16.485: VNAV - Visual Navigation for Autonomous Vehicles

Luca Carlone

Lecture 1

To ask questions:

Raise Hand (under "Participants") or Chat

VNAV Staff

Instructors

Luca
Carlone

Vasileios
Tzoumas

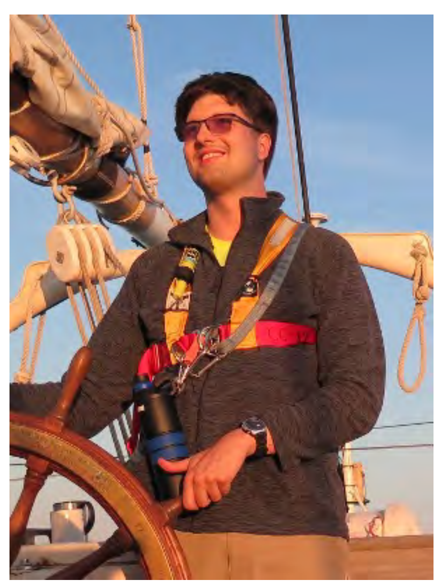
Rajat
Talak

Course Admin

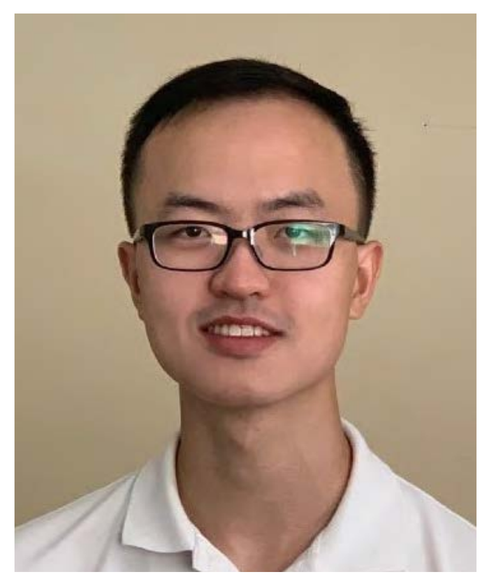
Quentin
Alexander

Teaching Assistants

Yun
Chang



Stewart
Jamieson



Jingnan
Shi

Heng “Hank”
Yang

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 (1/2)

- Mens / Theory:
  - Learn/develop/exercise **theoretical tools** necessary for robotics research (geometry, optimization, …)
  - Learn about state-of-the-art **algorithms** for 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 (6.141/16.405)
- **Note 3**: this is not an ML course (but we will use ML in some labs)
- **Overarching goal**: prepare you (or refine your skills) to perform state-of-the-art research in robotics (not necessarily in robot perception)

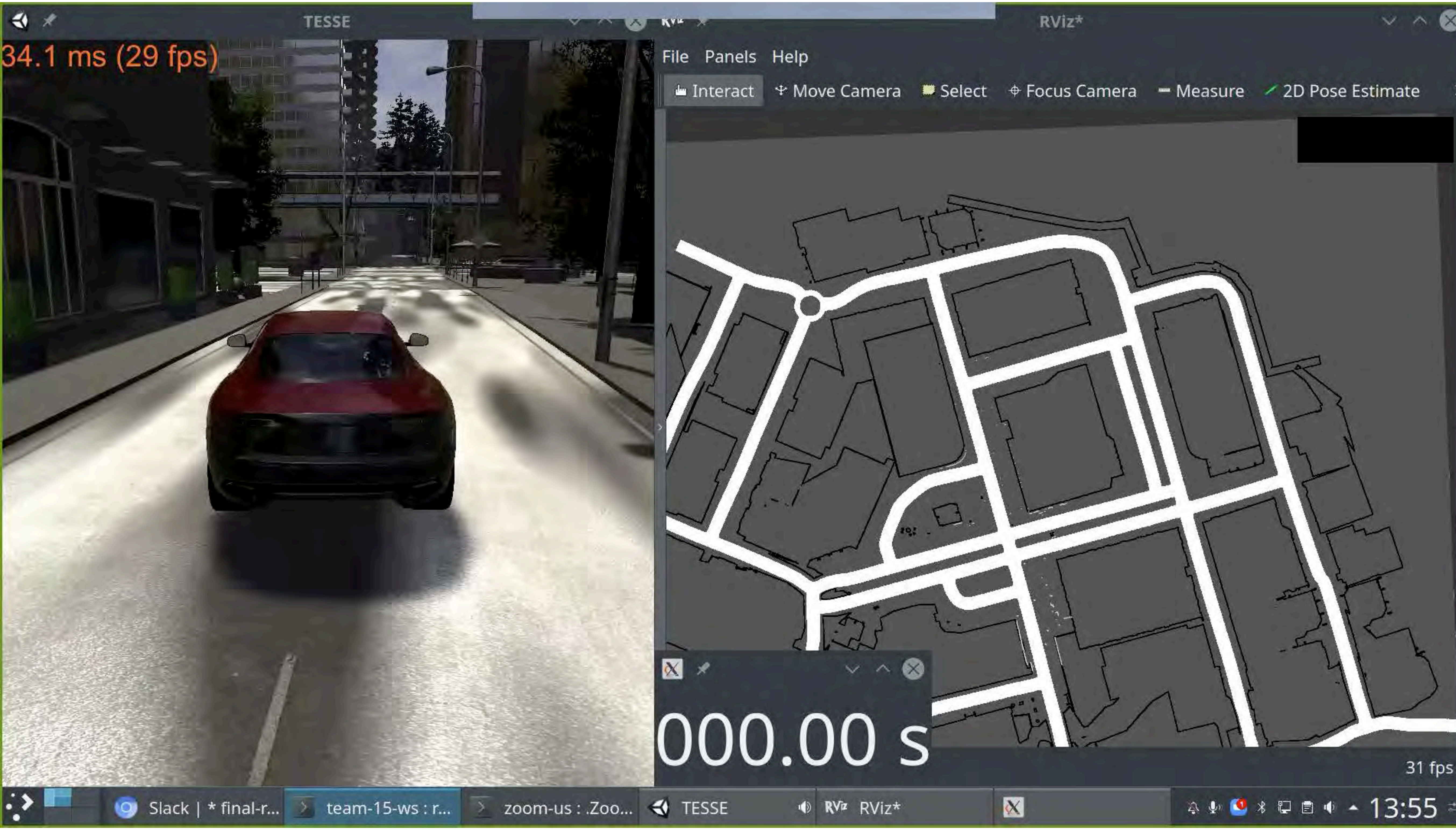
Goals of VNAV (2/2)

- Manus / Practice:
  - Learn/practice **ROS** (**R**obot **O**perating **S**ystem)
  - Rigorous testing of state-of-the-art implementations for perception, control, ML, ~~on **real platforms**~~ in photo-realistic simulator
  - Learn **limitations** of state-of-the-art implementations

- **Note**: If you do not like **coding (in C++)**, you may not like this class
- **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

Practice in Realistic Unity-based Simulator



but this time we fly!

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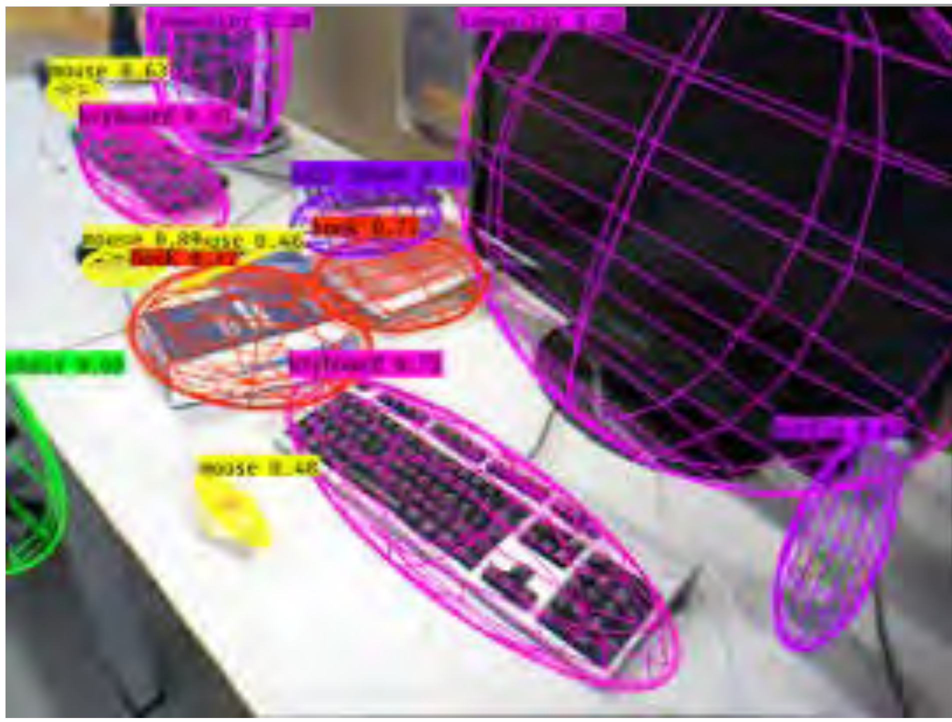
Final Projects (Samples)



Object-based SLAM

Mapping MIT tunnels

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

- Orthonormal rows: $RR^T = I$, which induces 6 scalar constraints:

$$q_{\tilde{P}^r_{ij}} = \tilde{r}^T \underbrace{\begin{bmatrix} -\delta_{ij} & \mathbf{0} \\ \mathbf{0} & I_3 \otimes ({}^{+}_{3}e_{ij}) \end{bmatrix}}_{\tilde{P}^r_{ij}} \tilde{r} = 0$$

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

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

$$q_{\tilde{P}^c_{ij}} = \tilde{r}^T \underbrace{\begin{bmatrix} -\delta_{ij} & \mathbf{0} \\ \mathbf{0} & ({}^{+}_{3}e_{ij} \otimes I_3) \end{bmatrix}}_{\tilde{P}^c_{ij}} \tilde{r} = 0$$

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

- Right-handedness: $(Re_i) \times (Re_j) = (Re_k)$, which induces 9 scalar constraints:

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

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

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

Robust 2-view

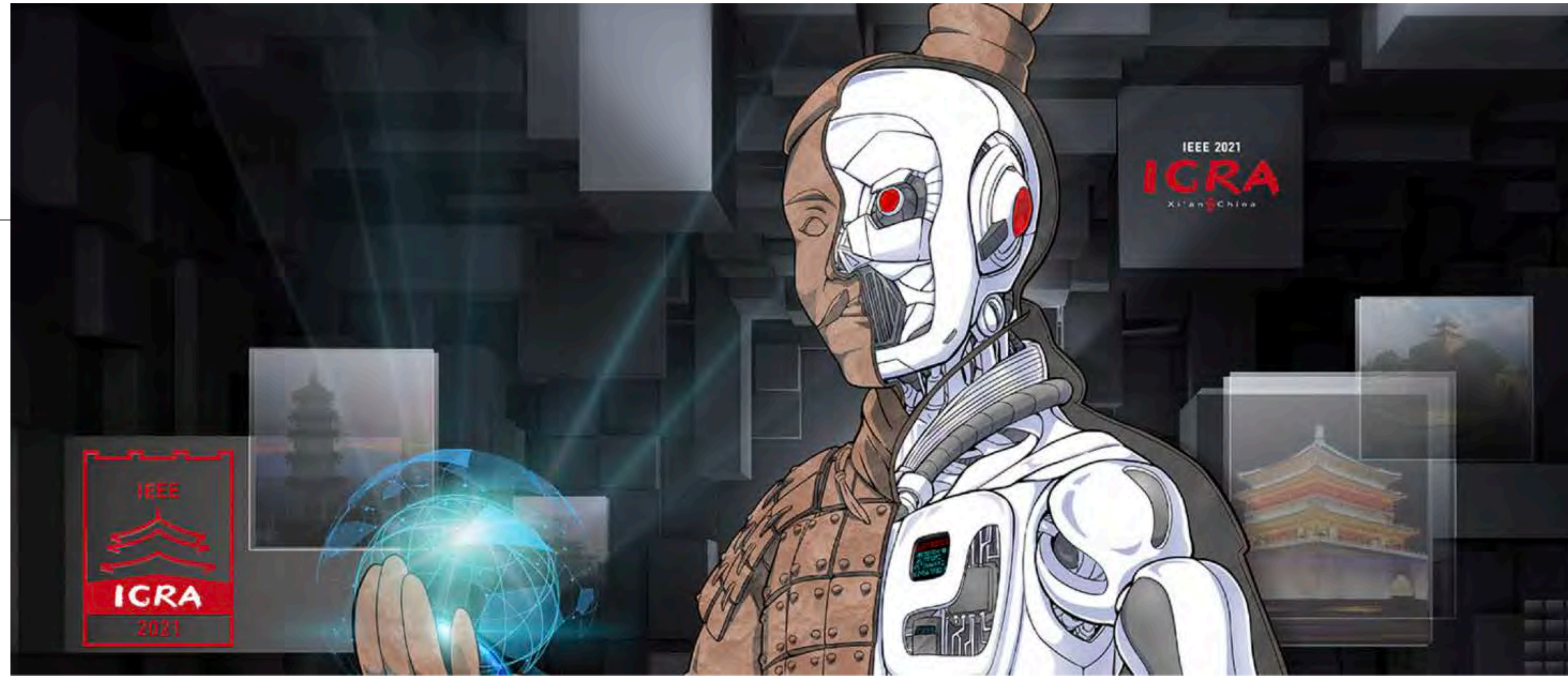
outcomes:

- 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

ICRA what?

ICRA: International Conference on Robotics and Automation



ROBOTICS SCIENCE AND SYSTEMS

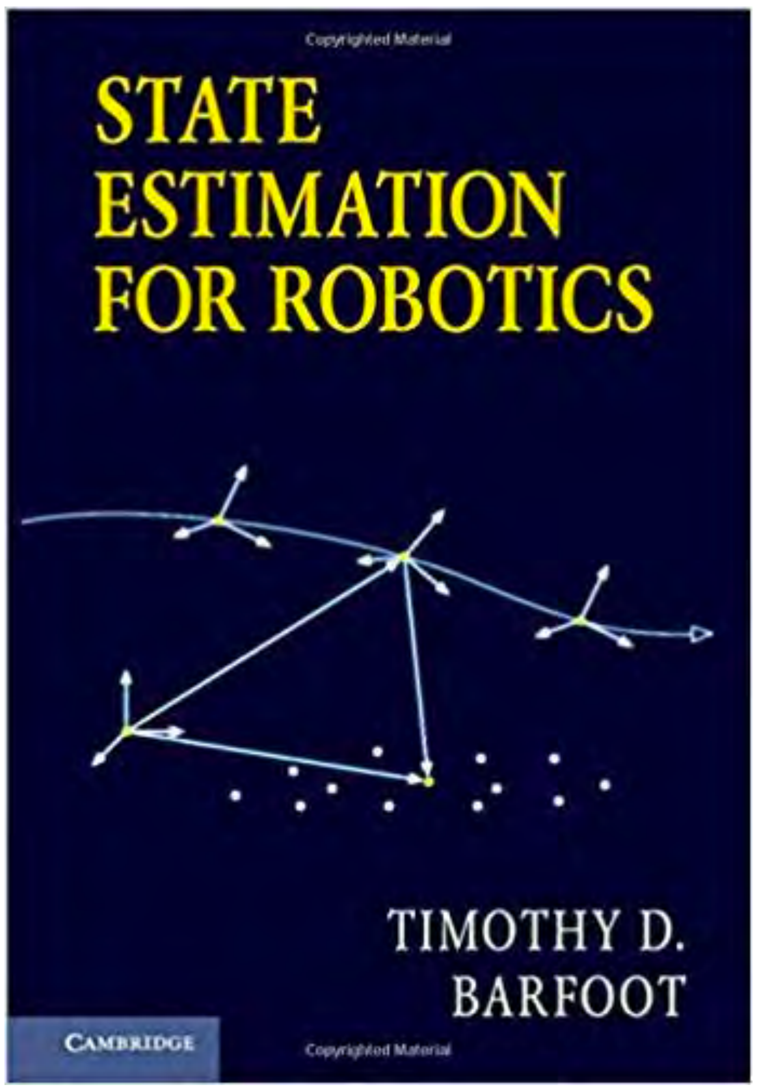
RSS

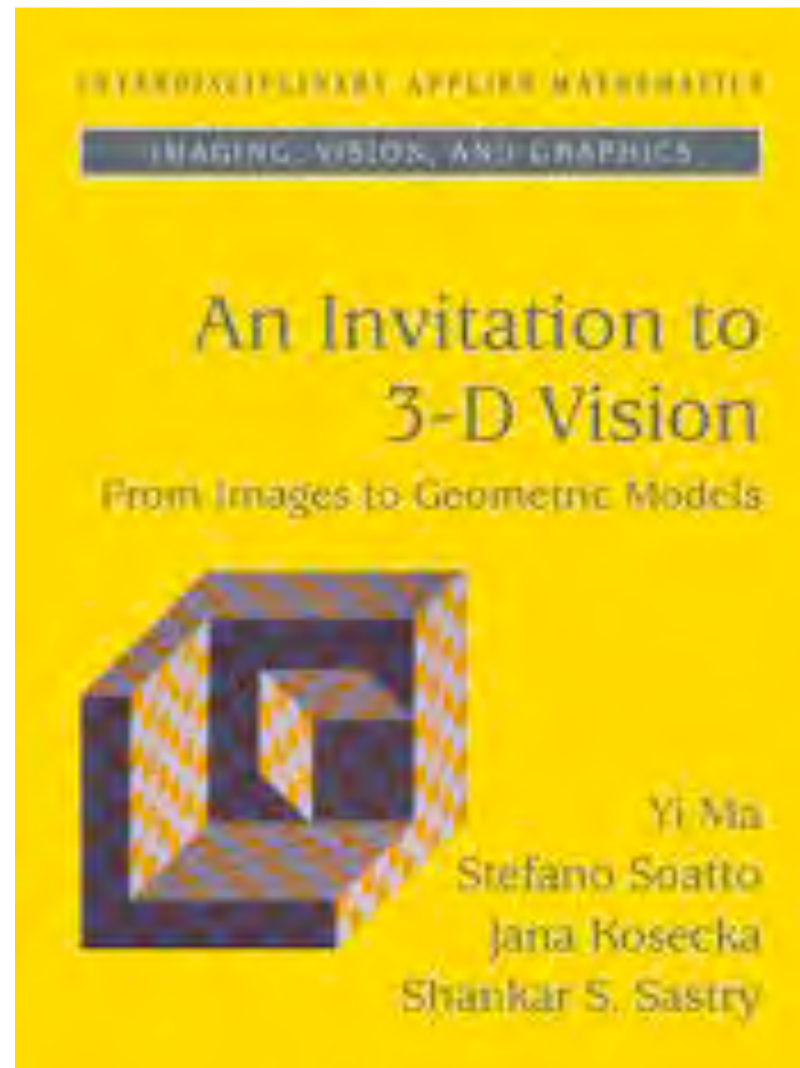
IROS

Submission deadlines	
ICRA 2021	Oct. 31, 2020
RSS 2021	Feb. 1, 2020 (?)
IROS 2021	Mar. 1, 2020 (?)
ICRA 2022	Sep. 15, 2020 (?)

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)
    - Recitation today!
- Good to have:
    - Independent experience (UROPs, competitions, etc.)
    - Some background in optimization
  - [online questionnaire distributed at the end of this lecture]

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The Robot Revolution: Self-driving Cars

https://www.youtube.com/watch?v=NoSuXFc7Eo4

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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

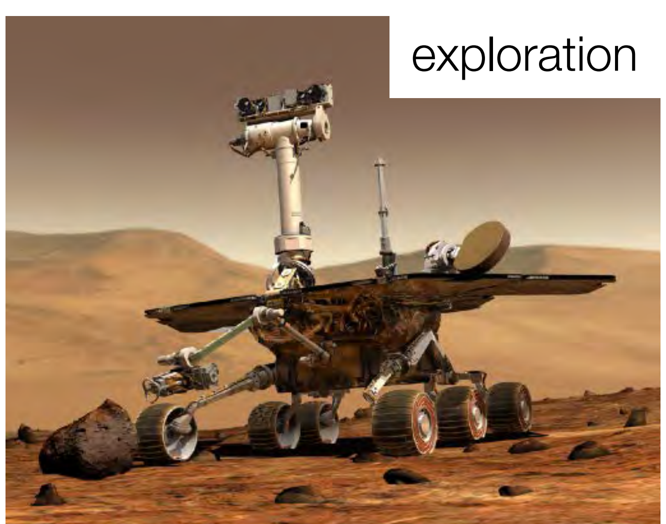

goods, manufacturing

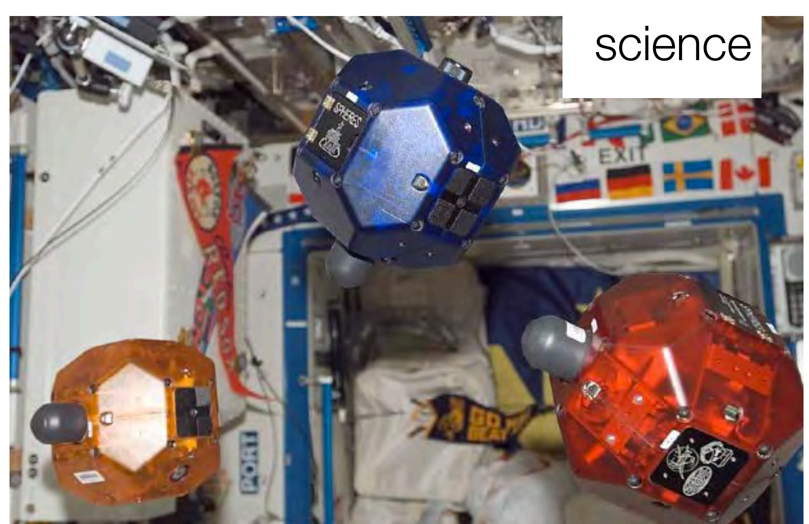
air


monitoring,disaster response

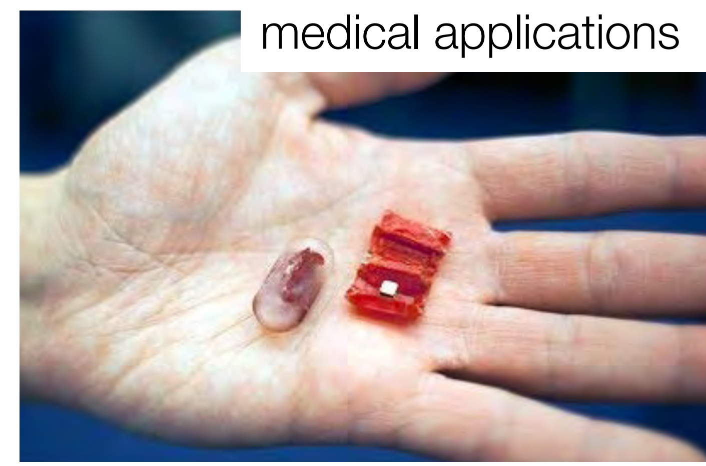
precision agriculture

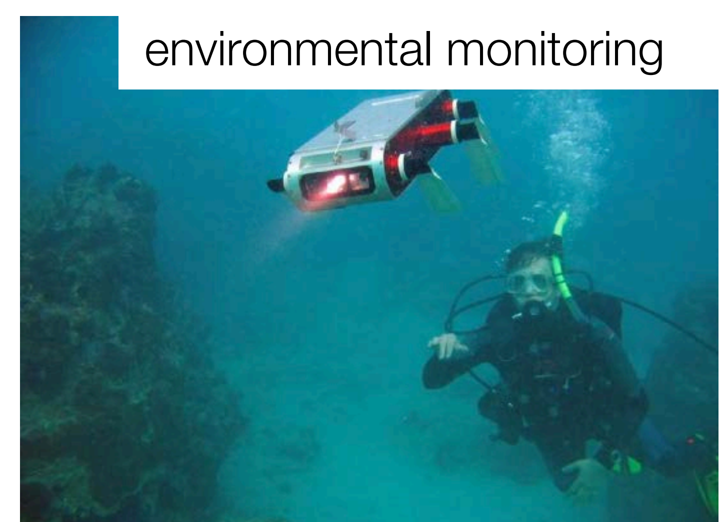
space


exploration


science

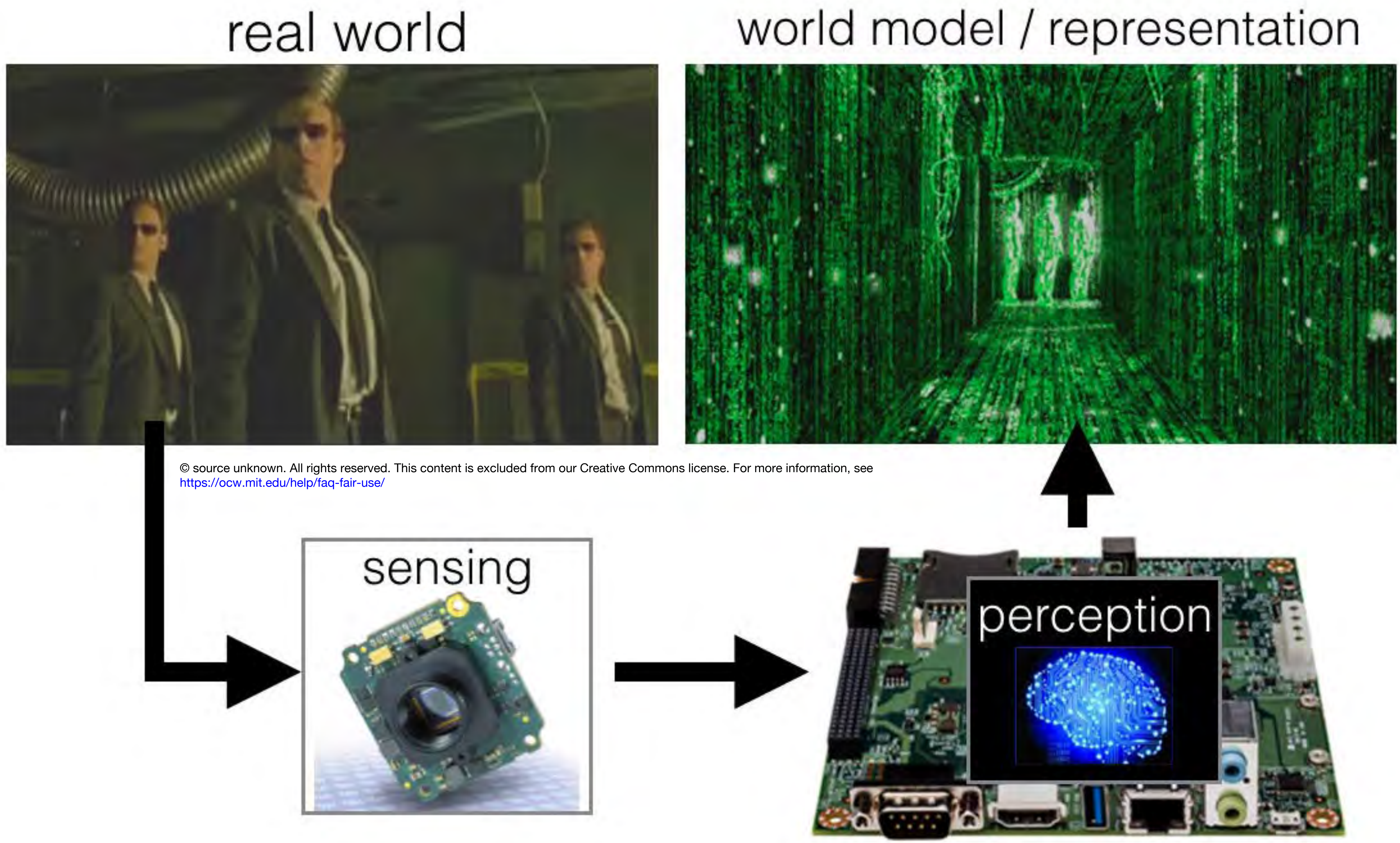
and more ...


medical applications


environmental monitoring

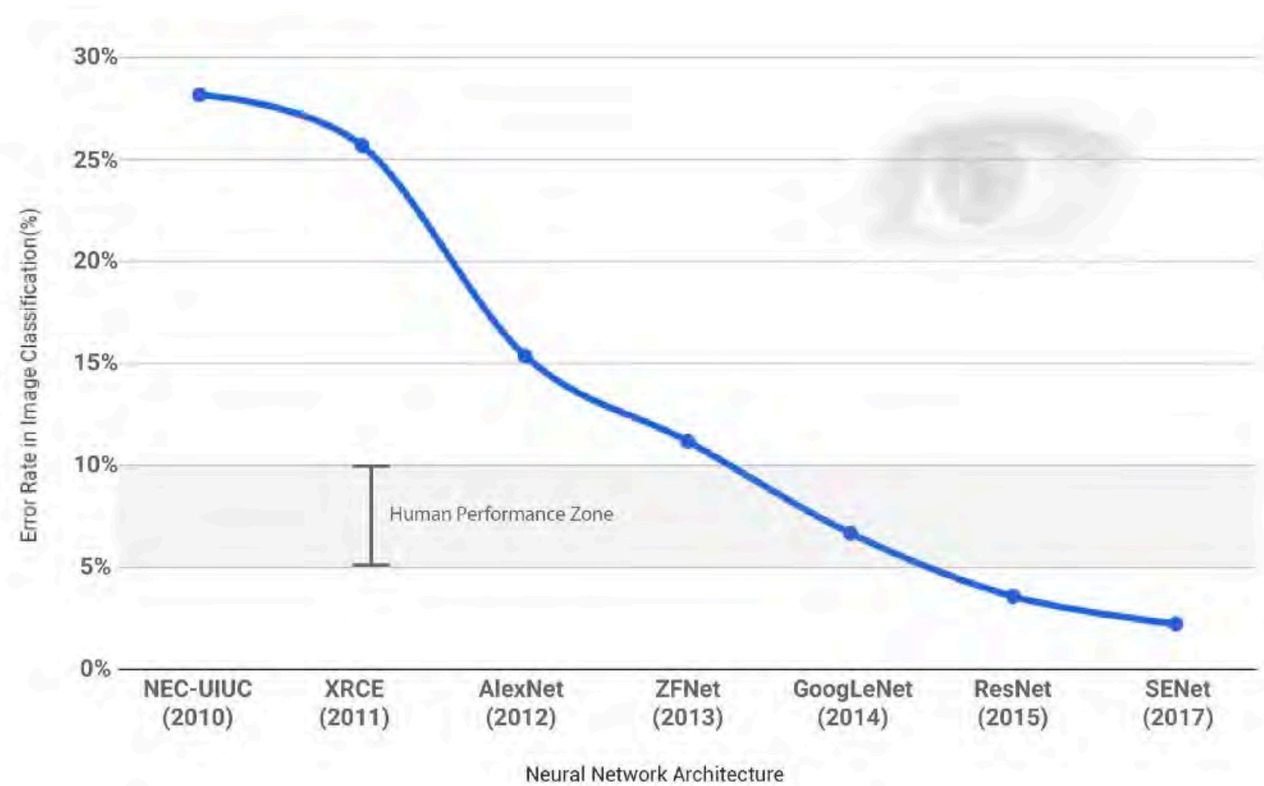
reasons for adoption: faster, better, safer, cheaper, access

Robot Perception

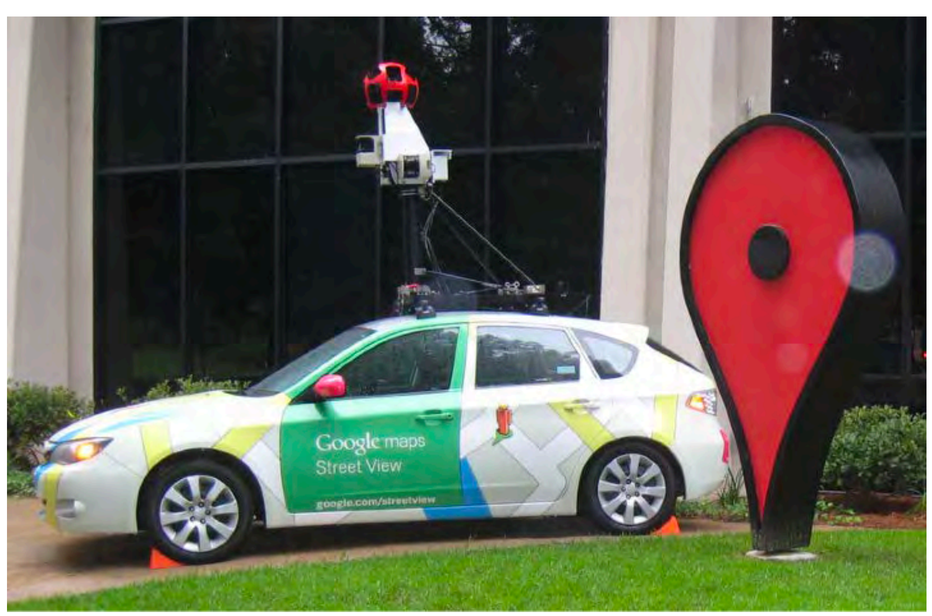


Why Perception?

Things are starting to work!



Google Street View



Oculus Rift Goggles

Why Perception?

Perception success.. and its failures

Images: Evtimov et al

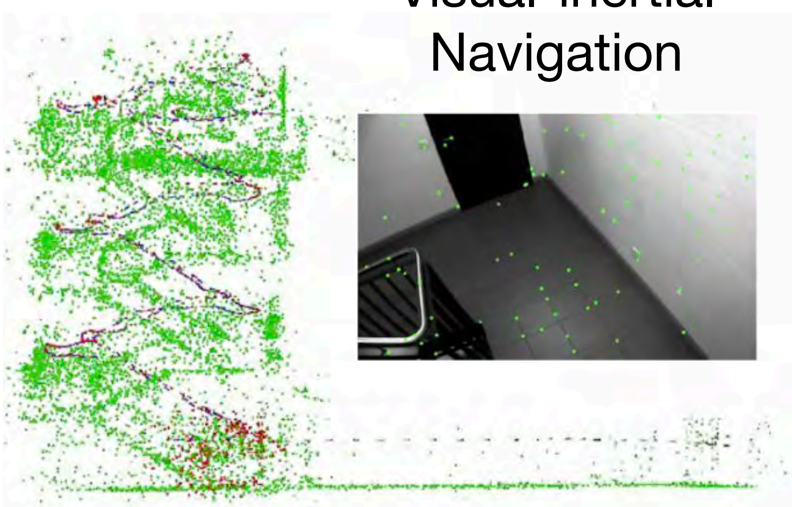
Camouflage graffiti and art stickers cause a neural network to misclassify stop signs as speed limit 45 signs or yield signs.

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

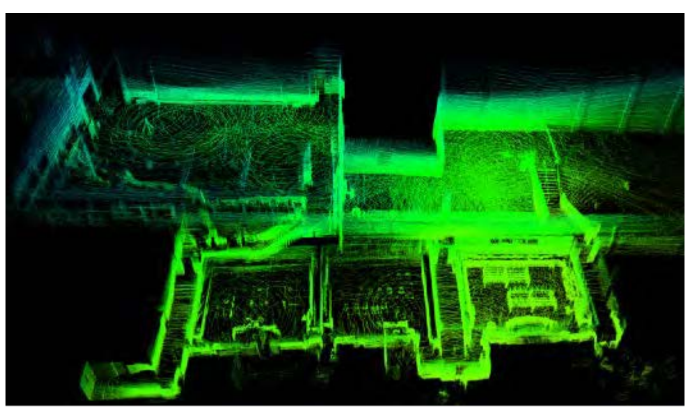
Sensing **P**erception **A**utonomy and **R**obot **K**inetics

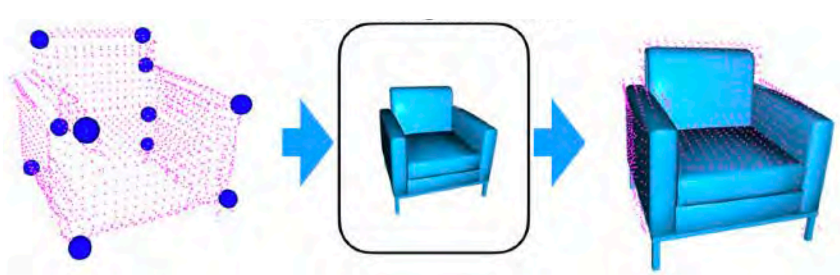
Robust Perception, Localization and Mapping

Visual-inertial Navigation



Lidar-based SLAM

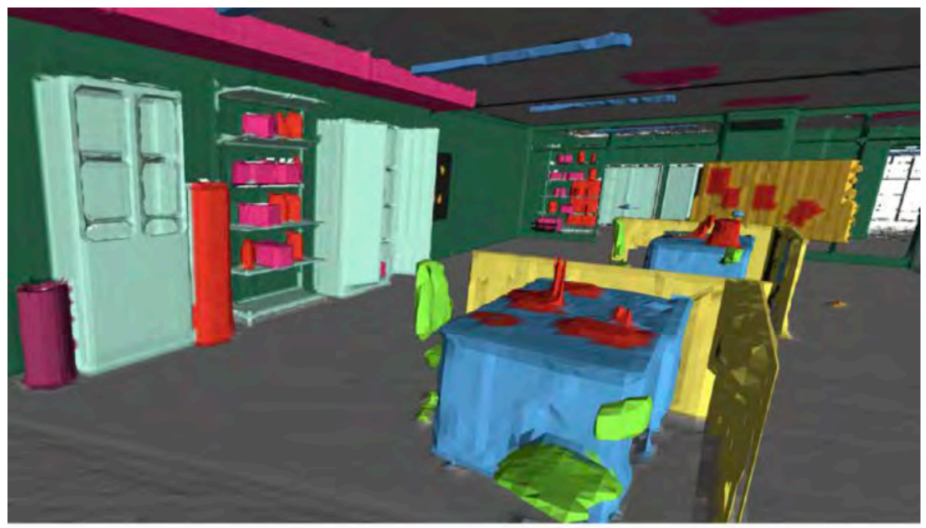


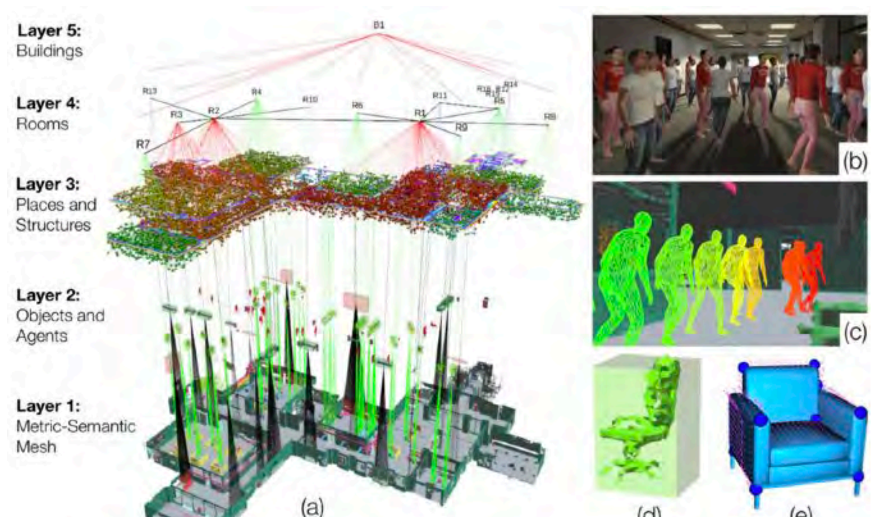


Certifiable Algorithms

High-level Scene Understanding (Spatial AI)

Kimera: Metrics-semantic SLAM

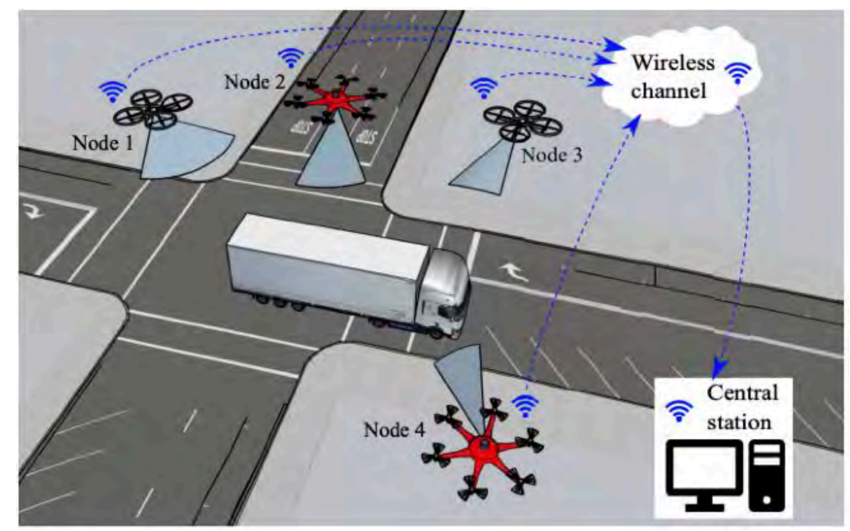


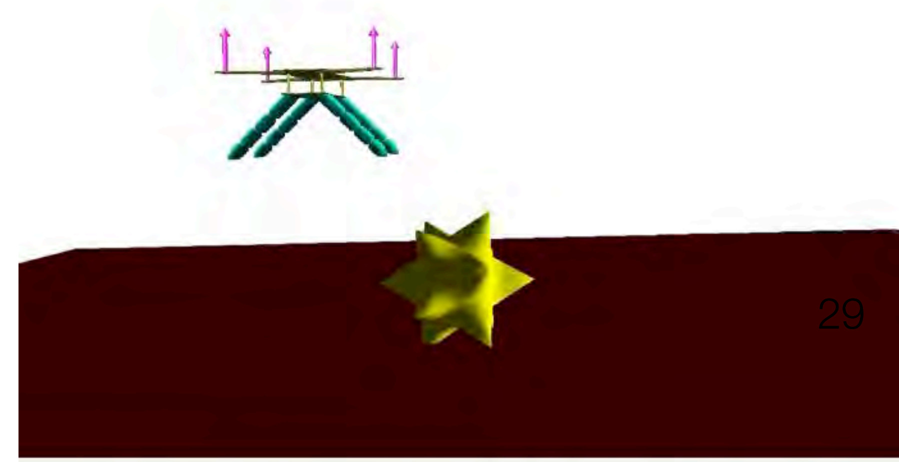


3D Dynamic Scene Graphs

Co-design

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





Soft Drones and Soft Aerial Manipulation

Vasileios Tzoumas

Cyber-Physical Systems (CPS)

Control

Planning

Perception

Resource-Aware Perception and Control

TAC '16, '20
TCNS '18
CDC '15, '16
ACC '15, '16, '17, '18

Outlier-Robust Perception

TRO '20, RAL '20, ICRA '20, IROS '19

Combinatorial Optimization

Algorithmic Foundations of Trustworthy Autonomy

Non-convex Optimization

Denial-of-Service (DoS) Robust Combinatorial Optimization

TAC '20, CDC '18, CDC '18

Inapproximability of Outlier-Robust Perception

IROS '19

Provable Near-Optimality

Hardness

Inapproximability of Resource-Aware State Reachability

TAC '18

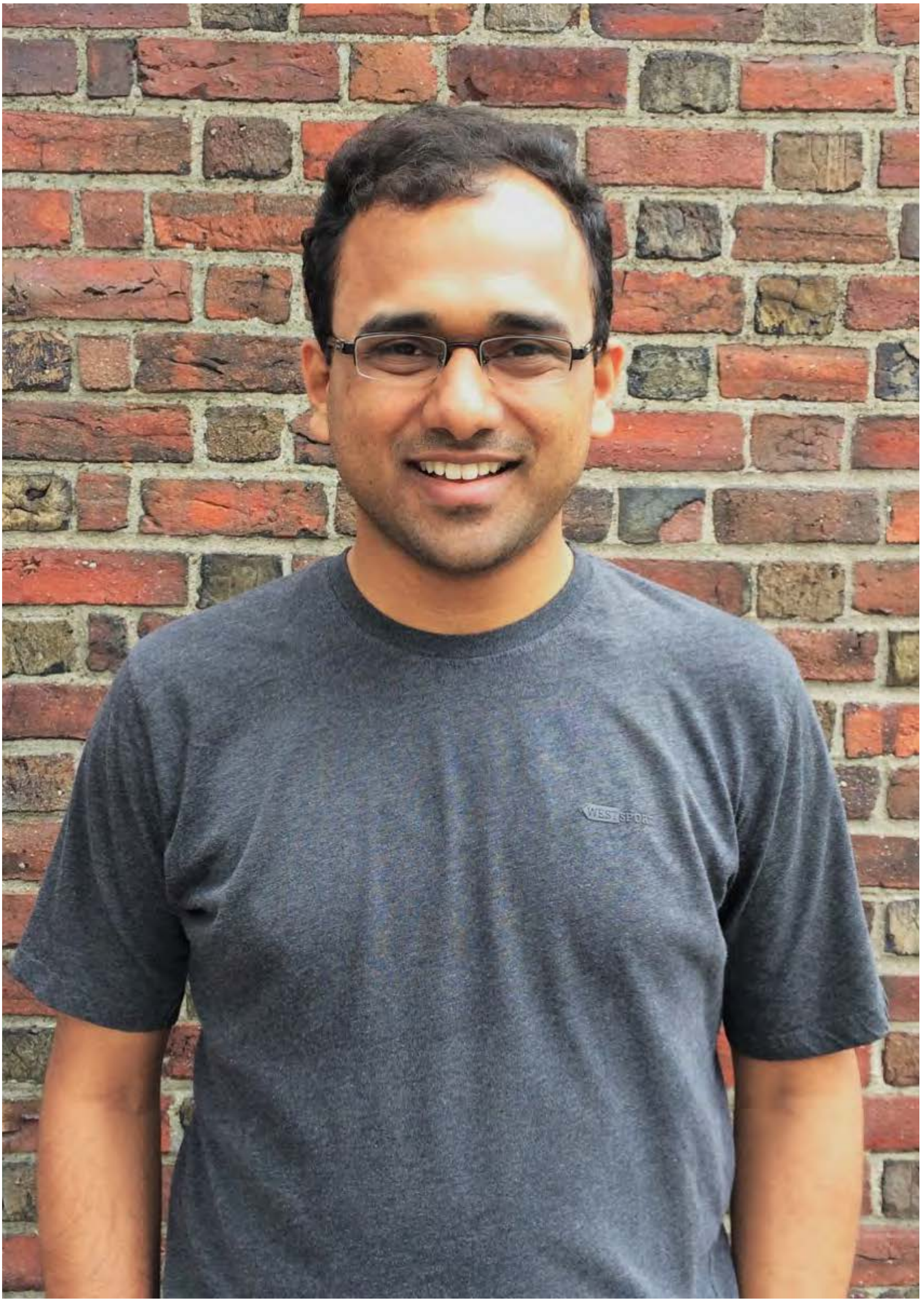
DoS-Robust Multi-Robot Planning

RAL '19, TRO '20
ICRA '19, '20
IROS '18

Research Scientist
he/him/his

MIT AEROASTRO

Rajat Talak



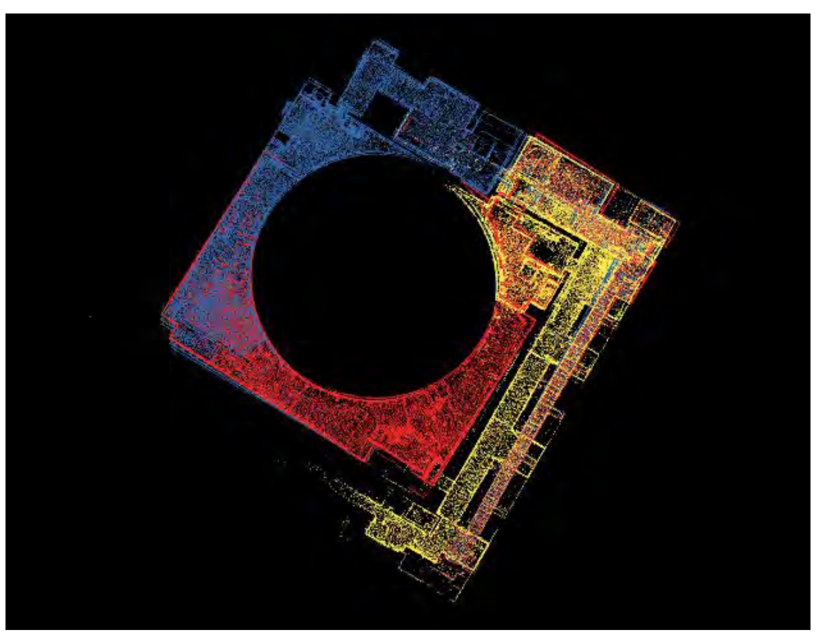
Post-doctoral researcher at SPARKlab MIT.

Recently completed PhD from AeroAstro at MIT.

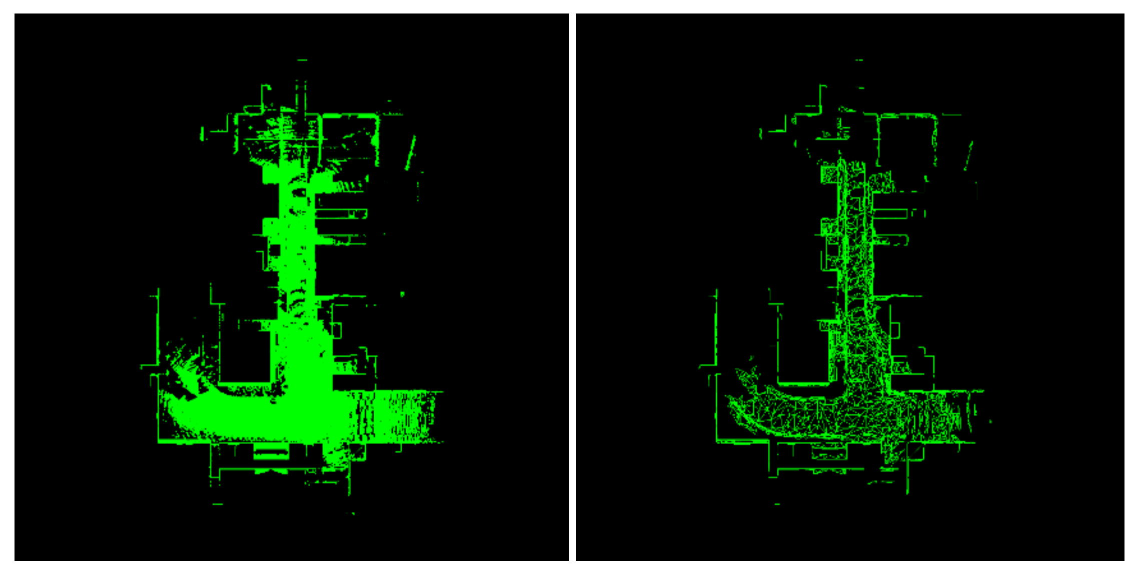
Research Interests: Optimization, Inference on Graphs, Machine Learning

Yun Chang

Multi-robot SLAM with dense 3D reconstructions



Robust multirobot SLAM (Darpa SubT Challenge)



Task driven representations

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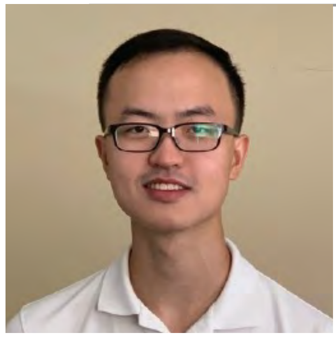
Stewart Jamieson

- MIT-WHOI Joint Program PhD Student
- Research focuses on robot vision and semantic mapping in novel and unfamiliar environments
- Applies to scientific exploration in remote and bandwidth-limited environments (e.g. deep ocean)
- Affiliations:
  - MIT Aerospace Controls Lab (ACL)
  - WHOI's Autonomous Robotics & Perception Lab (WARPLab)

Jingnan Shi



Jingnan Shi

- 2nd year AeroAstro Master student

- Undergrad at Harvey Mudd College

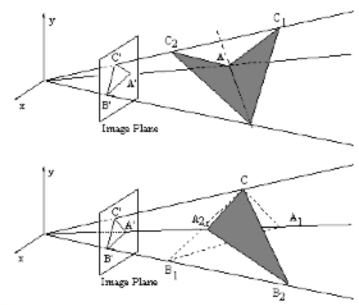
- Likes to cook

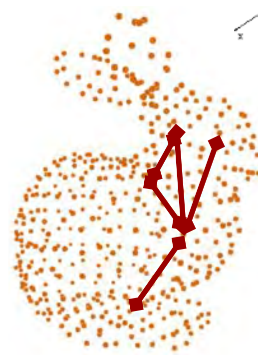
- Have a shiba inu

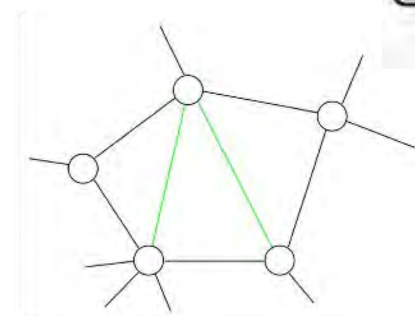
30,000 foot view:

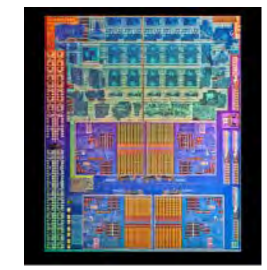
Reliable Robotic Perception

Specific interests:









Fast Outlier Rejection Algorithms

Design-informed performance engineering

Hardware-informed algorithmic design

Fast Deployable Implementations

Heng “Hank” Yang

Research interests:

- Computer Vision, Robot Perception
  - Certifiably robust geometric perception (with performance guarantees)
  - Extremely robust perception algorithms (>90% outliers)
- Optimization
  - Convex relaxations, semidefinite and sums-of-squares relaxations
  - Scalable algorithms for large-scale optimization
- Deep Learning for 3D Vision
  - Robust geometric perception + deep learning

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Why Perception?