# **16.485: VNAV** - Visual Navigation for Autonomous Vehicles

**Luca Carlone**

Lecture 1

# VNAV Staff

## Instructor

Luca
Carlone

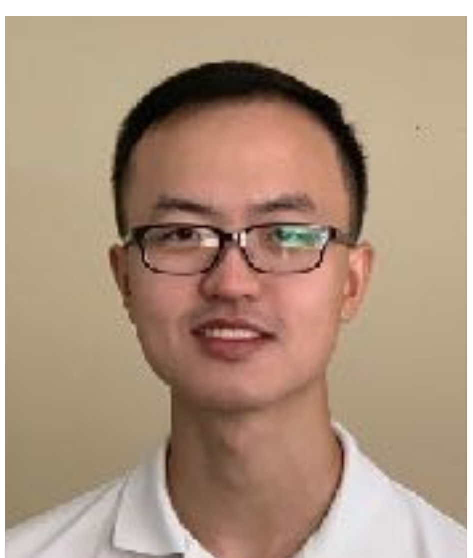
## Guest Lecturers

Rajat
Talak

Jared
Strader

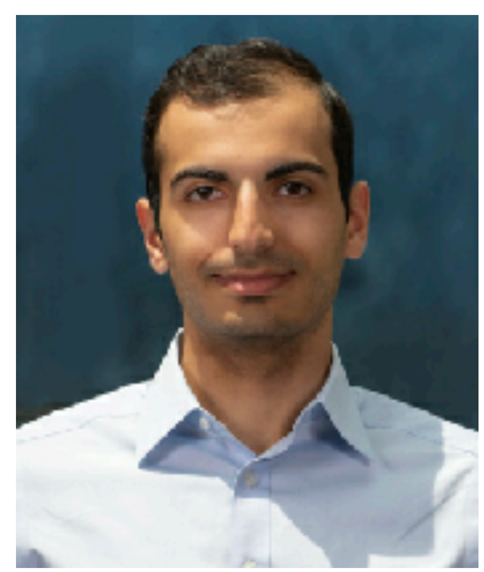
Yulun
Tian

## Teaching Assistants



Jingnan Shi

Nathan Hughes



Dominic Maggio

Yulun Tian

# Lecture Outline

- **Logistics**
  - Goals of VNAV
  - Structure
  - Assignments & Grading
  - Requirements & Pre-reqs

- **Visual Navigation for Autonomous Vehicles**
  - The robot revolution
  - Why perception?
  - More on the VNAV Staff

# Goals of VNAV (1/3)

Learn the state of the art in robot perception (2D computer vision, localization, mapping, object pose estimation, semantic understanding,…) for visual navigation


[iRobot]


[Amazon]


[Forbes]

Self-driving cars, drones, domestic and service robots, virtual and augmented reality

MIT AEROASTRO

# Goals of VNAV (2/3)

- Mens / Theory:
  - Learn/develop/exercise **theoretical tools** necessary for robotics research (geometry, optimization, …)
  - Learn about state-of-the-art **algorithms** for robot perception (+ selected topics in control, trajectory optimization, learning)
  - Get an overview of **open problems** in robot perception

- **Note 1**: If you don't like writing (some) **math**, you may not like this class
- **Note 2**: this course is much more theoretical than RSS (6.4200/16.405)
- **Note 3**: this is not an ML course (but we use ML in some labs/lecture)
- **Overarching goal**: prepare you (or refine your skills) to perform state-of-the-art research in robotics (not necessarily in robot perception)

# Goals of VNAV (3/3)

- Manus / Practice:
  - Learn/practice **ROS** (**R**obot **O**perating **S**ystem)
  - Rigorous testing of state-of-the-art implementations for perception, control, ML, in a **photo-realistic simulator**
  - Possibility to use **physical robots** for final projects
  - Learn **limitations** of state-of-the-art implementations

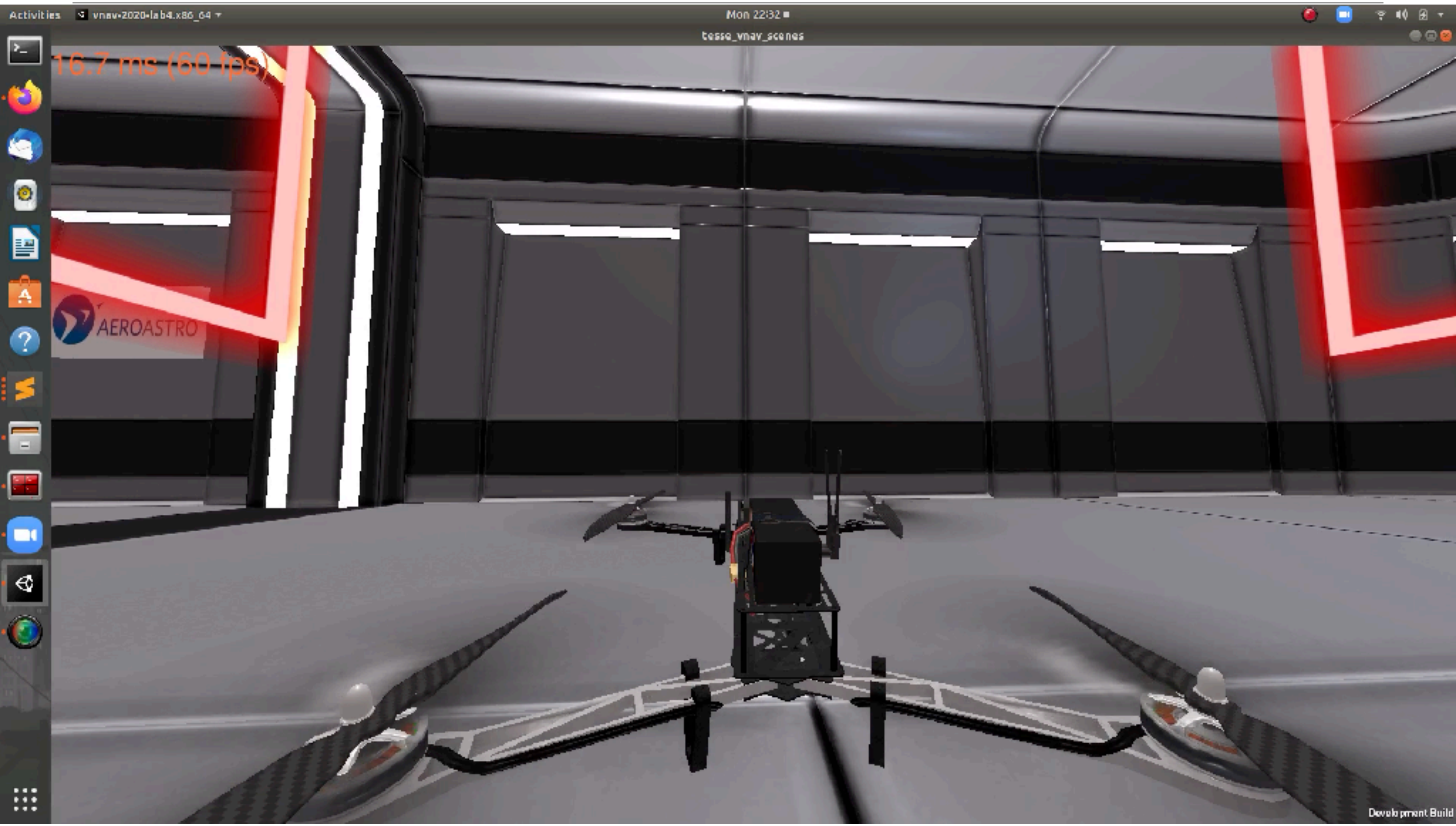
- **Note**: If you do not like **coding (in C++)**, you may not like this class
  -> **C++ refresher**: https://youtu.be/F_vIB3yjxaM
- **Overarching goal**: prepare you (or refine your skills) to perform state-of-the-art research in robotics (not necessarily in robot perception)

# Practice on Real Robots: Intel Aero Drone



MIT AEROASTRO

# Practice in Realistic Unity-based Simulator




MIT AEROASTRO

# Structure of VNAV

- Lectures:
  - M/W/F at 1-2pm EDT (35-225)
  - Mostly on the board
- Labs:
  - W at 3-5pm EDT (typically in 33-116)
  - Code, assignments, OH
- Office Hours:
  - OH: TBA on Piazza
- Final project:
  - Push the boundary of the state of the art

| Week | Dates | Lecture topic | Lab |
|---|---|---|---|
| 1 | Sep 6, 8 | Introduction | Lab 1: Linux, C++, Git |
| 2 | Sep 11, 13, 15 | 3D Geometry | Lab 2: ROS |
| 3 | Sep 18, 20 | Geometric Control | Lab 3: 3D trajectory following |
| 4 | Sep 25, 27, 29 | Trajectory Optimization | Lab 4: 3D trajectory optimization |
| 5 | Oct 2, 4, 6 | 2D Computer Vision | Lab 5: feature detection |
| 6 | Oct 11, 13 | 2-view Geometry and Minimal Solvers | Lab 6: object localization |
| 7 | Oct 16, 18, 20 | Non-minimal Solvers and Visual Odometry | Lab 7: GTSAM |
| 8 | Oct 23, 25, 27 | Place Recognition | Lab 8: ML for robotics |
| 9 | Oct 30, Nov 1, 3 | SLAM and Visual-Inertial Navigation | Lab 9: SLAM |
| 10 | Nov 6, 8 | Advanced Topics | Final project |
| 11 | Nov 13, 15, 17 | Advanced Topics | Final project |
| 12 | Nov 20, 22 | Advanced Topics | Final project |
| 13 | Nov 23-26 | Thanksgiving Break | |
| 14 | Nov 27, 29, Dec 1, 4 ,6, 11, 13 | Guest Lectures and Students Presentations | Final project |

# Structure of VNAV

- Lectures:
  - M/W/F at 1-2pm EDT (35-225)
  - Mostly on the board
- Labs:
  - W at 3-5pm EDT (typically in 33-116)
  - Code, assignments, OH
- Office Hours:
  - OH: TBA on Piazza
- Final project:
  - Push the boundary of the state of the art

| Week | Dates | Lecture topic | Lab |
|---|---|---|---|
| 1 | Sep 6, 8 | Introduction | Lab 1: Linux, C++, Git |
| 2 | Sep 11, 13, 15 | 3D Geometry | Lab 2: ROS |
| 3 | Sep 18, 20 | Geometric Control | Lab 3: 3D trajectory following |
| 4 | Sep 25, 27, 29 | Trajectory Optimization | Lab 4: 3D trajectory optimization |
| 5 | Oct 2, 4, 6 | 2D Computer Vision | Lab 5: feature detection |
| 6 | Oct 11, 13 | 2-view Geometry and Minimal Solvers | Lab 6: object localization |
| 7 | Oct 16, 18, 20 | Non-minimal Solvers and Visual Odometry | Lab 7: GTSAM |
| 8 | Oct 23, 25, 27 | Place Recognition | Lab 8: ML for robotics |
| 9 | Oct 30, Nov 1, 3 | SLAM and Visual-Inertial Navigation | Lab 9: SLAM |
| 10 | Nov 6, 8 | Advanced Topics | Final project |
| 11 | Nov 13, 15, 17 | Advanced Topics | Final project |
| 12 | Nov 20, 22 | Advanced Topics | Final project |
| 13 | Nov 23-26 | Thanksgiving Break | |
| 14 | Nov 27, 29, Dec 1, 4 ,6, 11, 13 | Guest Lectures and Students Presentations | Final project |

# Structure of VNAV

- Lectures:
  - M/W/F at 1-2pm EDT (35-225)
  - Mostly on the board
- Labs:
  - W at 3-5pm EDT (typically in 33-116)
  - Code, assignments, OH
- Office Hours:
  - OH: TBA on Piazza
- Final project:
  - Push the boundary of the state of the art

| Week | Dates | Lecture topic | Lab |
|---|---|---|---|
| 1 | Sep 6, 8 | Introduction | Lab 1: Linux, C++, Git |
| 2 | Sep 11, 13, 15 | 3D Geometry | Lab 2: ROS |
| 3 | Sep 18, 20 | Geometric Control | Lab 3: 3D trajectory following |
| 4 | Sep 25, 27, 29 | Trajectory Optimization | Lab 4: 3D trajectory optimization |
| 5 | Oct 2, 4, 6 | 2D Computer Vision | Lab 5: feature detection |
| 6 | Oct 11, 13 | 2-view Geometry and Minimal Solvers | Lab 6: object localization |
| 7 | Oct 16, 18, 20 | Non-minimal Solvers and Visual Odometry | Lab 7: GTSAM |
| 8 | Oct 23, 25, 27 | Place Recognition | Lab 8: ML for robotics |
| 9 | Oct 30, Nov 1, 3 | SLAM and Visual-Inertial Navigation | Lab 9: SLAM |
| 10 | Nov 6, 8 | Advanced Topics | Final project |
| 11 | Nov 13, 15, 17 | Advanced Topics | Final project |
| 12 | Nov 20, 22 | Advanced Topics | Final project |
| 13 | Nov 23-26 | Thanksgiving Break | |
| 14 | Nov 27, 29, Dec 1, 4 ,6, 11, 13 | Guest Lectures and Students Presentations | Final project |

# Structure of VNAV

- Lectures:
  - M/W/F at 1-2pm EDT (35-225)
  - Mostly on the board
- Labs:
  - W at 3-5pm EDT (typically in 33-116)
  - Code, assignments, OH
- Office Hours:
  - OH: TBA on Piazza
- Final project:
  - Push the boundary of the state of the art

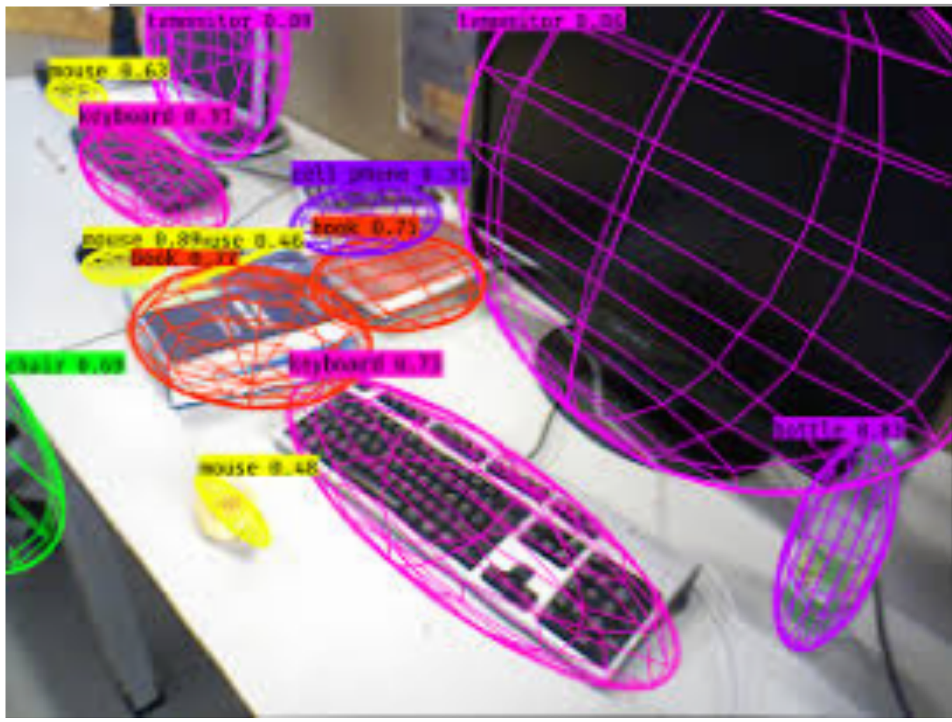
| Week | Dates | Lecture topic | Lab |
|---|---|---|---|
| 1 | Sep 6, 8 | Introduction | Lab 1: Linux, C++, Git |
| 2 | Sep 11, 13, 15 | 3D Geometry | Lab 2: ROS |
| 3 | Sep 18, 20 | Geometric Control | Lab 3: 3D trajectory following |
| 4 | Sep 25, 27, 29 | Trajectory Optimization | Lab 4: 3D trajectory optimization |
| 5 | Oct 2, 4, 6 | 2D Computer Vision | Lab 5: feature detection |
| 6 | Oct 11, 13 | 2-view Geometry and Minimal Solvers | Lab 6: object localization |
| 7 | Oct 16, 18, 20 | Non-minimal Solvers and Visual Odometry | Lab 7: GTSAM |
| 8 | Oct 23, 25, 27 | Place Recognition | Lab 8: ML for robotics |
| 9 | Oct 30, Nov 1, 3 | SLAM and Visual-Inertial Navigation | Lab 9: SLAM |
| 10 | Nov 6, 8 | Advanced Topics | Final project |
| 11 | Nov 13, 15, 17 | Advanced Topics | Final project |
| 12 | Nov 20, 22 | Advanced Topics | Final project |
| 13 | Nov 23-26 | Thanksgiving Break | |
| 14 | Nov 27, 29, Dec 1, 4 ,6, 11, 13 | Guest Lectures and Students Presentations | Final project |

# Structure of VNAV

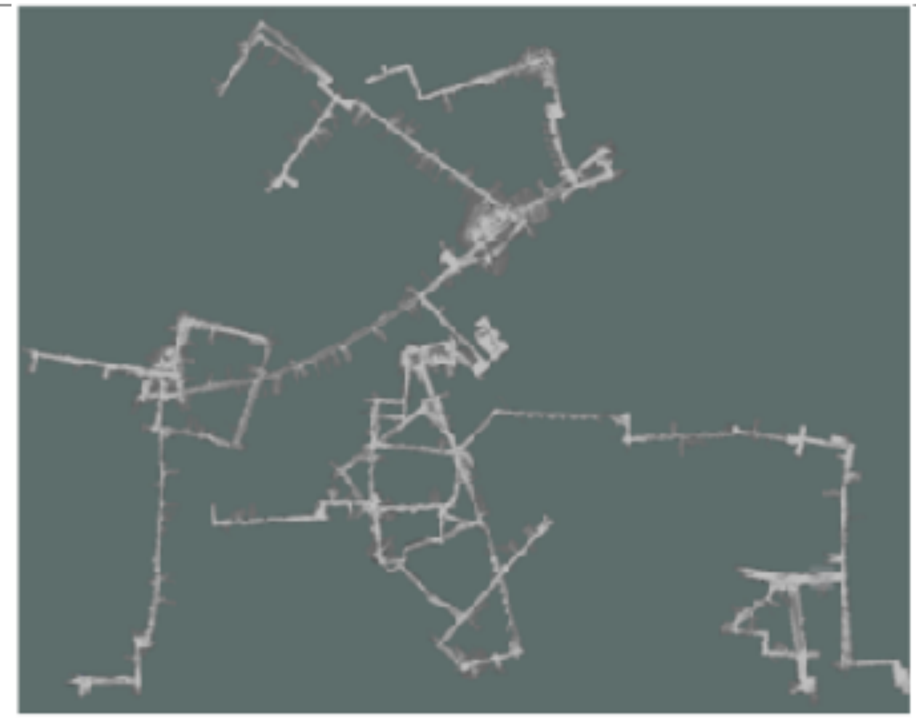
- Lectures:
  - M/W/F at 1-2pm EDT (35-225)
  - Mostly on the board
- Labs:
  - W at 3-5pm EDT (typically in 33-116)
  - Code, assignments, OH
- Office Hours:
  - OH: TBA on Piazza
- Final project:
  - Push the boundary of the state of the art

| Week | Dates | Lecture topic | Lab |
|---|---|---|---|
| 1 | Sep 6, 8 | Introduction | Lab 1: Linux, C++, Git |
| 2 | Sep 11, 13, 15 | 3D Geometry | Lab 2: ROS |
| 3 | Sep 18, 20 | Geometric Control | Lab 3: 3D trajectory following |
| 4 | Sep 25, 27, 29 | Trajectory Optimization | Lab 4: 3D trajectory optimization |
| 5 | Oct 2, 4, 6 | 2D Computer Vision | Lab 5: feature detection |
| 6 | Oct 11, 13 | 2-view Geometry and Minimal Solvers | Lab 6: object localization |
| 7 | Oct 16, 18, 20 | Non-minimal Solvers and Visual Odometry | Lab 7: GTSAM |
| 8 | Oct 23, 25, 27 | Place Recognition | Lab 8: ML for robotics |
| 9 | Oct 30, Nov 1, 3 | SLAM and Visual-Inertial Navigation | Lab 9: SLAM |
| 10 | Nov 6, 8 | Advanced Topics | Final project |
| 11 | Nov 13, 15, 17 | Advanced Topics | Final project |
| 12 | Nov 20, 22 | Advanced Topics | Final project |
| 13 | Nov 23-26 | Thanksgiving Break | |
| 14 | Nov 27, 29, Dec 1, 4 ,6, 11, 13 | Guest Lectures and Students Presentations | Final project |

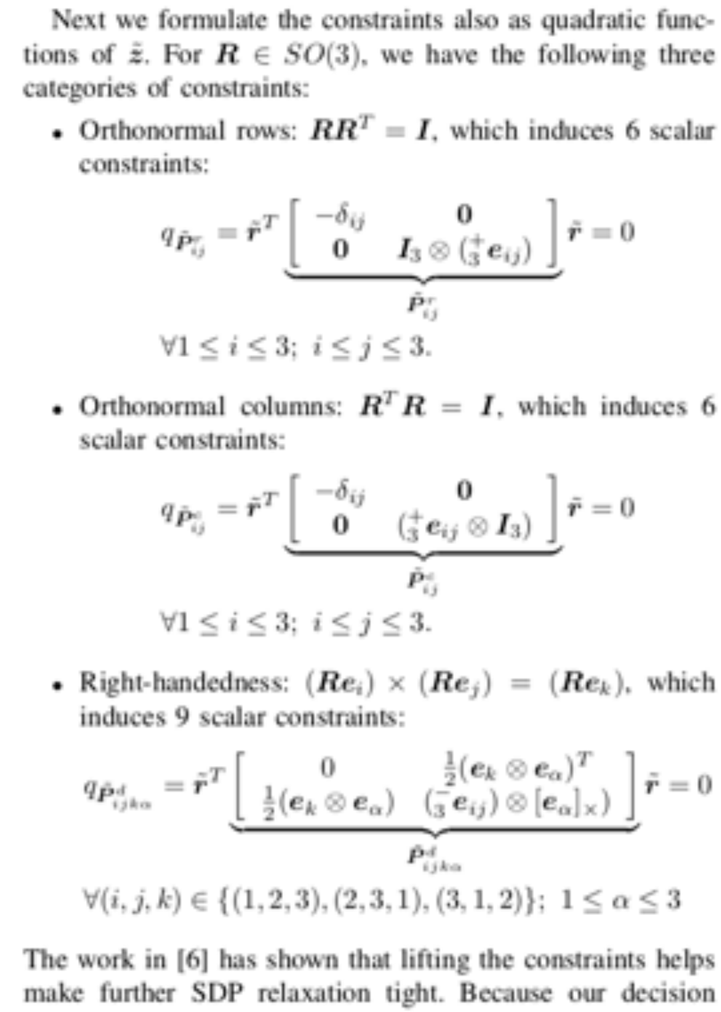
# Final Projects (Samples)




Object-based SLAM



Mapping MIT tunnels



Next we formulate the constraints also as quadratic functions of $\tilde{\boldsymbol{z}}$. For $\boldsymbol{R} \in SO(3)$, we have the following three categories of constraints:

- Orthonormal rows: $\boldsymbol{R}\boldsymbol{R}^T = \boldsymbol{I}$, which induces 6 scalar constraints:

$$q_{\tilde{\boldsymbol{P}}^r_{ij}} = \tilde{\boldsymbol{r}}^T \underbrace{\begin{bmatrix} -\delta_{ij} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{I}_3 \otimes ({}^{+}_{3}\boldsymbol{e}_{ij}) \end{bmatrix}}_{\tilde{\boldsymbol{P}}^r_{ij}} \tilde{\boldsymbol{r}} = 0$$

$\forall 1 \leq i \leq 3;\ i \leq j \leq 3.$

- Orthonormal columns: $\boldsymbol{R}^T\boldsymbol{R} = \boldsymbol{I}$, which induces 6 scalar constraints:

$$q_{\tilde{\boldsymbol{P}}^c_{ij}} = \tilde{\boldsymbol{r}}^T \underbrace{\begin{bmatrix} -\delta_{ij} & \boldsymbol{0} \\ \boldsymbol{0} & ({}^{+}_{3}\boldsymbol{e}_{ij} \otimes \boldsymbol{I}_3) \end{bmatrix}}_{\tilde{\boldsymbol{P}}^c_{ij}} \tilde{\boldsymbol{r}} = 0$$

$\forall 1 \leq i \leq 3;\ i \leq j \leq 3.$

- Right-handedness: $(\boldsymbol{R}\boldsymbol{e}_i) \times (\boldsymbol{R}\boldsymbol{e}_j) = (\boldsymbol{R}\boldsymbol{e}_k)$, which induces 9 scalar constraints:

$$q_{\tilde{\boldsymbol{P}}^d_{ijk\alpha}} = \tilde{\boldsymbol{r}}^T \underbrace{\begin{bmatrix} 0 & \frac{1}{2}(\boldsymbol{e}_k \otimes \boldsymbol{e}_\alpha)^T \\ \frac{1}{2}(\boldsymbol{e}_k \otimes \boldsymbol{e}_\alpha) & ({}^{-}_{3}\boldsymbol{e}_{ij}) \otimes [\boldsymbol{e}_\alpha]_\times) \end{bmatrix}}_{\tilde{\boldsymbol{P}}^d_{ijk\alpha}} \tilde{\boldsymbol{r}} = 0$$

$\forall (i,j,k) \in \{(1,2,3),(2,3,1),(3,1,2)\};\ 1 \leq \alpha \leq 3$

The work in [6] has shown that lifting the constraints helps make further SDP relaxation tight. Because our decision

Robust 2-view

outcomes:

- ICRA'19-20, IROS'19, RSS'19, ICCV'19 papers
- "The VNAV class has been a deciding factor for the completion of my thesis."


Drone racing

# Assignments & Grading

- Assignment schedule
  - Lab exercises announced on Wednesdays
  - Lab exercises due the following Wednesday
  - Lab handouts include:
    - Setup **instructions**
    - 3-5 **questions**
      - **Theoretical and**
      - **Experimental**
  - Work in teams of 2-3 students but questions may be individual

| Week | assignment | Individual/ Team | Announced | Due |
|---|---|---|---|---|
| 1 | Lab 1: Linux, C++, Git | I | W Sept 06 | W Sept 13 |
| 2 | Lab 2: ROS | I | W Sept 13 | W Sept 20 |
| 3 | Lab 3: 3D trajectory following | T/I | W Sept 20 | W Sep 27 |
| 4 | Lab 4: 3D trajectory optimization | T/I | W Sep 27 | W Oct 4 |
| 5 | Lab 5: Feature detection | T/I | W Oct 4 | W Oct 11 |
| 6 | Lab 6: Object localization | T/I | W Oct 11 | W Oct 18 |
| 7 | Lab 7: GTSAM | T/I | W Oct 18 | W Oct 25 |
| 8 | Lab 8: Place recognition | T/I | W Oct 25 | W Nov 1 |
| 9 | Lab 9: SLAM | T/I | W Nov 1 | W Nov 8 |
| 10-14 | Final project (report, demo, presentation) | T | W Nov 8 | M Dec 4, W Dec 6, M Dec 11, W Dec 13 |

MIT AEROASTRO

# Assignments & Grading

- no final exam but final project
  - Final **demo**, showcasing the project outcome
  - Team **presentation**, including a video abstract of the project
  - Technical **report** (formatted using ICRA guidelines)

| Week | assignment | Individual/ Team | Announced | Due |
|---|---|---|---|---|
| 1 | Lab 1: Linux, C++, Git | I | W Sept 06 | W Sept 13 |
| 2 | Lab 2: ROS | I | W Sept 13 | W Sept 20 |
| 3 | Lab 3: 3D trajectory following | T/I | W Sept 20 | W Sep 27 |
| 4 | Lab 4: 3D trajectory optimization | T/I | W Sep 27 | W Oct 4 |
| 5 | Lab 5: Feature detection | T/I | W Oct 4 | W Oct 11 |
| 6 | Lab 6: Object localization | T/I | W Oct 11 | W Oct 18 |
| 7 | Lab 7: GTSAM | T/I | W Oct 18 | W Oct 25 |
| 8 | Lab 8: Place recognition | T/I | W Oct 25 | W Nov 1 |
| 9 | Lab 9: SLAM | T/I | W Nov 1 | W Nov 8 |
| 10-14 | Final project (report, demo, presentation) | T | W Nov 8 | M Dec 4, W Dec 6, M Dec 11, W Dec 13 |

MIT AEROASTRO

# ICRA what?

**ICRA: International Conference on Robotics and Automation**


ROBOTICS SCIENCE AND SYSTEMS

**RSS**


**IROS**

| Submission deadlines | |
|---|---|
| ICRA 2024 | Sept. 15, 2023 |
| RSS 2024 | Feb. 1, 2023 (?) |
| IROS 2024 | Mar. 1, 2023 (?) |
| ICRA 2025 | Sep. 15, 2024 (?) |

# Assignments & Grading

- Syllabus: https://tinyurl.com/VNAV2023-syllabus
- All assignments are announced on Canvas: https://tinyurl.com/VNAV2023-canvas (lab handouts: https://vnav.mit.edu/)

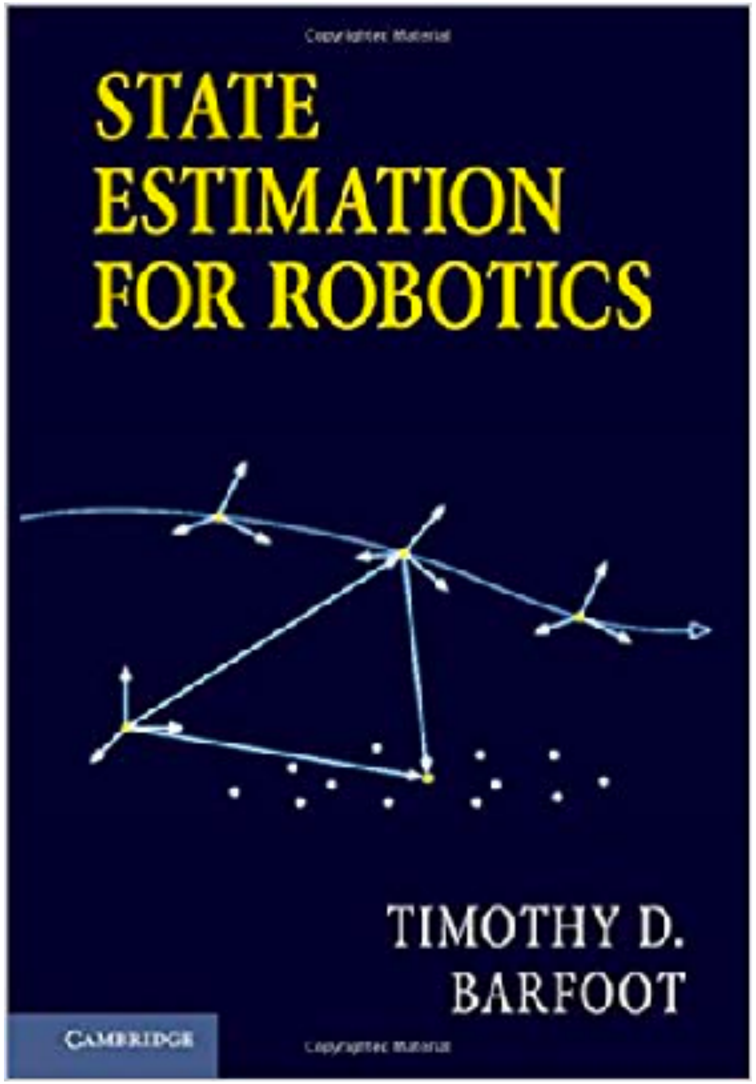
- [65%] Lab exercises and code
- [25%] Final project: demo, presentation, technical report
- [ 5%] Participation and TA/LA evaluation
- [ 5%] Team members' assessment

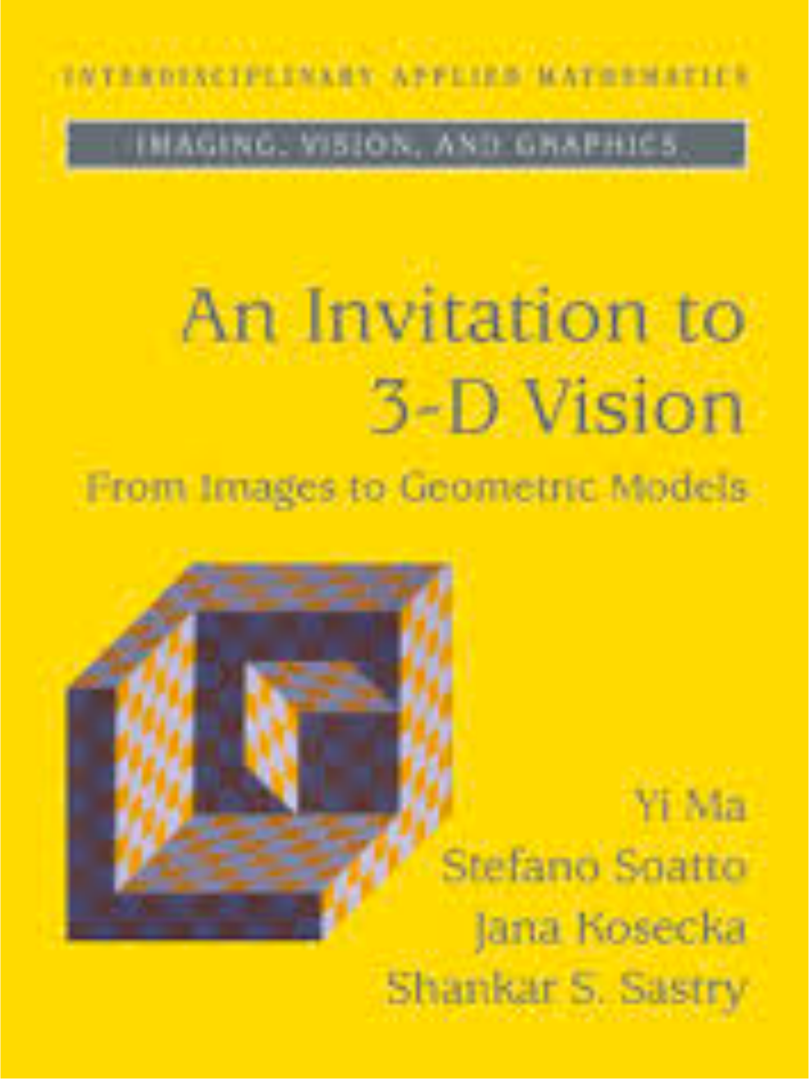
- Penalty on late submissions:
  grade_late_submission = grade * max(1 - 0.15 * days_late, 0)
- Q&A with TAs and Instructors on Piazza: https://tinyurl.com/VNAV2023-piazza

MIT AEROASTRO

# Textbooks

- Both textbooks are recommended, but not required
- Both available online




- Specific pointers to chapters in these books and other resources (papers) will be provided in each lecture

# Requirements & Pre-reqs

- Requirements satisfied by VNAV:
  - 12 units: 3 - 2 - 7
  - Field Evaluation Subject in Course 16
- Prerequisites:
  - Programming and algorithms (16.35 or similar)
    - Familiarity with coding and **C++**
  - Optimal estimation and control (16.32 or similar)
    - PID, Kalman Filtering, …
  - Linear algebra (18.06 or similar)
- Good to have:
    - Independent experience (UROPs, competitions, etc.)
    - Some background in optimization
  - [online questionnaire distributed at the end of this lecture]

# Lecture Outline

- **Logistics**
  - Goals of VNAV
  - Structure
  - Assignments & Grading
  - Requirements & Pre-reqs

- **Visual Navigation for Autonomous Vehicles**
  - The robot revolution
  - Why perception?
  - More on the VNAV Staff

# The Robot Revolution: Self-driving Cars


Oct, 2016

https://www.tesla.com/videos/full-self-driving-hardware-all-tesla-cars

https://www.cnn.com/2023/01/17/tech/tesla-self-driving-video-staged/index.html#:~:text=A%202016%20video%20that%20Tesla,testimony%20by%20a%20senior%20engineer.

# The Robot Revolution: Drones


https://www.youtube.com/watch?v=gsfkGlSajHQ

# The DARPA **Subt**erranean Challenge


Source: public domain.

# The Robot Revolution

ground

transportation

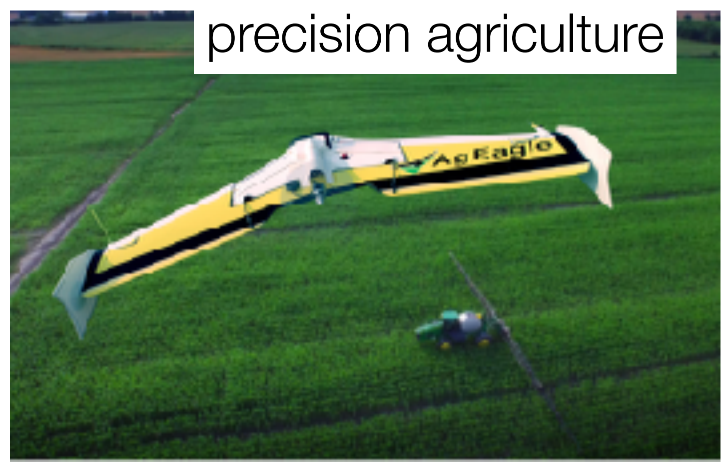
mining

domestic

goods, manufacturing

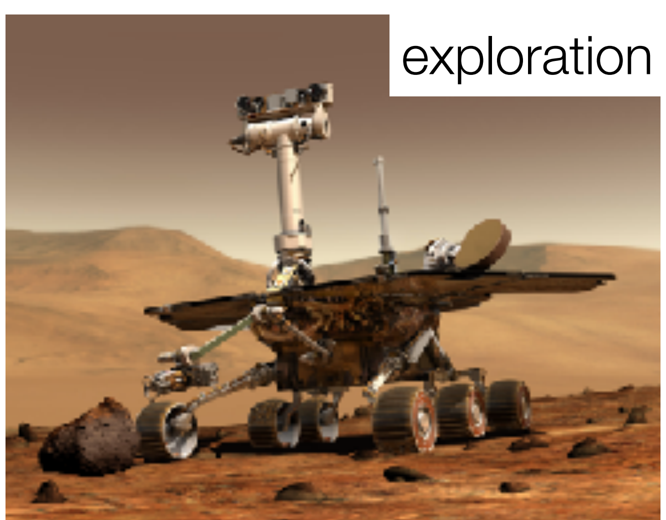
air

monitoring, disaster response

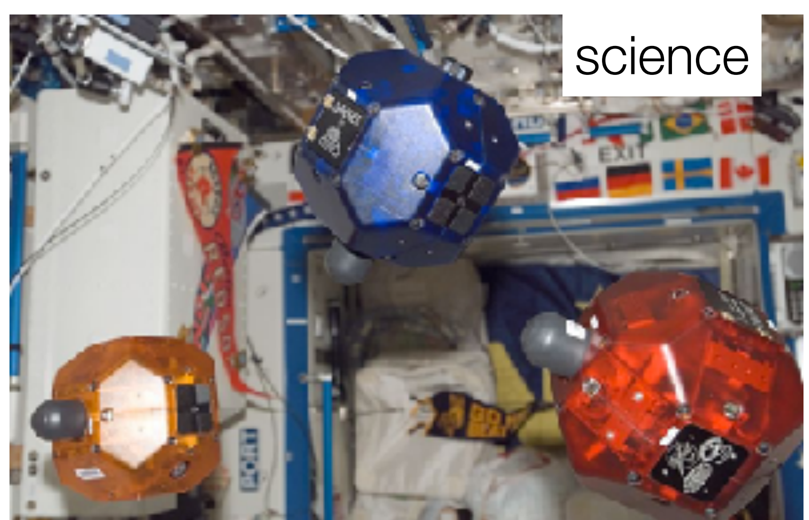


precision agriculture


space



exploration



science

and more ...

medical applications

environmental monitoring

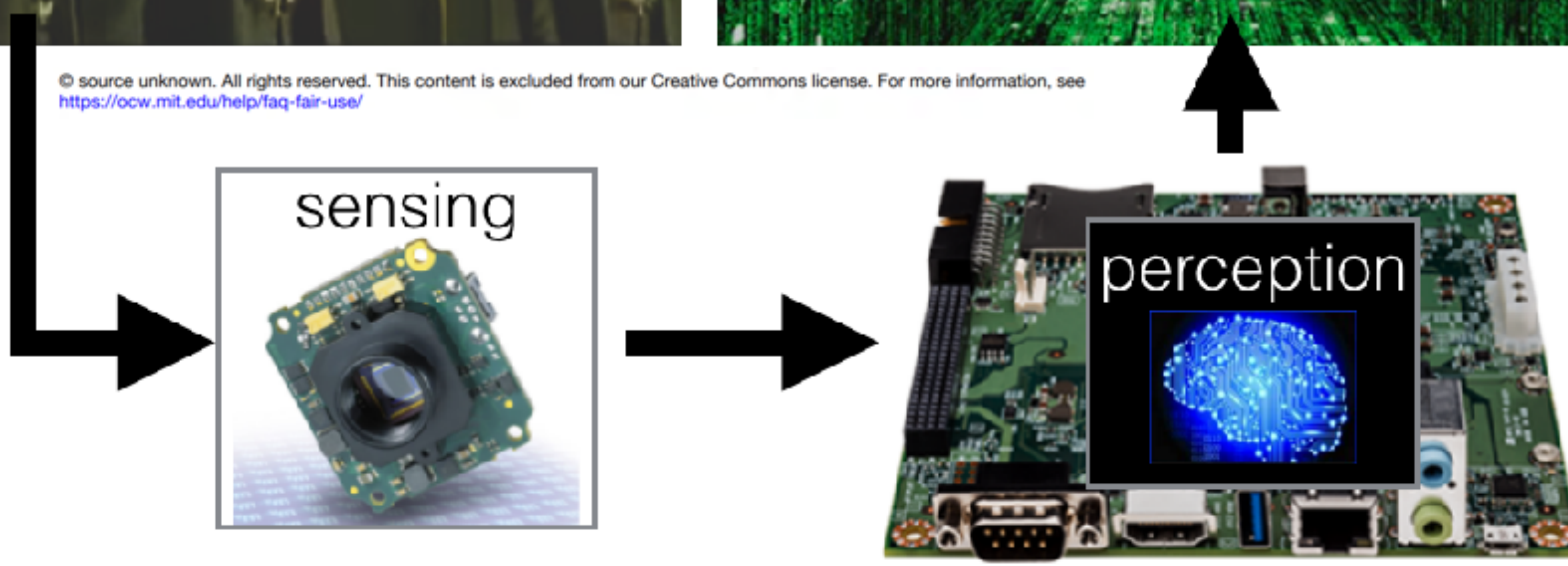
**reasons for adoption**: faster, better, safer, cheaper, access

# Robot Perception

real world

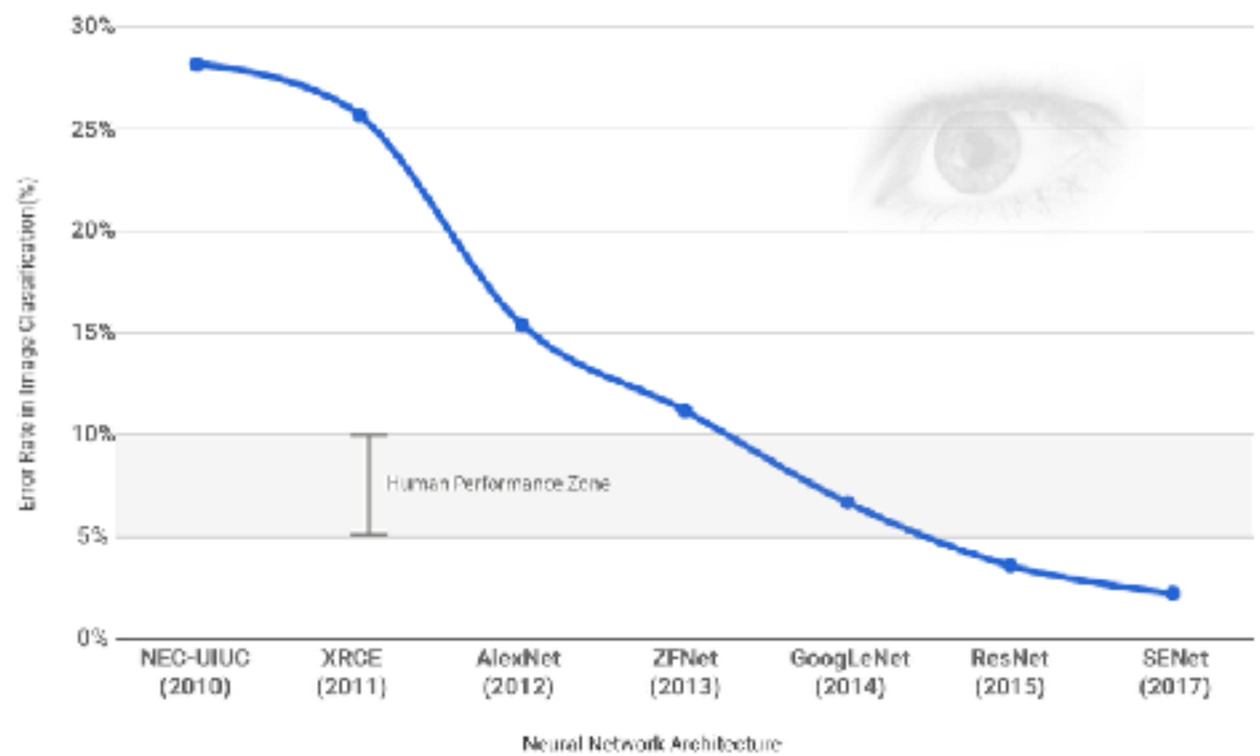
world model / representation





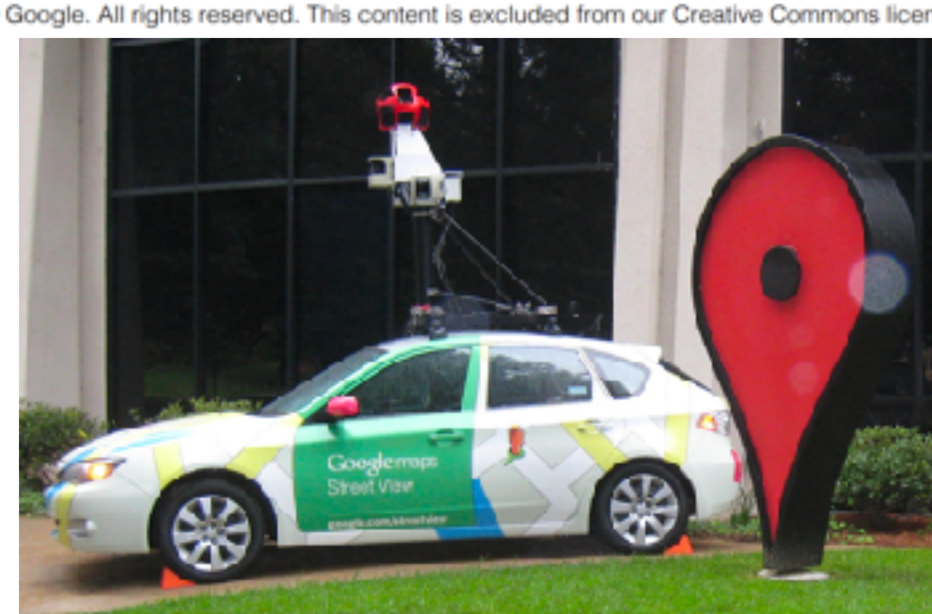
# Why Perception?


Things are starting to work!






Google Street View



Oculus Rift Goggles

# Why Perception?

Perception success.. and its failures


Images: Evtimov et al 

Camouflage graffiti and art stickers cause a neural network to misclassify stop signs as speed limit 45 signs or yield signs.

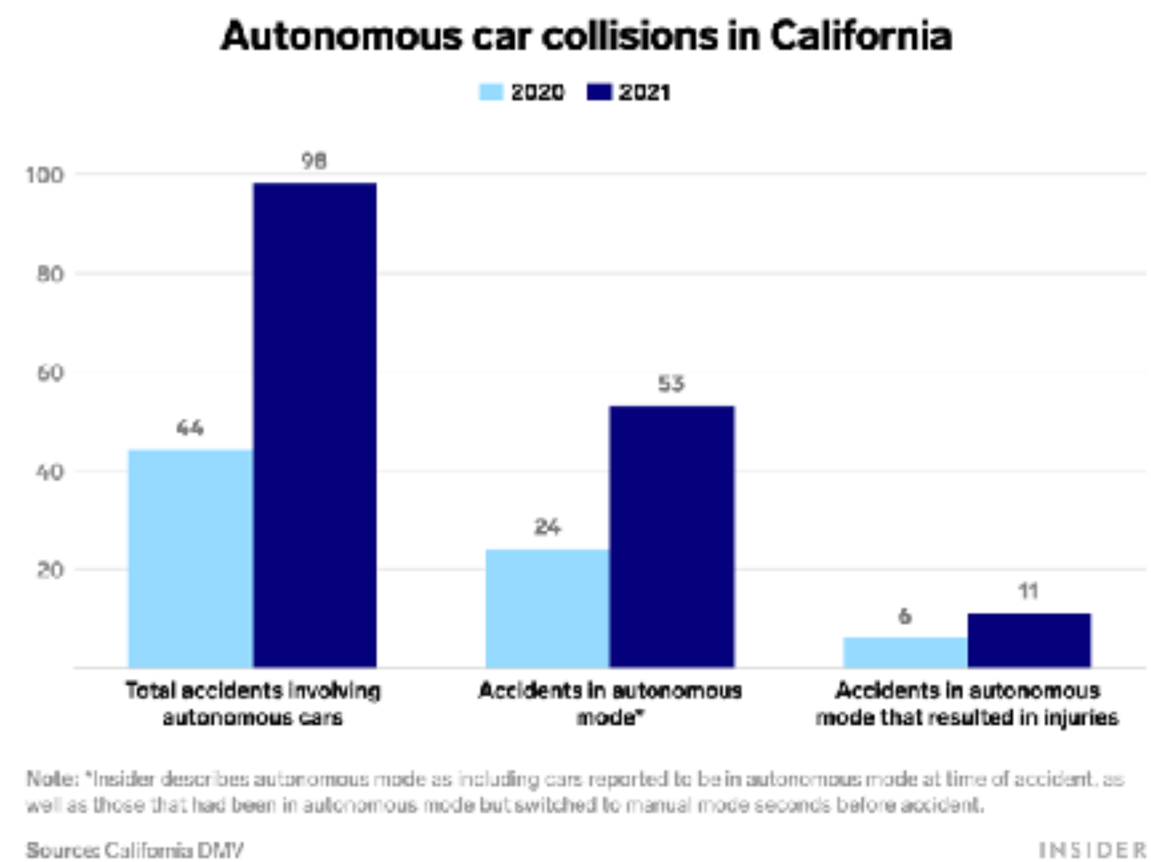


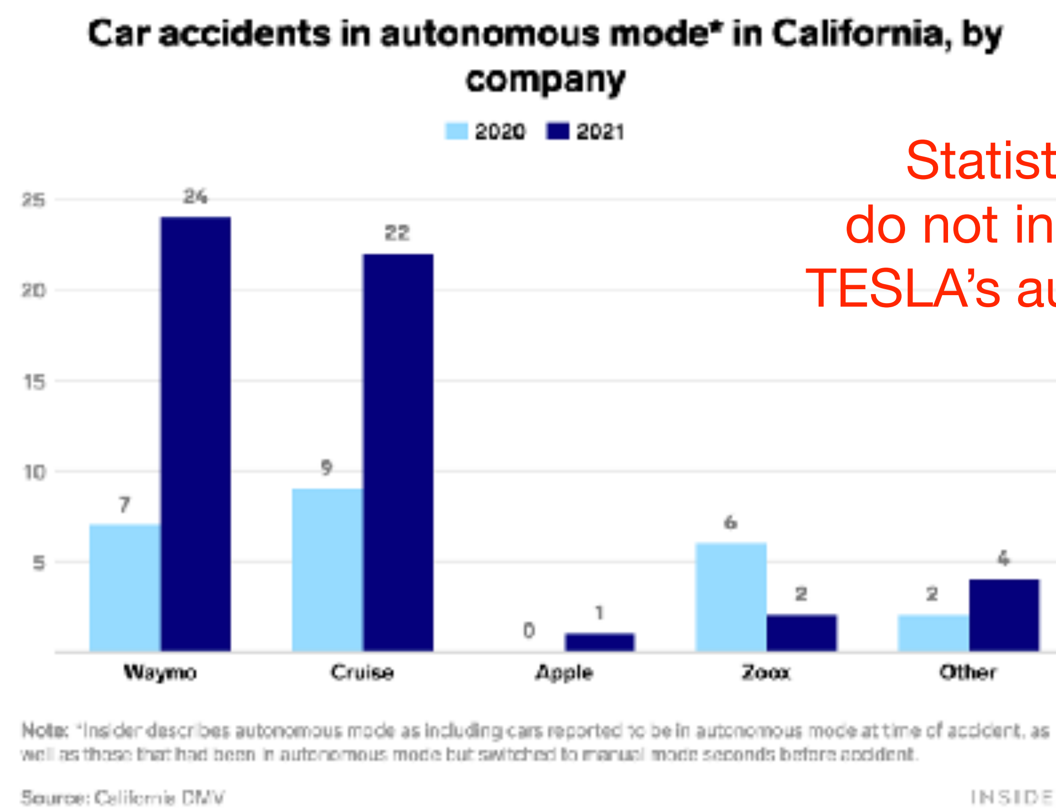
"Google employs a small army of human operators to manually check and correct the maps" [Wired]

# A long road ahead

## Robust perception is crucial in safety critical applications

**Waymo and Cruise self-driving cars took over San Francisco streets at record levels in 2021 — so did collisions with other cars, scooters, and bikes**



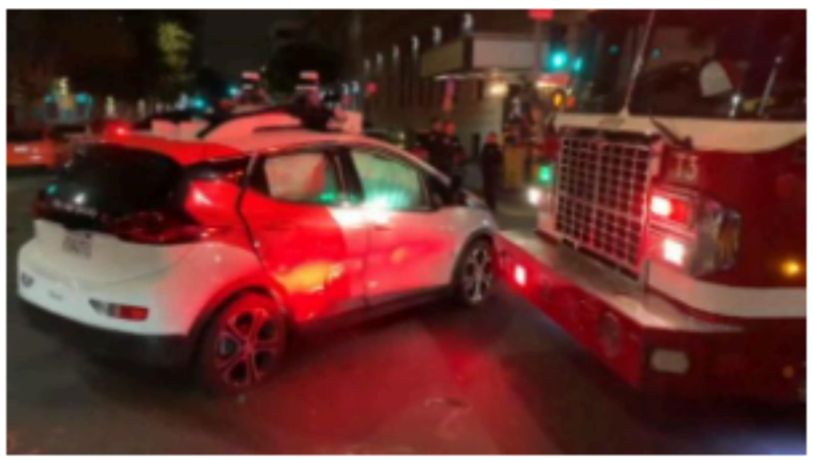




Statistics do not include TESLA's autopilot



[https://www.businessinsider.com/self-driving-car-accidents-waymo-cruise-tesla-zoox-san-francisco-2022-1]

# 2 robotaxi crashes in San Francisco put focus on autonomous vehicle safety


A Cruise driverless taxi collided with a San Francisco Fire Department engine.

KPIX

*August 18, 2023 / 9:05 PM*

"The fire engine was operating in Code 3 emergency mode, with lights and sirens. It's really a reminder to everyone you are required to yield whether it's a vehicle driven by a human operator or an autonomous vehicle," said SFPD spokesperson Sgt. Kathryn Winters.

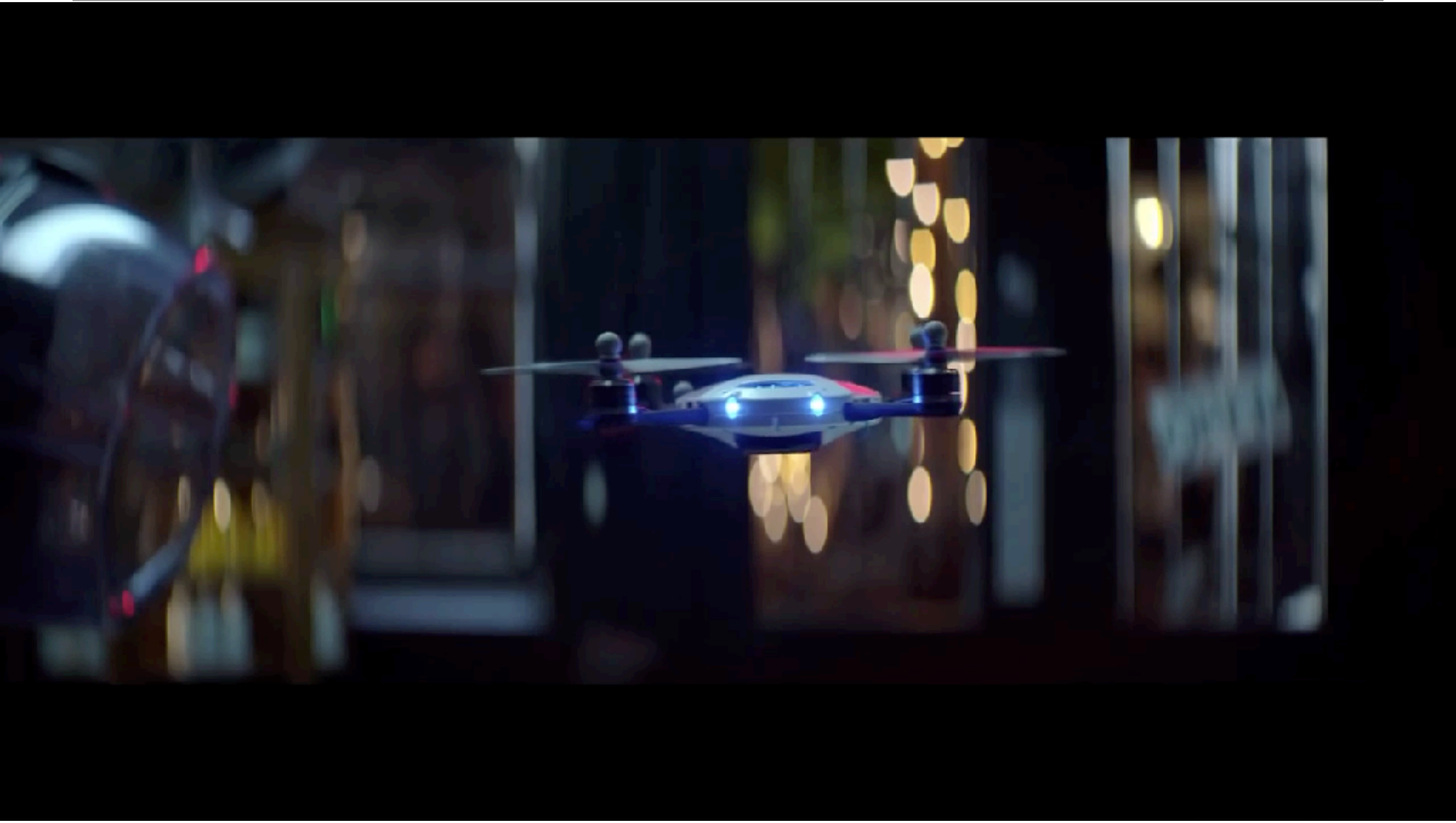
It was unclear why the self-driving car did not yield. Cruise said in a statement it's investigating to better understand the problem.

About two hours later, another Cruise driverless car was struck by Dodge Charger in the Mission District.

https://www.cbsnews.com/sanfrancisco/news/robotaxi-crashes-san-francisco-focus-autonomous-vehicle-safety/

# Why Perception?

# Why Perception?

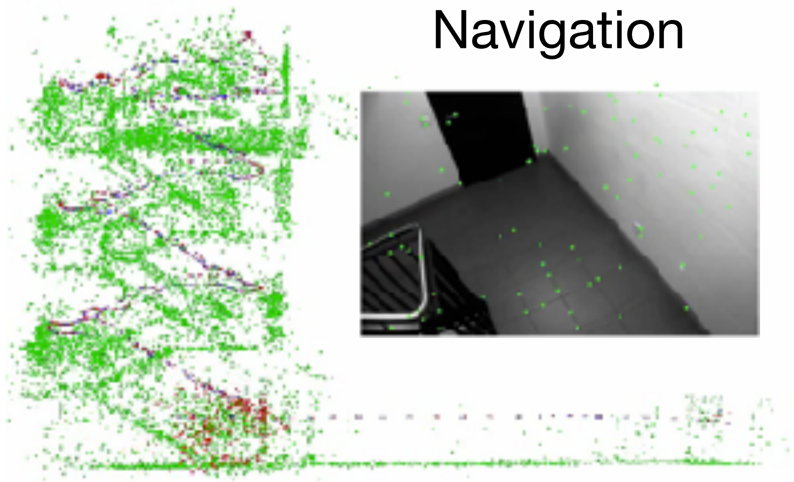


[computer animation, courtesy of Lexus]

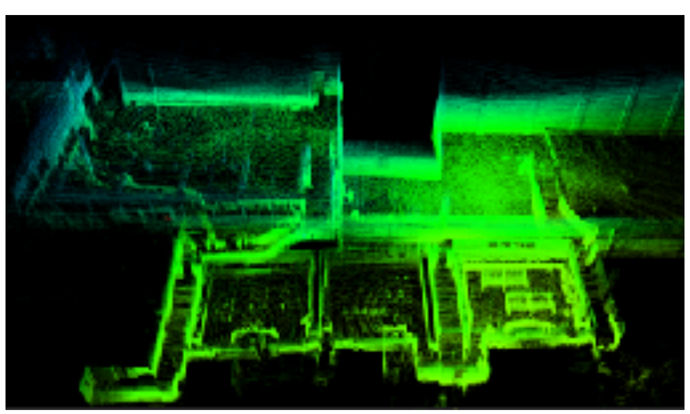
# **S**ensing **P**erception **A**utonomy and **R**obot **K**inetics

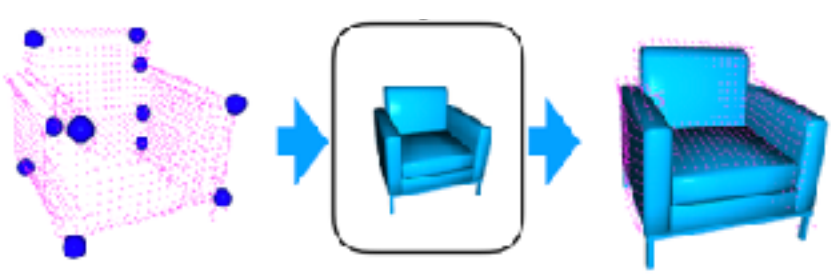
## Robust Perception, Localization and Mapping

Visual-inertial Navigation



Lidar-based SLAM

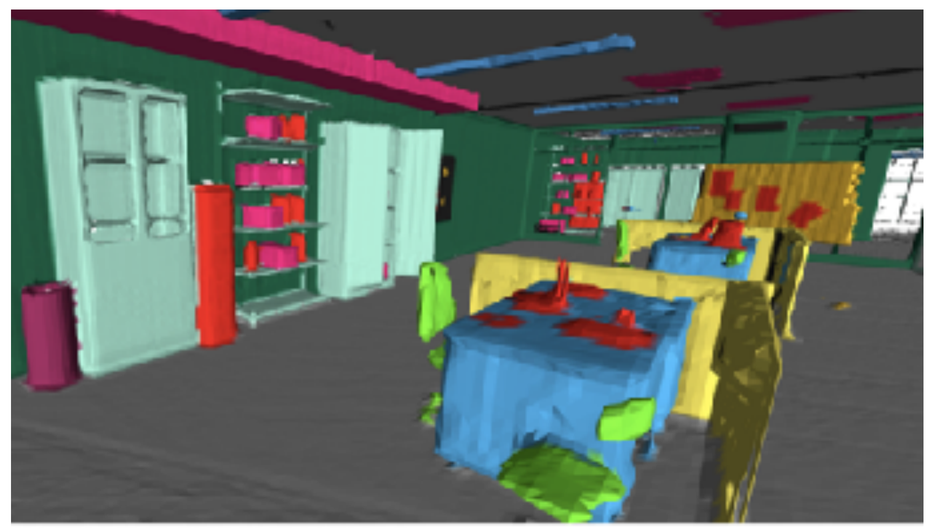


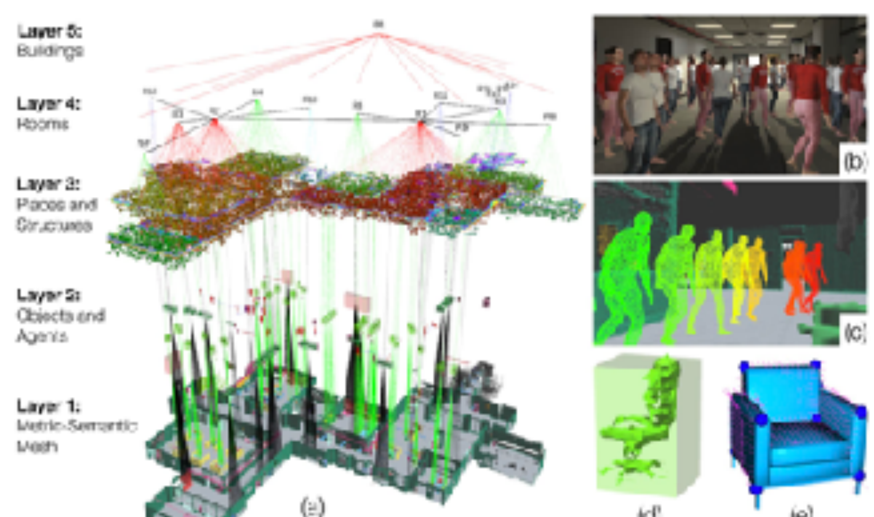


Certifiable Algorithms

## High-level Scene Understanding (Spatial AI)

Kimera: Metrics-semantic SLAM

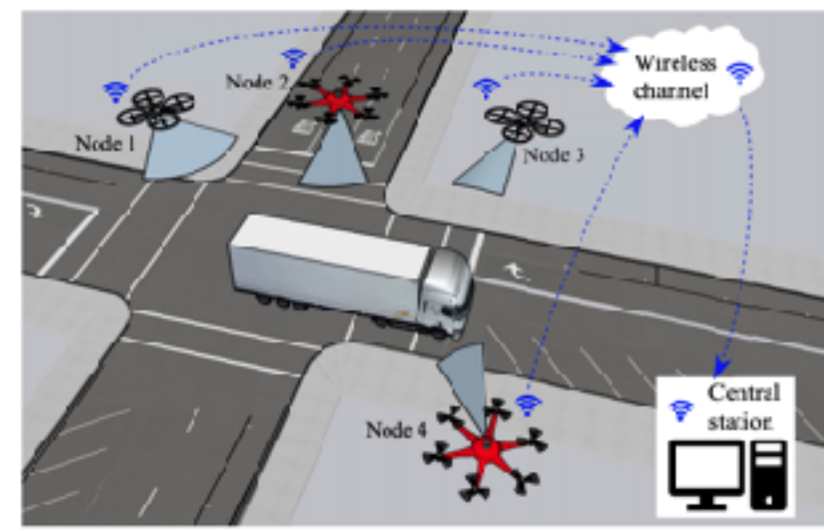


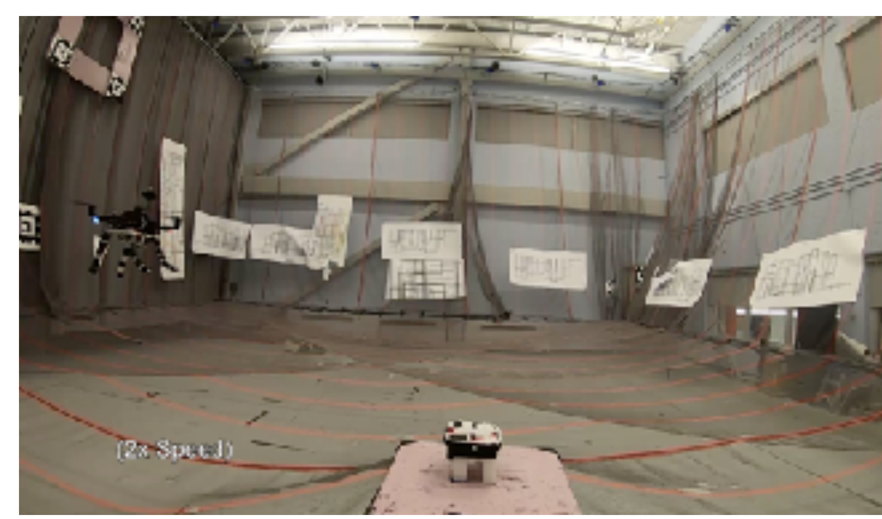



3D Scene Graphs

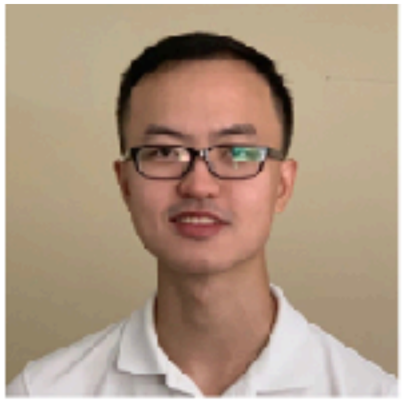
## Co-design

- Computation-communication co-design
- Control and sensing co-design



Soft Drones and Soft Aerial Manipulation




Jingnan Shi
jnshi@mit.edu


- AeroAstro MS, 3rd year PhD
- Undergrad at Harvey Mudd College
- Likes to cook
- Have a shiba inu

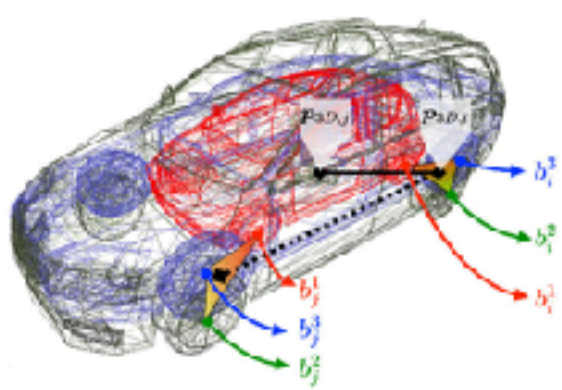
## Current Research

Research Question:

Can we implement object perception that is general, efficient and robust?

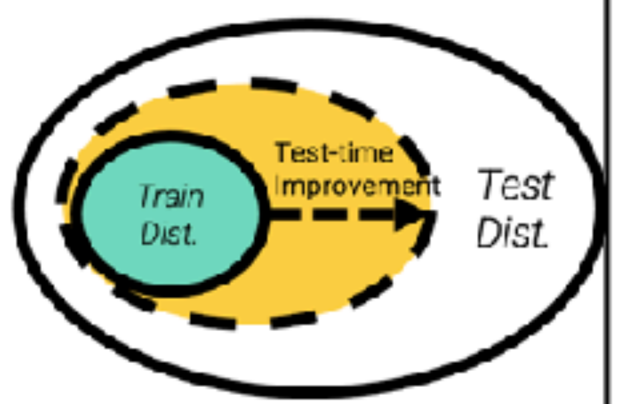
### Focus 1

Optimal and Robust Pose and Shape Estimation



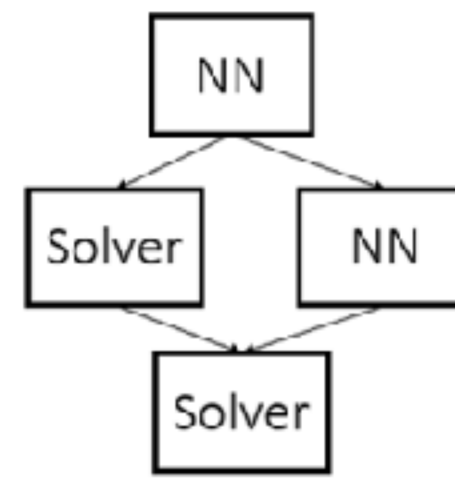
### Focus 2

Self-supervision of 3D Object Pose Estimation Pipelines Through Certification




### Focus 3

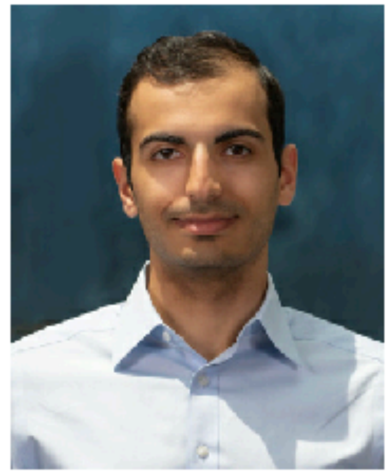
Lifelong and Continual Online Learning for 3D Perception Systems



# Dominic Maggio

3rd year grad student

- M.S. Course 16, 2023
- B.S. (16 & 6-2), 2021



Research

- High-altitude visual localization
- Using neural maps for visual localization

VNAV final project (2021)

- Visual Inertial Navigation at night using Infrared flashlights mounted to a drone

Outside School

- Hometown: Olive Branch, Louisiana
- Building Rockets, RC Planes, Boats

# Nathan Hughes

**Research Goal:** Actionable representations designed for robot interaction

2nd Year PhD Student
(AeroAstro)

**Undergraduate Education:** *WPI '16 (RBE / CS)*

**Research Focus:** 3D Scene Graphs

- Creation from visual-inertial data *(Hydra)*
- Richer scene representations

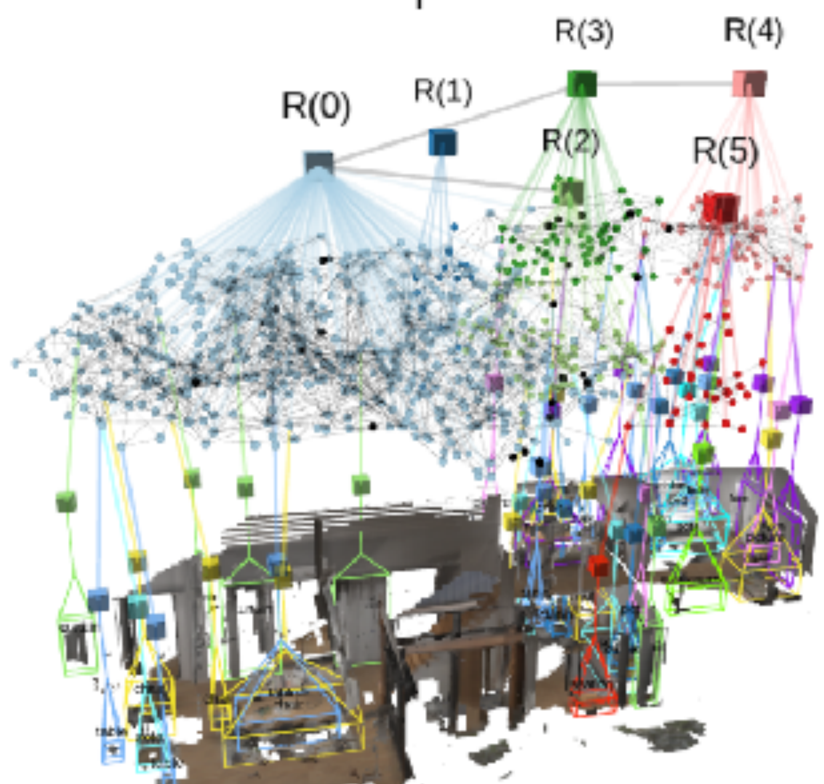



**Figure:** 3D Scene Graph Created by Hydra

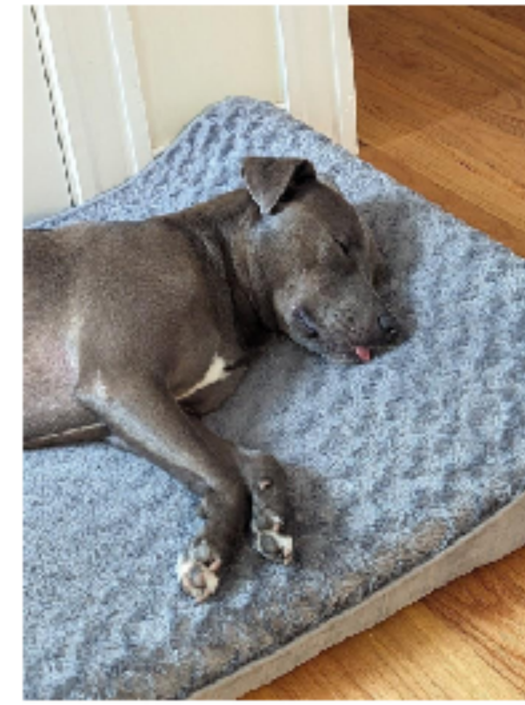
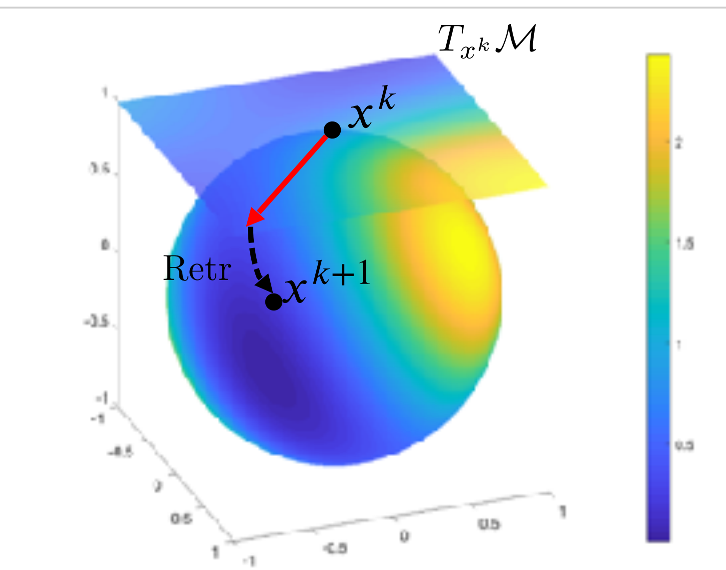


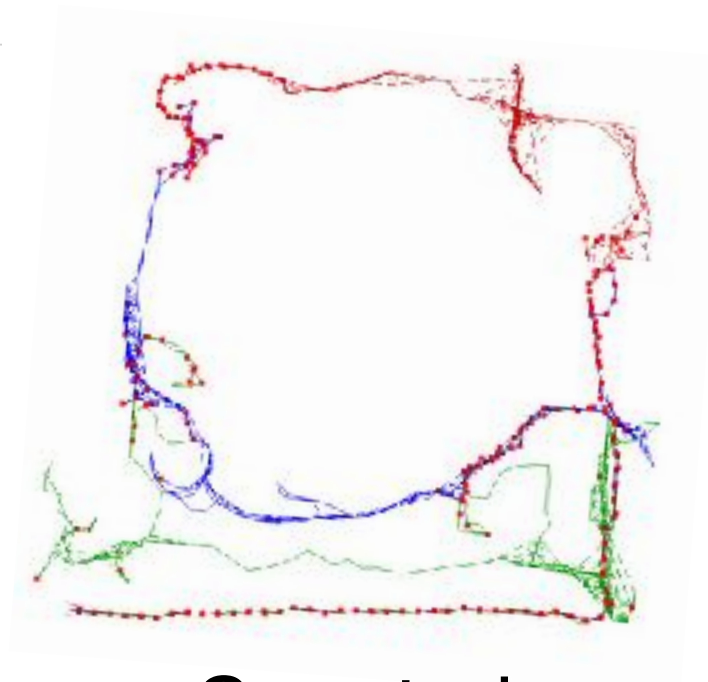
**Figure:** Dory (my dog)

## Yulun Tian

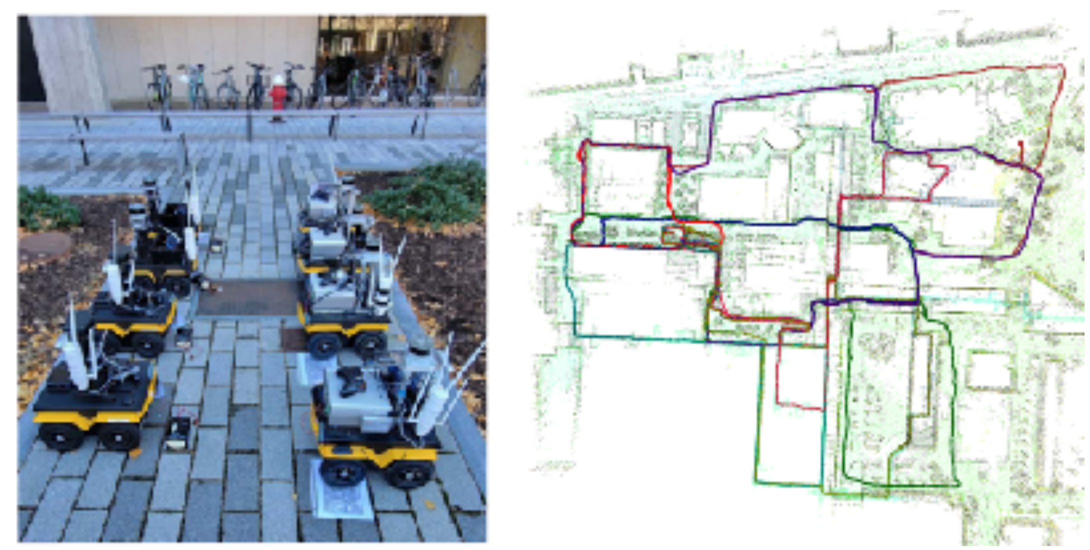
- **Who am I:** Postdoc at MIT AeroAstro working with Prof. Jon How
- **Research interests**: Perception, Optimization, Multi-Robot Systems


Optimization on manifolds



Spectral graph theory



Multi-Robot Distributed SLAM

https://robotics.mit.edu

# Robotics @ MIT

- Home
- News
- Robotics Seminar
- Email List
- Graduate Women In Robotics
- Robotics-Related Email List
- Robotics@MIT Student Conference

## Robotics Groups at MIT (listed by Principal Investigator)

| | |
|---|---|
| Perceptual Science Group | Ted Adelson |
| Improbable AI | Pulkit Agrawal |
| D'Arbeloff Lab: Robotics | Harry Asada |
| Lab website coming soon! | Navid Azizan |
| Center for Marine Robotics (at Woods Hole) | James Bellingham |
| Personal Robotics Group | Cynthia Breazeal |
| The SPARK (Sensing, Perception, Autonomy, and Robot Kinetics) Lab | Luca Carlone |
| Soft and Micro Robotics Laboratory | Kevin Chen |
| Control Networks Group | Domitilla Del Vecchio |
| Realm: REliable Autonomous systems Lab | Chuchu Fan |

# Admission questionnaire

Admission questionnaire at following link:

http://tinyurl.com/VNAV2023-survey

**Please fill in and submit by 5:00pm today**

**Lab 1** at 3pm today in 33-116

Thank you for the attention!

MIT AEROASTRO