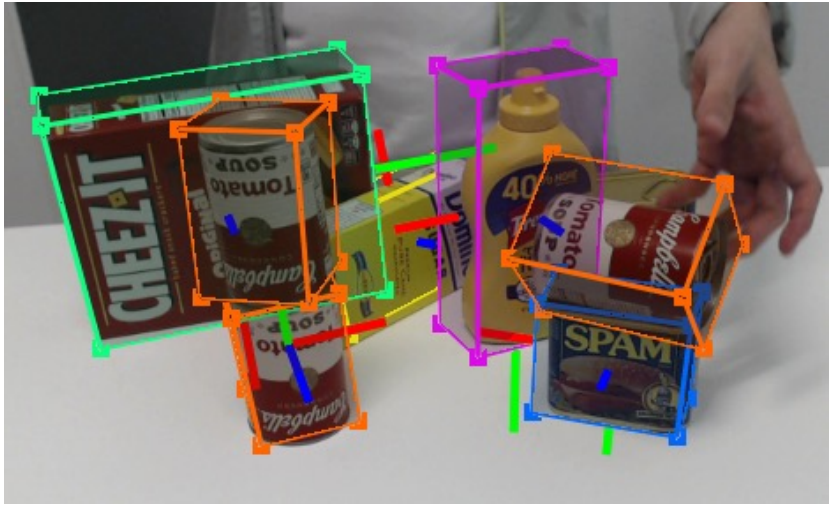


Lecture 13: 3D Segmentation and Semantic Fusion

Case Studies: **Object** Perception



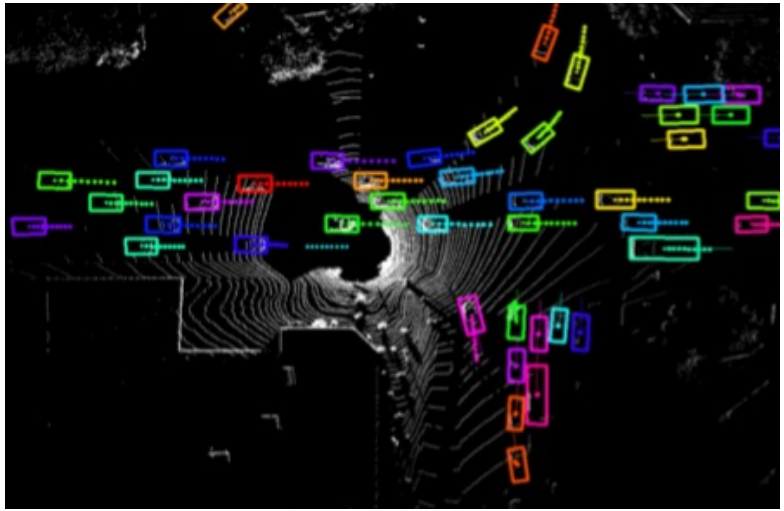
Lecture 14: Detection and Tracking



Lecture 15: 6-DoF Pose and Affordance

Frontiers: Perception in a **Moving** World

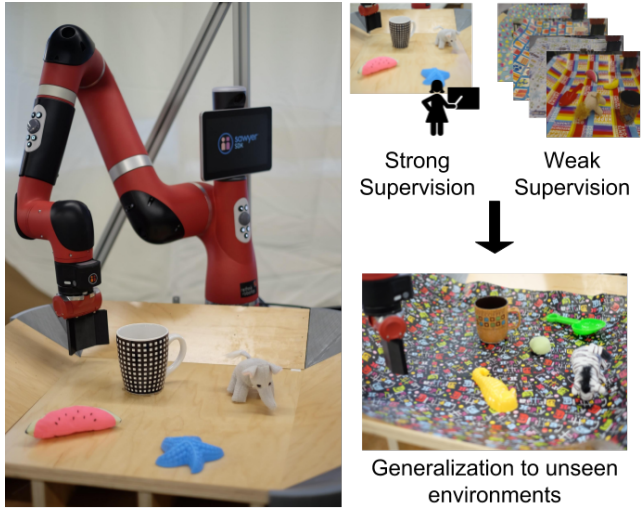
Lecture 16: Motion Estimation



Lecture 17: Motion Forecasting

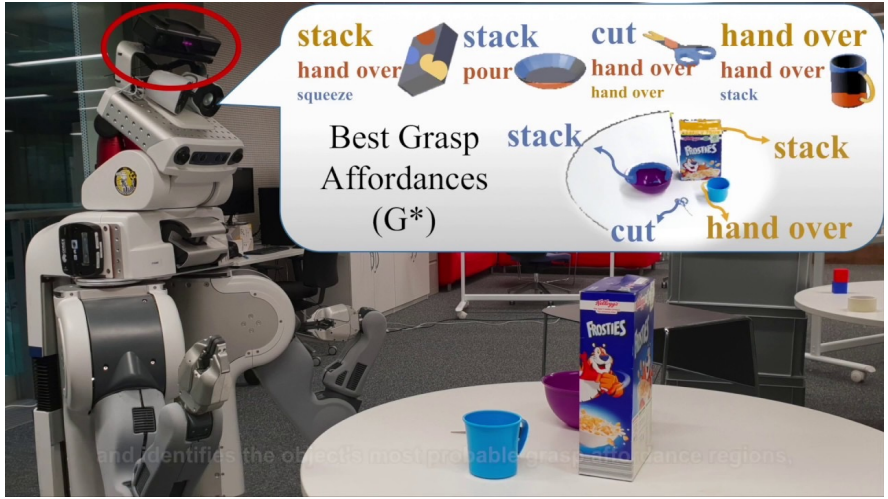
Frontiers: Perception in an **Open** World

Lecture 18: Modeling Instances from Unseen Categories



Lecture 19: Modeling Unseen Tasks / Environments

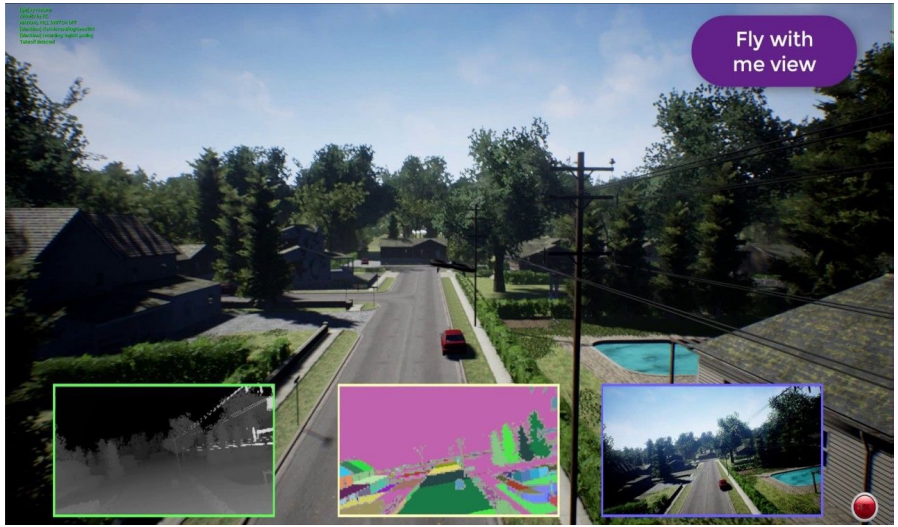
Frontiers: Perception and **Action**



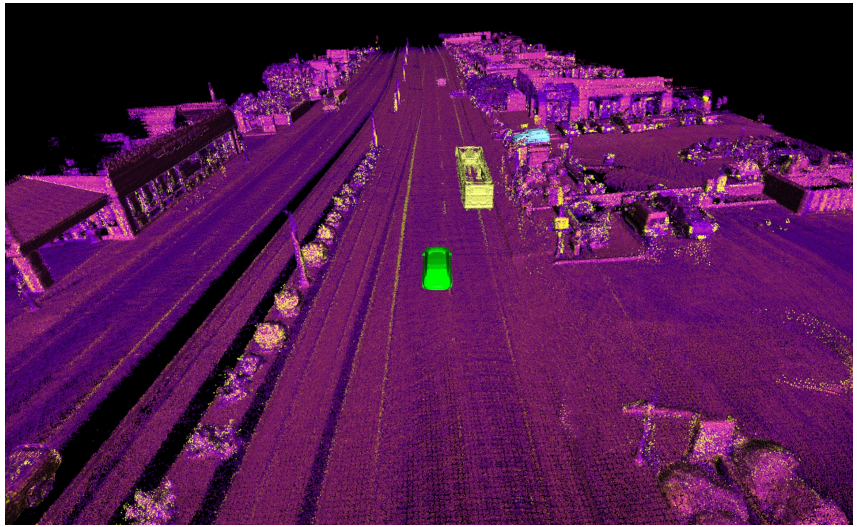
Lecture 20: See to Act

Lecture 21: Act to See

Frontiers: Perception and **Simulation**



Lecture 22: Classic Simulation, Sim2Real

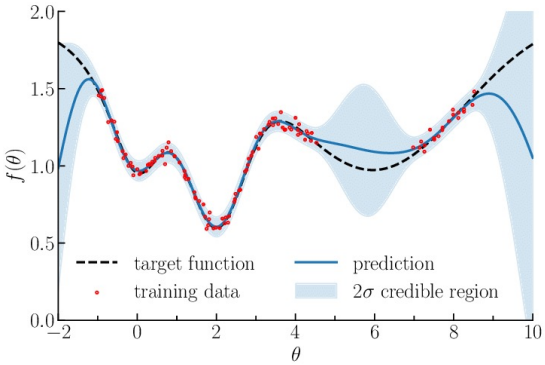


Lecture 23: Data-Driven Simulation

Frontiers: Perception with **Guarantees**

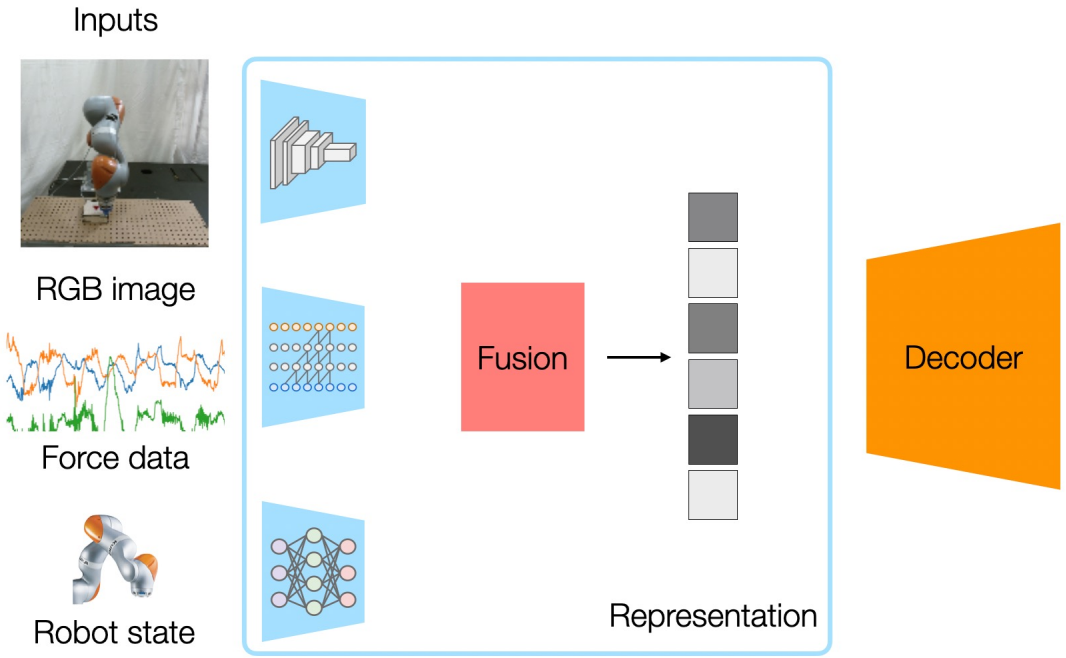
Lecture 23: Prune to Certain Noises/Attacks

Lecture 25: Know whether it succeeds



Lecture 26: Know whether it is confident

Frontiers: Perception with **Multiple Modalities**



Guest Speakers

Luca Carlone
Associate Professor, MIT

SLAM, and certifiable correct perception

German Ros
Research Scientist, Intel

Lead of Carla and Open3D

Logistics: Schedule

- Time: 2:00-3:15pm CT, Wednesday and Friday
- Location: Online (Zoom links on course website)

- Office Hour: after each lecture, same zoom with breakout rooms

Relevant Courses at UIUC

- CS598 3D Vision by Derek Hoiem.
- CS498 Mobile Robotics by Girish Chowdhary.
- CS598 Advanced Computational Topics in Robotics by Kris Hauser.
- CS598 Autonomous Vehicles by David Forsyth.
- ECE598 Robot Learning by Saurabh Gupta.

Grading Policy (Tentative)

- **Participation (10%)**. Participation in in-class discussion and on Piazza.
- **Paper Presentations (20%)**. Presenting 1-2 research topics in class.
- **Paper Reviews (20%)**. Writing reviews for research papers.
- **Final Project (50%)**. Completing a research project.

Logistics: Reading

9/24	Lecture #9 (TBD): **Spatial Perception: Map-based Localization** - Map Representations - Registration and Matching [slides I video I notes]	• Probabilistic Robotics, Ch. 9 • **[R]** Levinson et al., Robust vehicle localization in urban environments using probabilistic maps • **[R]** Sarlin et al., From Coarse to Fine Robust Hierarchical Localization at Large Scale • Barsan et al., Learning to Localize Using a LiDAR Intensity Map	Project Proposal due (11:59pm, Fri 9/24)

[R]: must read; choose to write reviews;
Others: optional readings, demos, tutorials, book chapters, etc.

Logistics: Reviewing

- Each student is required to submit at least **20 reviews**
- Each review will be worth **1%** of the total grade, summing up to **20%** of the course grade for paper reviewing.
- Students are recommended to submit one paper review per class. However, it is not a must.
- Reviews must be submitted **before the day** of lecture.
- Four-point system (100, 90, 80, 0)
- Instructor will only give constructive feedbacks to review comments if it needs necessary improvement.

Logistics: Presentation

Each student will present a research **topic** in a 30-min slot (25min + 5min QA)

- Map-based Localization
- Visual SLAM
- LiDAR SLAM
- 2D Detection
- 2D Segmentation
- …
- Active Perception
- Sim2Real
- …

Logistics: Presentation

The presentations will be graded in the following aspects:

- Clarity of presentation;
- Literature reviews and the key challenges addressed by this work;
- Analysis of the strengths and weaknesses of the research;
- Discussions of potential future research directions and applications;
- Response to questions and engage in open-ended discussions (in-class and on Piazza).

Four-point system (100, 90, 80, 0)

Logistics: Final Projects

- Projects should be done either individually or in a team of two students. Shenlong will discuss with you on your ideas and the execution throughout the semester.

- **Project Proposal** : 2 pages excluding references (15%)
- **Mid-term Presentation** : 5-min presentation on project update (15%)
- **Final Report** : 8 pages excluding references (50%)
- **Final Presentation** : 12-min talk + 2-min Q&A (20%)
- **Teaser Video** (optional) : 3-min teaser video (10% bonus)
- All write-ups should use the RSS latex template.

Course Reschedule

Sept-1 Wed course needs to be scheduled.

We will have a make up session for mid-term presentation.

- Extend one lecture in Oct: Say, extend Oct 20, 2pm to 4:30pm.
- Find another slot in Oct.

Todo List

- Join Piazza forum
- Check course website
- Filling your presentation form
- Ping me with questions on prerequisites
- Enjoy the rest of the day

Tell Us About **You**

Todo List

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- Enjoy the rest of the day