Challenges and Opportunities for Autonomous Vehicles

Dr. John J. Leonard

MIT CSAIL and MechE

and Toyota Research Institute

July, 2019

Amara's Law

Amara's Law

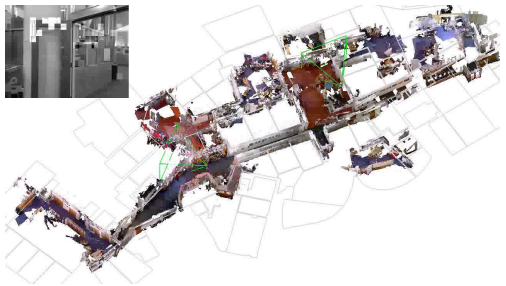
We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run

– Roy Amara

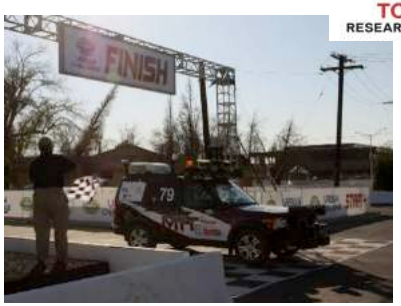
(Courtesy Rodney Brooks)

My Background

Autonomous Underwater Vehicles



Mapping and Localization



Self-Driving Vehicles

Education:

- University of Pennsylvania, BSEE (1987)
- University of Oxford, DPhil (1991)

History of MIT Positions:

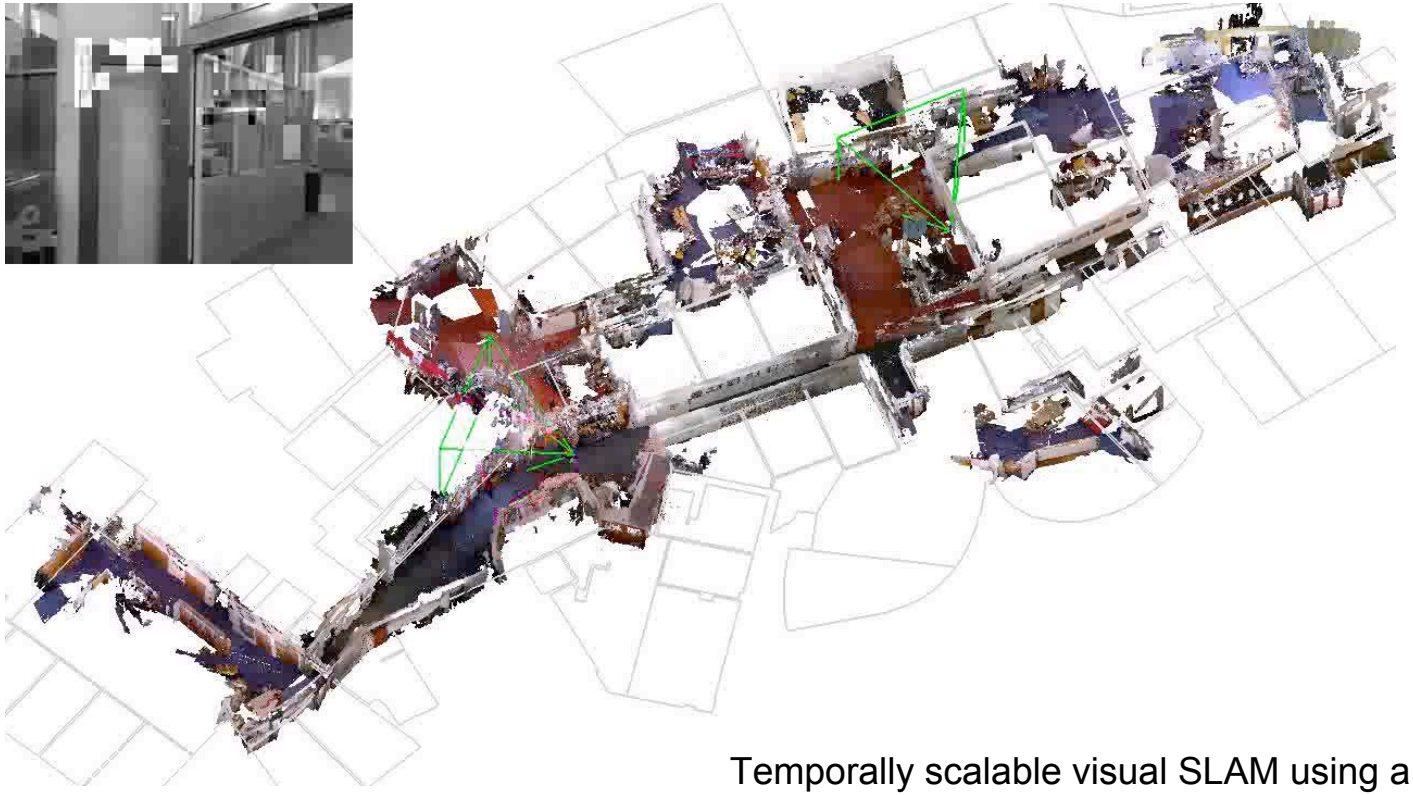
- MIT Sea Grant AUV Lab (1991-1996)
- Dept. of Ocean Engineering (1996-2004)
- Dept of Mechanical Engineering 2005-present
- Artificial Intelligence Laboratory (2002-2004) and CSAIL (2005-present)

Teaching: Measurement and Instrumentation, Robotics, Electronics, …

Research Interests: Self-Driving Vehicles; Mapping and Localization; AUVs

Since 2016: Also part of Toyota Research Institute (TRI)

Simultaneous Localization and Mapping (SLAM)

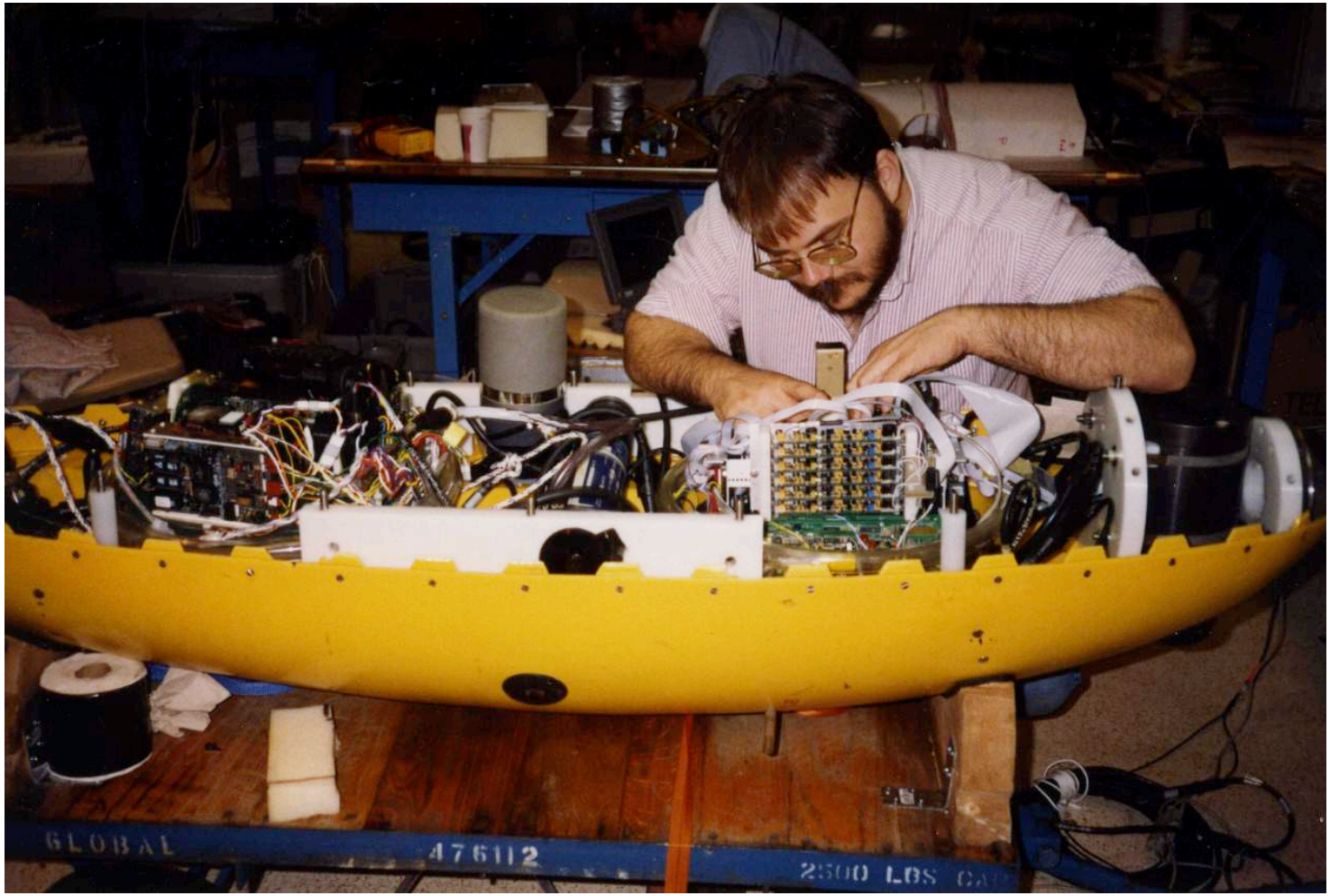


Temporally scalable visual SLAM using a reduced pose graph, H. Johannsson et al., ICRA 2013

Autonomous Underwater Vehicles

Jim Bellingham, 1994


Cliff
Goudey



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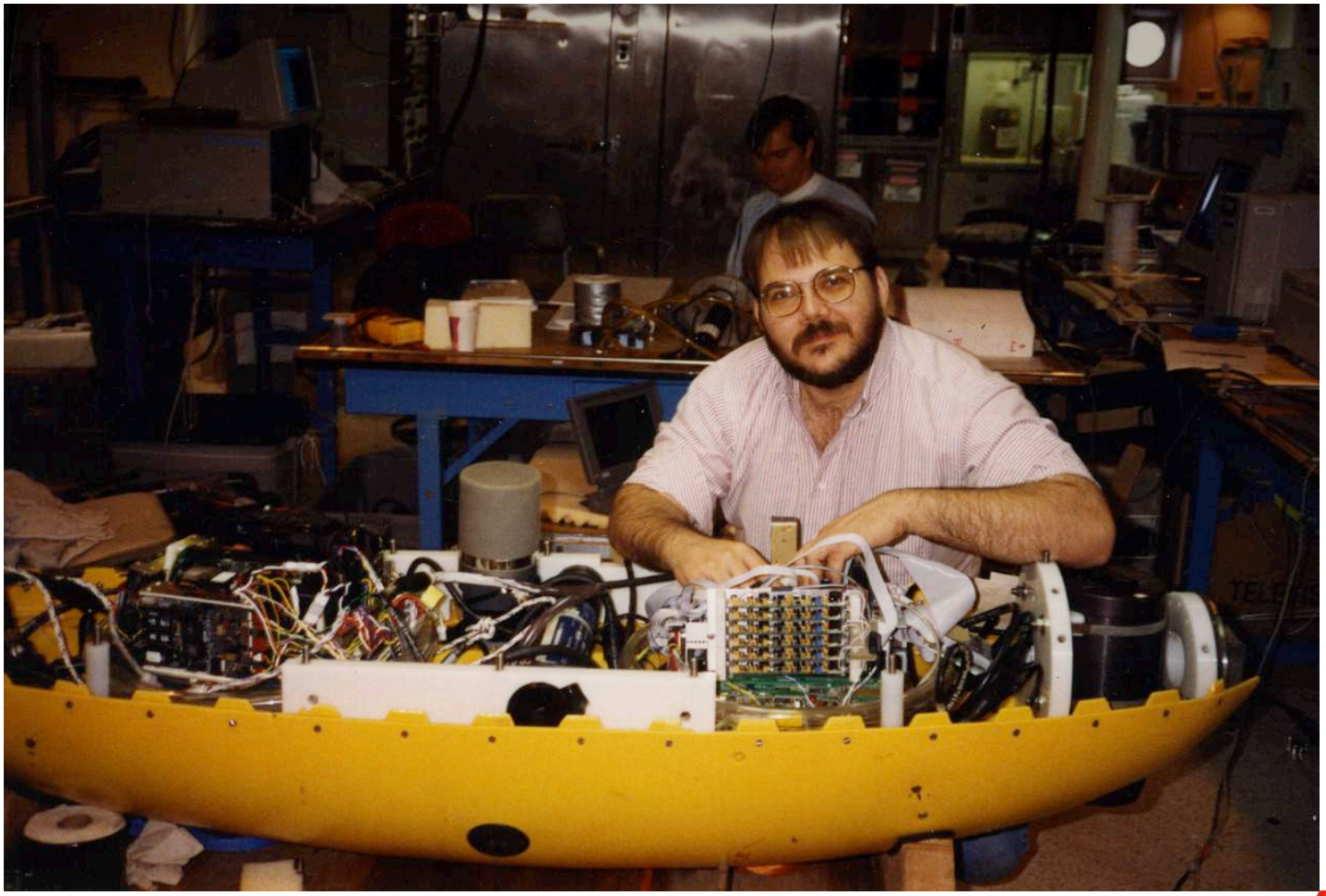
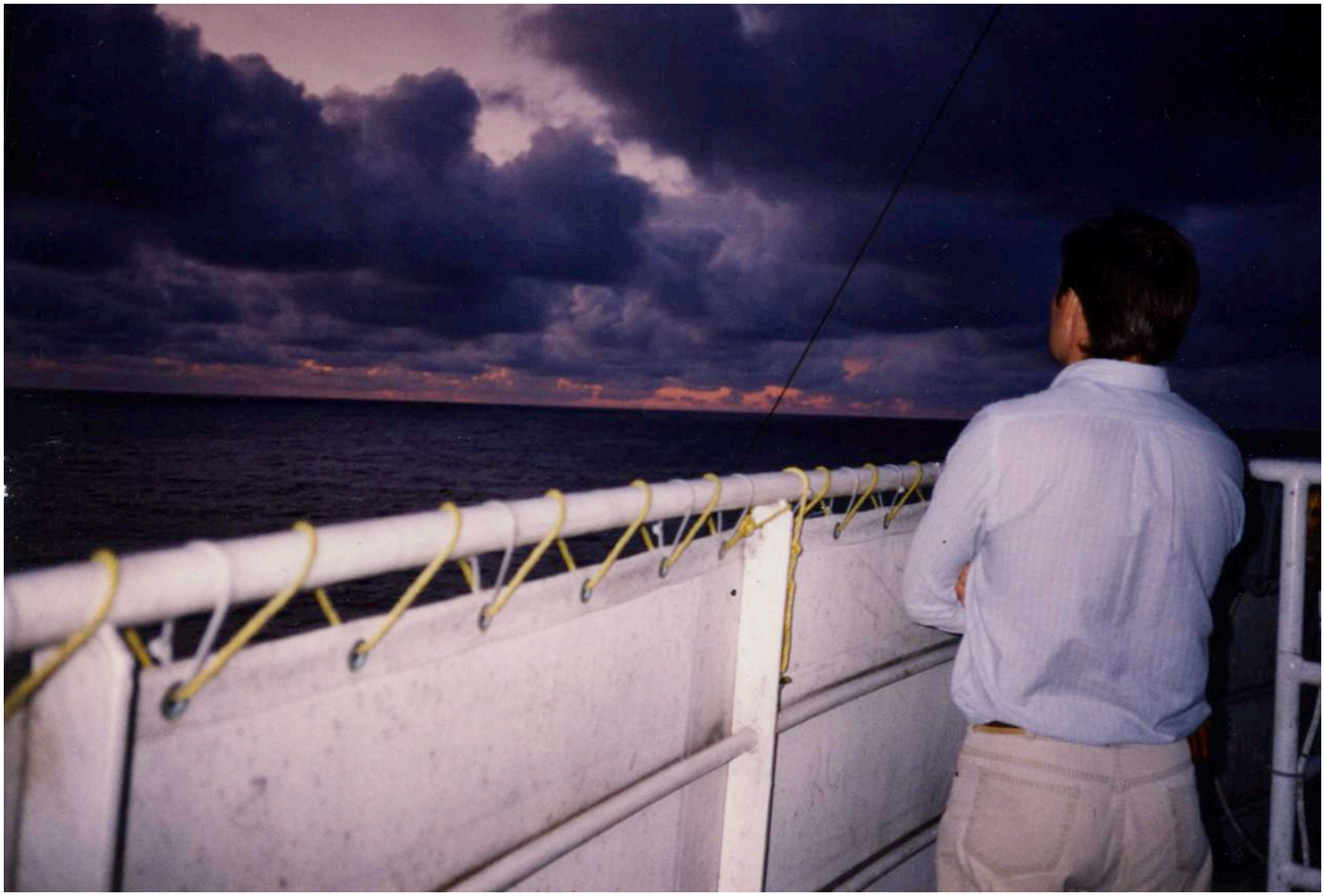




1994


1994

Autonomous Driving in the News

Left Turn Across Traffic

Autonomous Driving in the News

Why did a Rhode Island police officer pull over a self-driving shuttle on its first day?

Matt O'Brien, Associated Press Published 7:10 p.m. ET May 15, 2019

A self-driving shuttle, one of a fleet of vehicles unveiled in February by May Mobility, got pulled over by police on its first day carrying passengers on a new Rhode Island route. *(Photo: Matt O'Brien, AP)*

PROVIDENCE, R.I. – A self-driving shuttle got pulled over by police on its first day carrying passengers on a new Rhode Island route.

Providence Police Chief Hugh Clements said an officer pulled over the odd-looking autonomous vehicle because he had never seen one before.

"It looked like an oversize golf cart," Clements said.

The vehicle, operated by Michigan-based May Mobility, was dropping off passengers Wednesday morning at Providence's Olneyville Square when a police cruiser arrived with blinking lights and a siren.

It was just hours after the public launch of a state-funded pilot for a shuttle service called "Little Roady." The shuttle offers free rides on a 12-stop urban loop that links to a train station. Each vehicle holds six people, including an attendant who takes control when the self-driving technology falls short, such as on difficult left turns with oncoming traffic.

Clements said the curious police officer had a cordial conversation with the attendant and didn't issue any tickets or warnings.

leadership team

Meet our leadership team who has extensive experience with startups, robotics, and the automotive industry

Edwin Olson

Chief Executive Officer & Founder

Edwin founded May Mobility to forge together his experience in academia and the real world to develop a solution that would benefit communities, now. He remains to be a top robotics professor at the University of Michigan and his involvement with autonomous vehicles dates back to the original DARPA challenge in 2007.

Alisyn Malek

Chief Operating Officer & Co-Founder

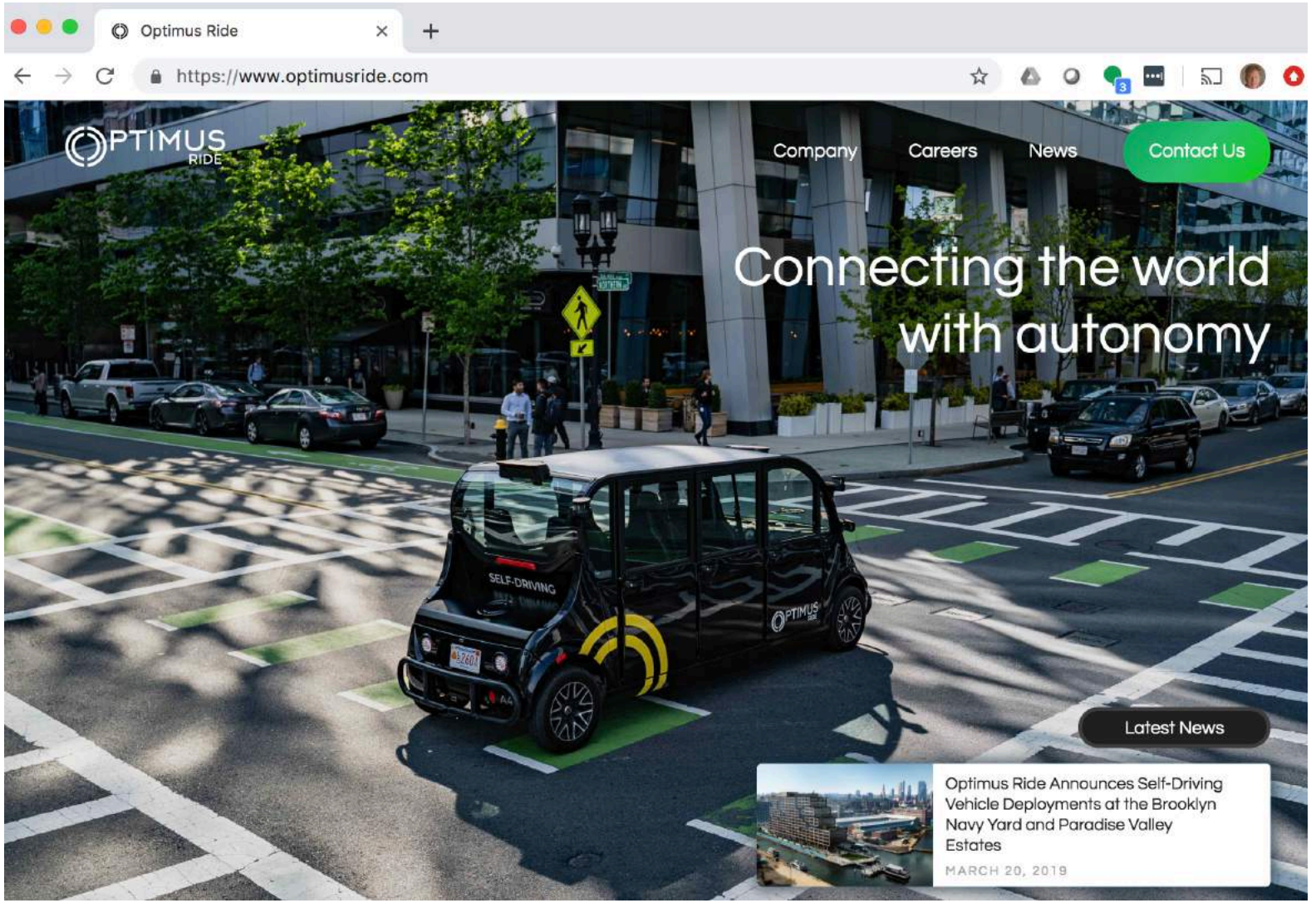
Alisyn started as an engineer working on cutting-edge electronic technology at General Motors, before moving to the venture side. Her unparalleled understanding of how big automotive and innovative technologies work together, made founding May Mobility to build an autonomous vehicle solution an obvious next step.

Steve Vozar

Chief Technology Officer & Co-Founder

Steve focused on next-generation automated vehicles during his tenure with the APRIL and PeRL Labs at the University of Michigan. His passion for robotics and extensive research has impacted technology used by DARPA, NASA and Ford Motor Company, and can be found in each May Mobility solution from software to hardware.

Albert Huang, David Moore, and Edwin Olson, 2007


Optimus Ride
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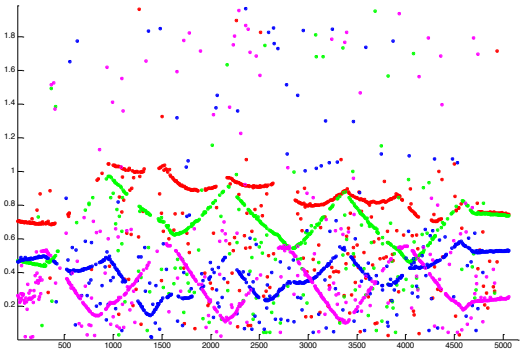
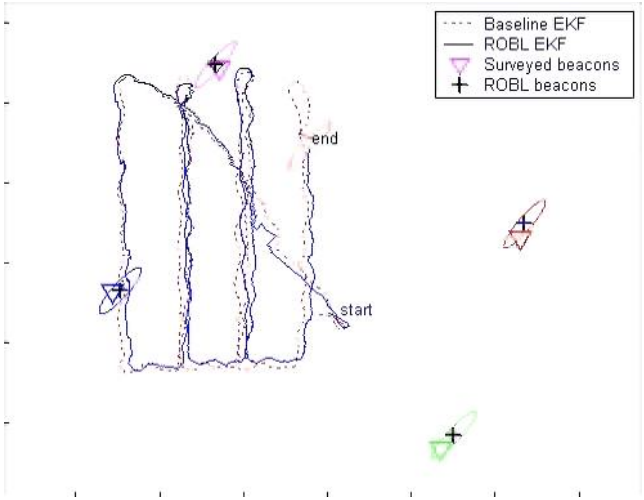
Latest News
Optimus Ride Announces Self-Driving Vehicle Deployments at the Brooklyn Navy Yard and Paradise Valley Estates
MARCH 20, 2019

Robust Range Only Beacon Localization

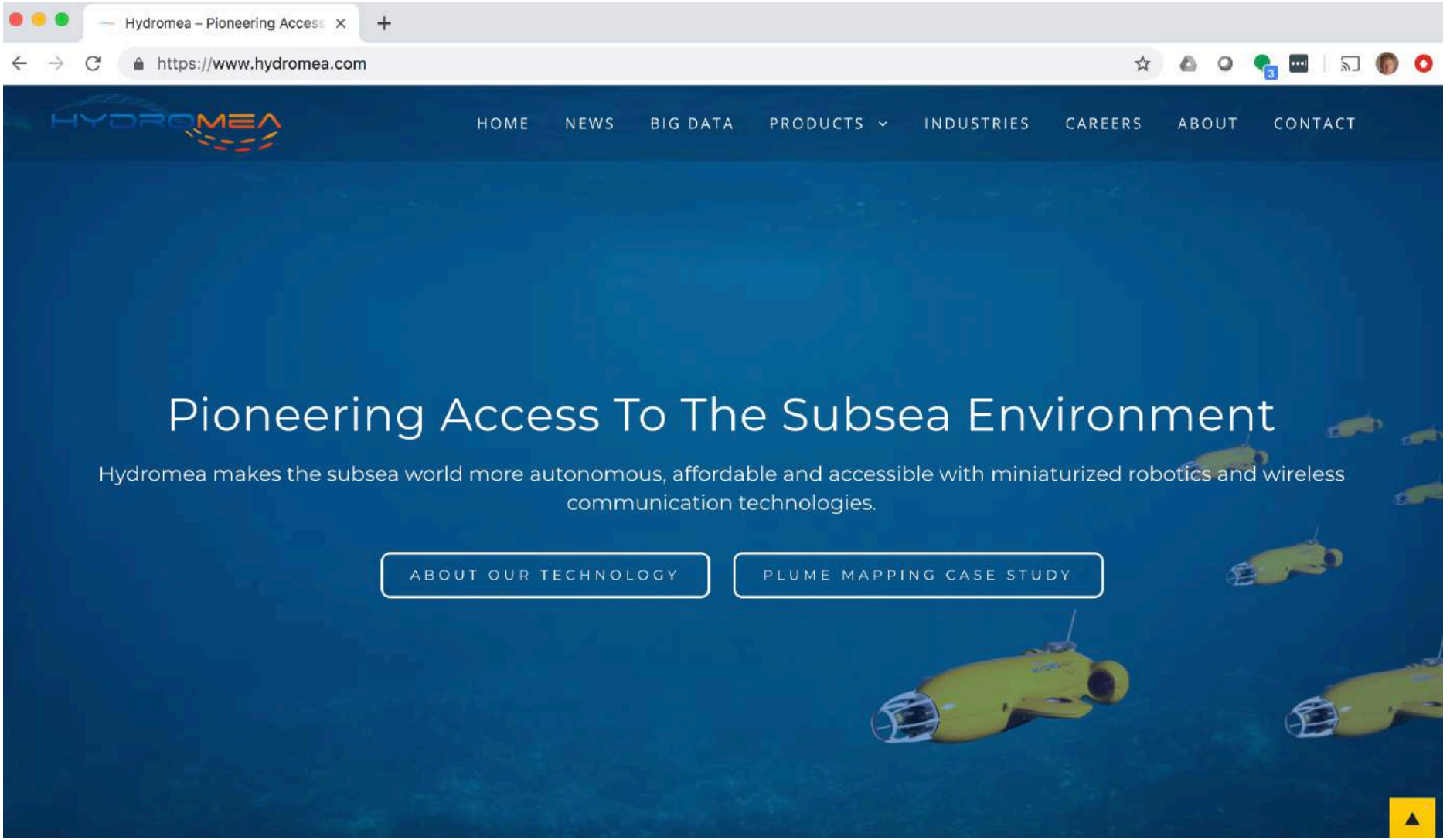




Olson et al., IEEE AUV 2004

Alexander Bahr, Pianosa 2005


HACK
WALL STREET
MIT
WILDERNESS
Pungo100


Hydromea – Pioneering Access
https://www.hydromea.com
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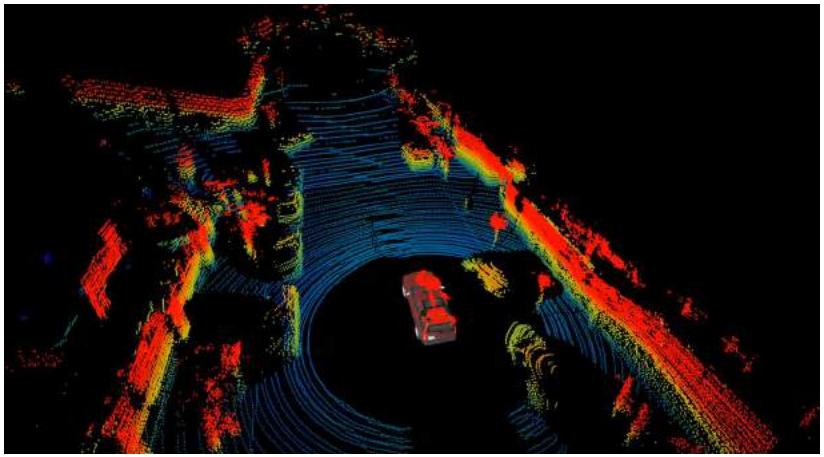
Pioneering Access To The Subsea Environment
Hydromea makes the subsea world more autonomous, affordable and accessible with miniaturized robotics and wireless communication technologies.
ABOUT OUR TECHNOLOGY
PLUME MAPPING CASE STUDY

MIT DARPA Urban Challenge (2006-2007)


URBAN
CHALLENGE


svn: 7877 0h00m26s, 0.03 mi @ 4.1 mph, 28 checkpoints, Failsafe 0 time 0.12 log: 02




FINISH

With David Barrett, Seth Teller, and Jonathan How

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Meeting Room

Seth Teller, Ed Olson, and Albert Huang

MIT Land Rover LR3 (Talos)

Blade cluster

10 blades each with two 2.33GHz dual-core processors ➔ 40 cores

A **lot** of sensors

Applanix IMU/GPS

12 SICK Lidars

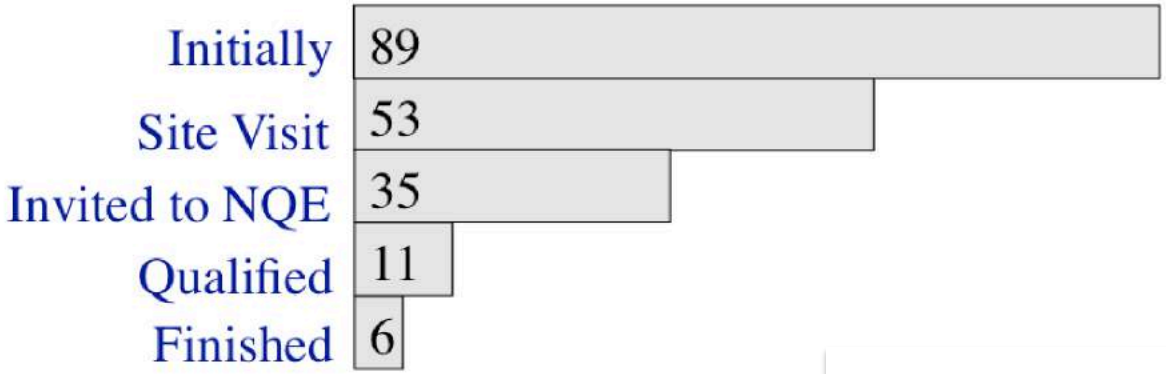
Velodyne (~64 Lidars)

15 radars

5 cameras

6 kW generator

2007 Urban Challenge Results

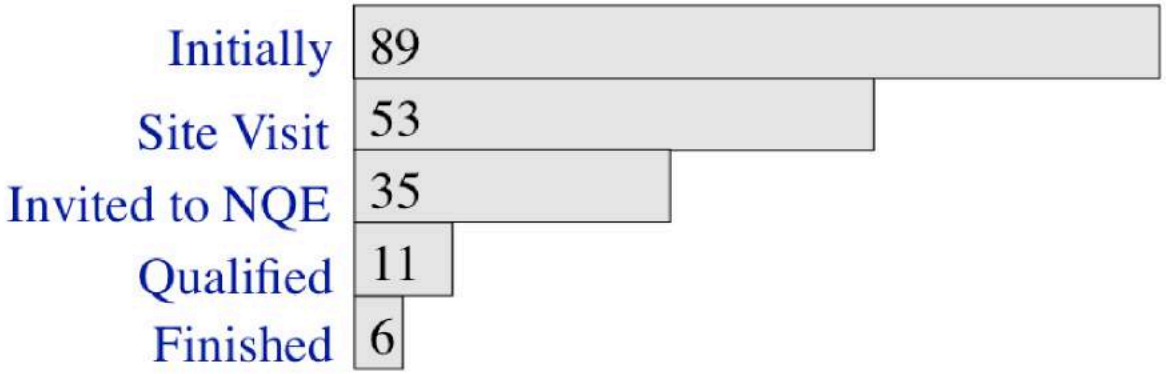


CMU
1st place

Stanford
2nd place

Virginia Tech
3rd place

2007 Urban Challenge Results



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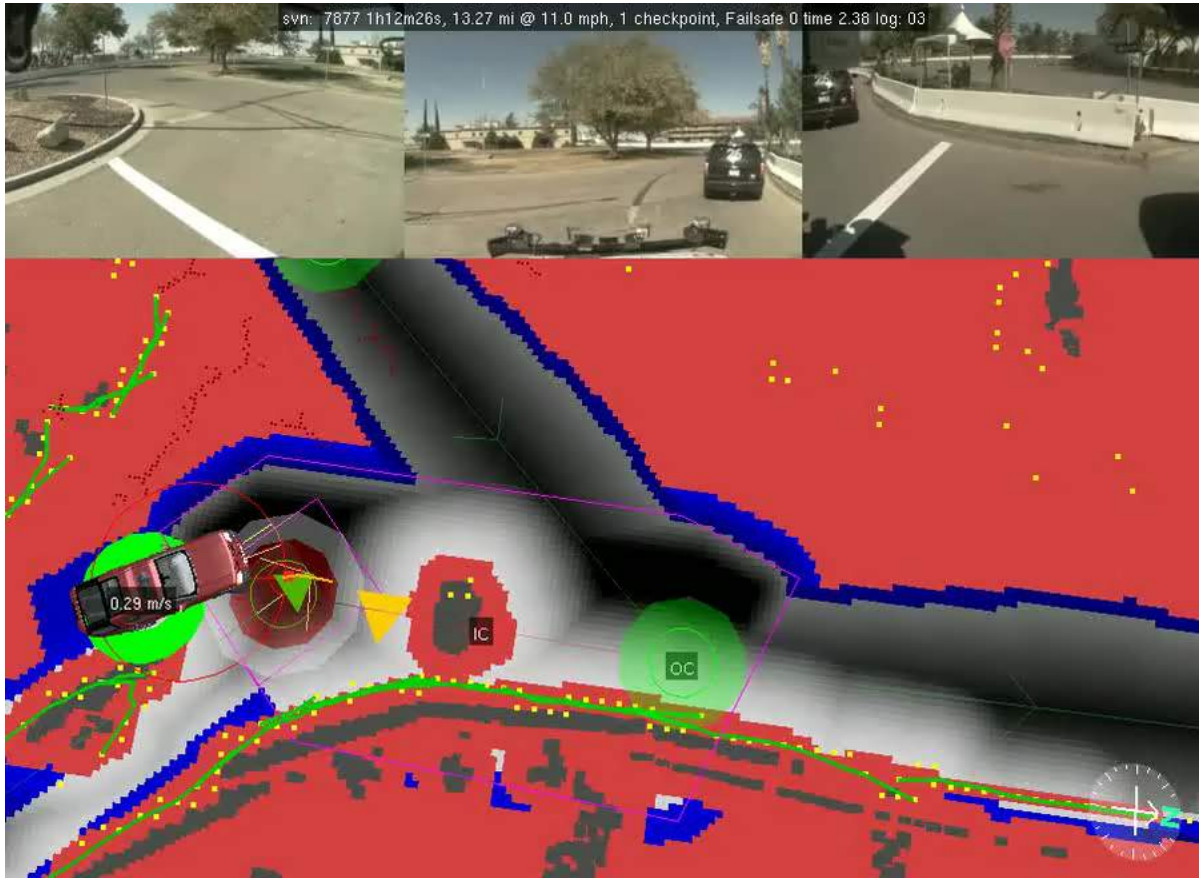
MIT
4th place

2007 DARPA Urban Challenge – Collision between MIT and Cornell

2007 DARPA Urban Challenge – Collision between MIT and Cornell



2007 DARPA Urban Challenge – Collision between MIT and Cornell

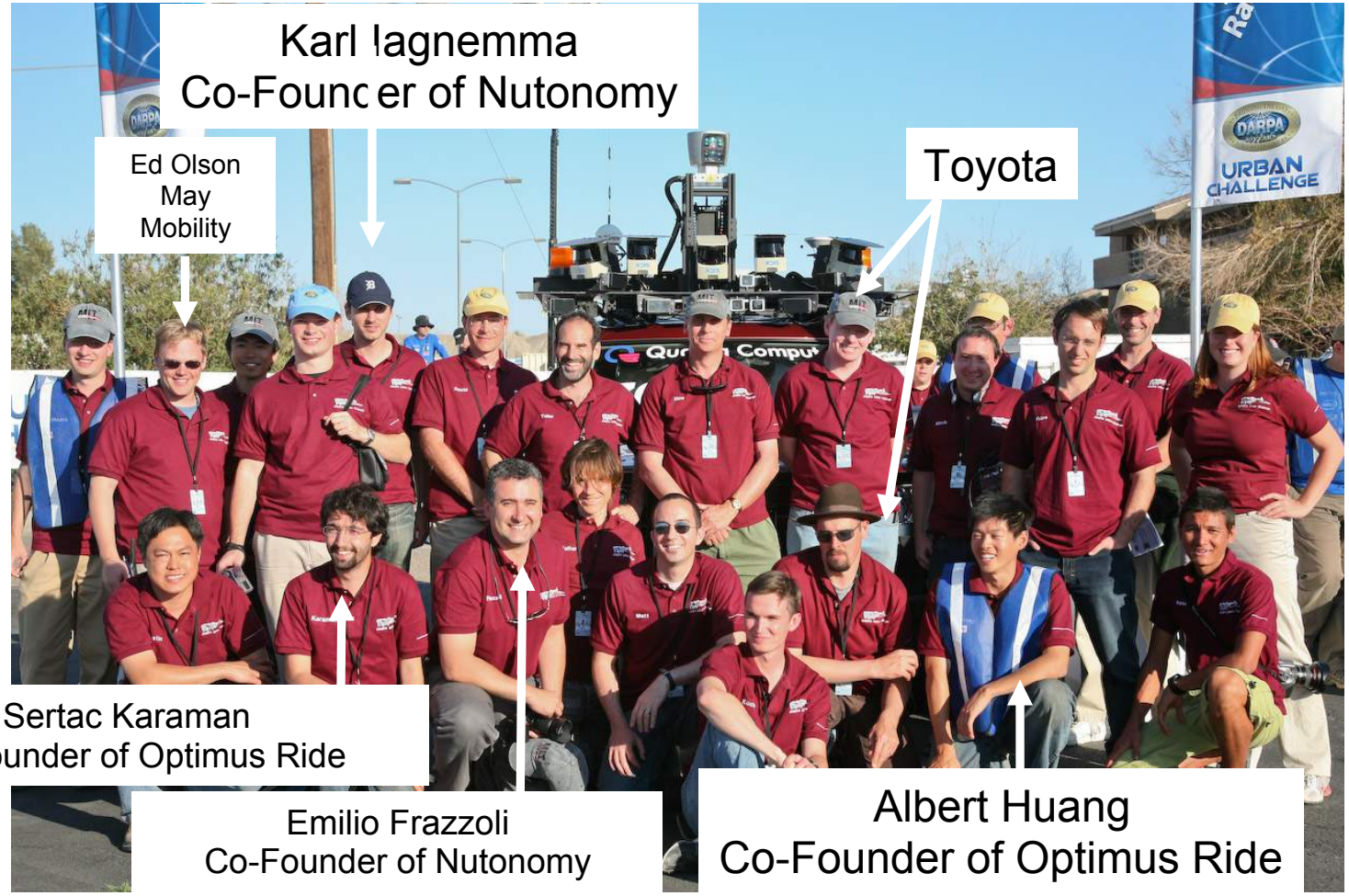
L. Fletcher, S. Teller, E. Olson, D. Moore, Y. Kuwata, J. How, J. Leonard, I. Miller, M. Campbell, D. Huttenlocher, and others, "The MIT–Cornell collision and why it happened." In Journal of Field Robotics, 25(10), pages 775-807. 2008.

```
int use_track = 0, use_rects = 1;
//          if (t->vmag > 4)
//              use_rects = 0;

      if (t->vmag > 3.0 && t->maturity > 8)
            use_track = 1;
      double MAX_DIM = 10;
      if (t->box.size[0] > MAX_DIM || t->box.size[1] >
MAX_DIM)
            use_track = 0;
```

That was 2007 …
what is happening
today?

MIT Team Photo, November 2007



MIT Team Photo, November 2007

SMARTER THAN YOU THINK

Google Cars Drive Themselves, in Traffic

Ramin Rahimian for The New York Times

Dmitri Dolgov, a Google engineer, in a self-driving car parked in Silicon Valley after a road test.

By JOHN MARKOFF
Published: October 9, 2010

MOUNTAIN VIEW, Calif. — Anyone driving the twists of Highway 1 between San Francisco and Los Angeles recently may have glimpsed a Toyota Prius with a curious funnel-like cylinder on the roof. Harder to notice was that the person at the wheel was not actually driving.

RECOMMEND
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COMMENTS (298)
SIGN IN TO E-MAIL
PRINT

New York Times Oct 9th, 2010

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Image: Google (2011)

Potential Benefits of Self-Driving Vehicles

- Safety
  - Over 5 Million vehicle crashes per year in the US
  - 93% of accidents have human error as a primary factor
  - Over 30,000 fatalities in the US due to traffic accidents per year
- Increased Road Network Efficiency
- Recovery of Time Lost due to Commuting
- Reduced Need for Parking in Cities
- Radically New Models for Personal Mobility and the Distribution of Goods and Services

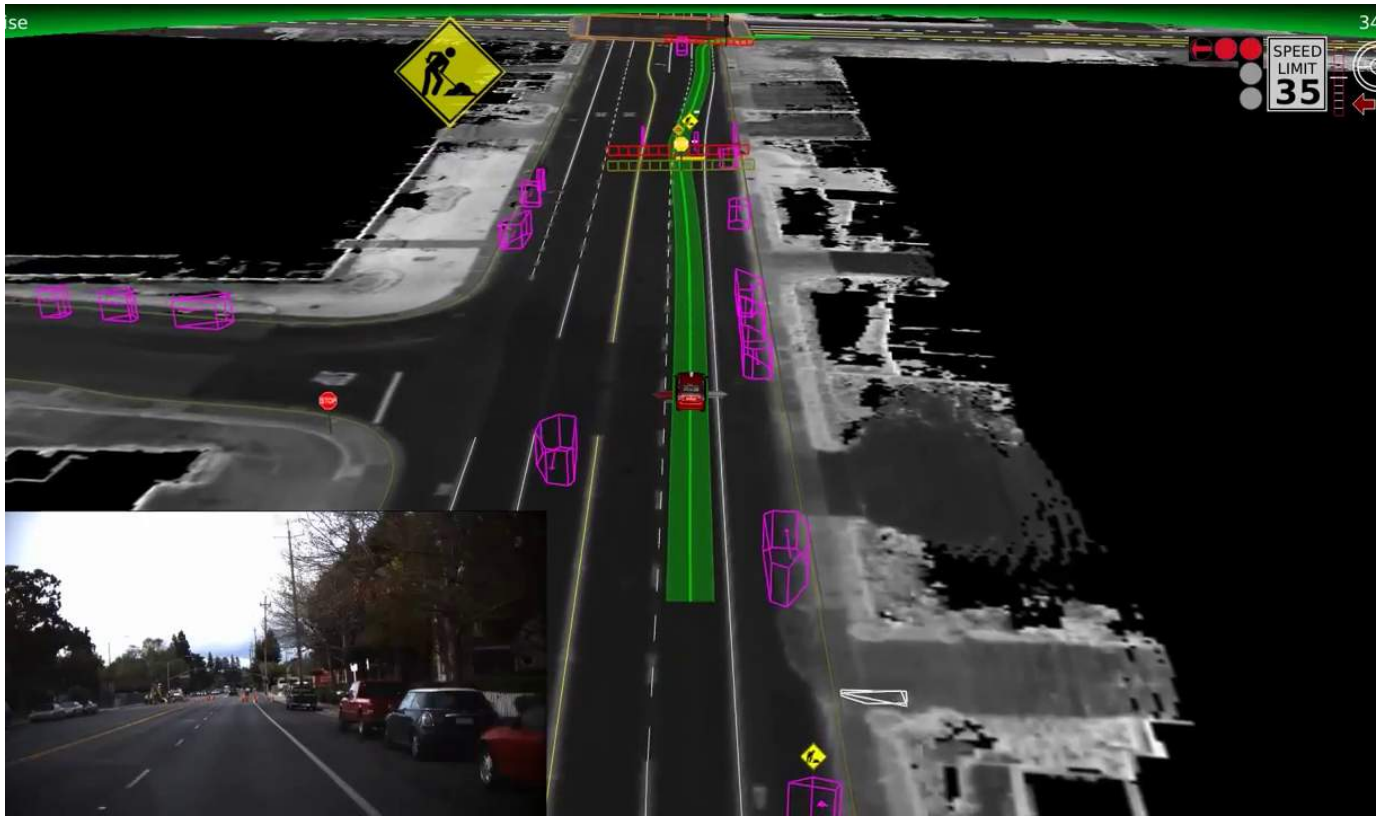
"Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations" Daniel J. Fagnant and Kara M. Kockelman, Eno Center for Transportation, October 2013

Police Officers Directing Traffic

What do you see in this picture?

Difficult Weather Conditions

Localization Using High-Definition Maps



Source: https://plus.google.com/+GoogleSelfDrivingCars/videos

The Big Questions Going Forward




Technical Challenges:

- Maintaining Maps
- Adverse Weather
- Interacting with People
- Robust Computer Vision (perfect detection, no false alarms?)

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The big question for Level 2 and Level 3 approaches?

- Can humans be trusted to take control when necessary?

The Big Questions Going Forward




Technical Challenges:

- Maintaining Maps
- Adverse Weather
- Interacting with People
- Robust Computer Vision (perfect detection, no false alarms?)

The big question for Level 2 and Level 3 approaches?

- Can humans be trusted to take control when necessary?

The big question for Level 4 approaches?

- Can near-perfect detection be obtained in a wide variety of demanding settings?

Gill Pratt Discusses Toyota's AI

https://spectrum.ieee.org/automaton/robotics/artificial-intelligence/gill-pratt-on-toyota-robot-plans

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11 Sep 2015 | 15:45 GMT

Gill Pratt Discusses Toyota's AI Plans and the Future of Robots and Cars

The former DARPA program manager discusses what he's going to do next

By **Erico Guizzo and Evan Ackerman**

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Our goal, which is a little different than the approach that others take, is to build intelligence to help the car be really a guardian angel for you and keeping you from having a wreck. That's the hardest part of this whole thing, but that's the part that we're going to do first. We want to enhance the fun of driving for the human being while making it far more safe.

Gill Pratt, September 2015

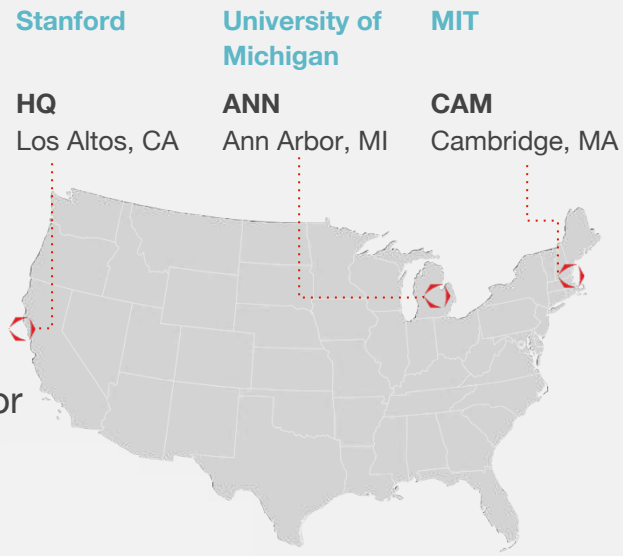
Toyota Research Institute

321
Employees, secondees, & assignees as of Jan 2019

3
sites

- Established in January 2016
  - Leadership with experience from key government agencies & companies (i.e., U.S. DARPA, U.S. Dept. of Transportation, Google, Lyft, Zoox, Ford, U.S.-Japan Council)
  - More than 50% of technical staff hold PhD degrees
- Three facilities in Cambridge, Ann Arbor, & Silicon Valley
- Focus Areas: Automated Driving; Robotics; and AI for Advanced Material Design and Discovery
- Working closely with related Toyota Companies:

TOYOTA AI VENTURES · TOYOTA connected · CSRC Collaborative Safety Research Center TOYOTA · TRI-AD



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TRI All-Hands On-Site, Ann Arbor MI, Oct., 2018

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Ryan Eustice (WHOI, U. Michigan, Toyota Research Institute) and Chris Roman (WHOI, University of Rhode Island)

2005

Automated Driving Team

- Vehicle Hardware
- Vehicle Software
- Safety & System Engineering
- Mapping and Localization
- Perception and Prediction
- Planning and Control
- Driver Risk Assessment
- Machine Learning
- Simulation
- Cloud Data Processing
- User Experience
- Vehicle Operations

Automated Driving Approach:
One System, Two Modes

GUARDIAN

CHAUFFEUR

Driver always engaged, but vehicle monitors and intervenes to help prevent collisions

Builds on similar hardware and software development as fully-autonomous Chauffeur

Fully autonomous driving system engaged at all times

Staged commercial release, likely beginning with shared mobility fleets

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Guardian First – *“AI Guards the Human”*

- More immediate deployment for saving human lives
- Enhances joy of driving
- “Guardian for All”

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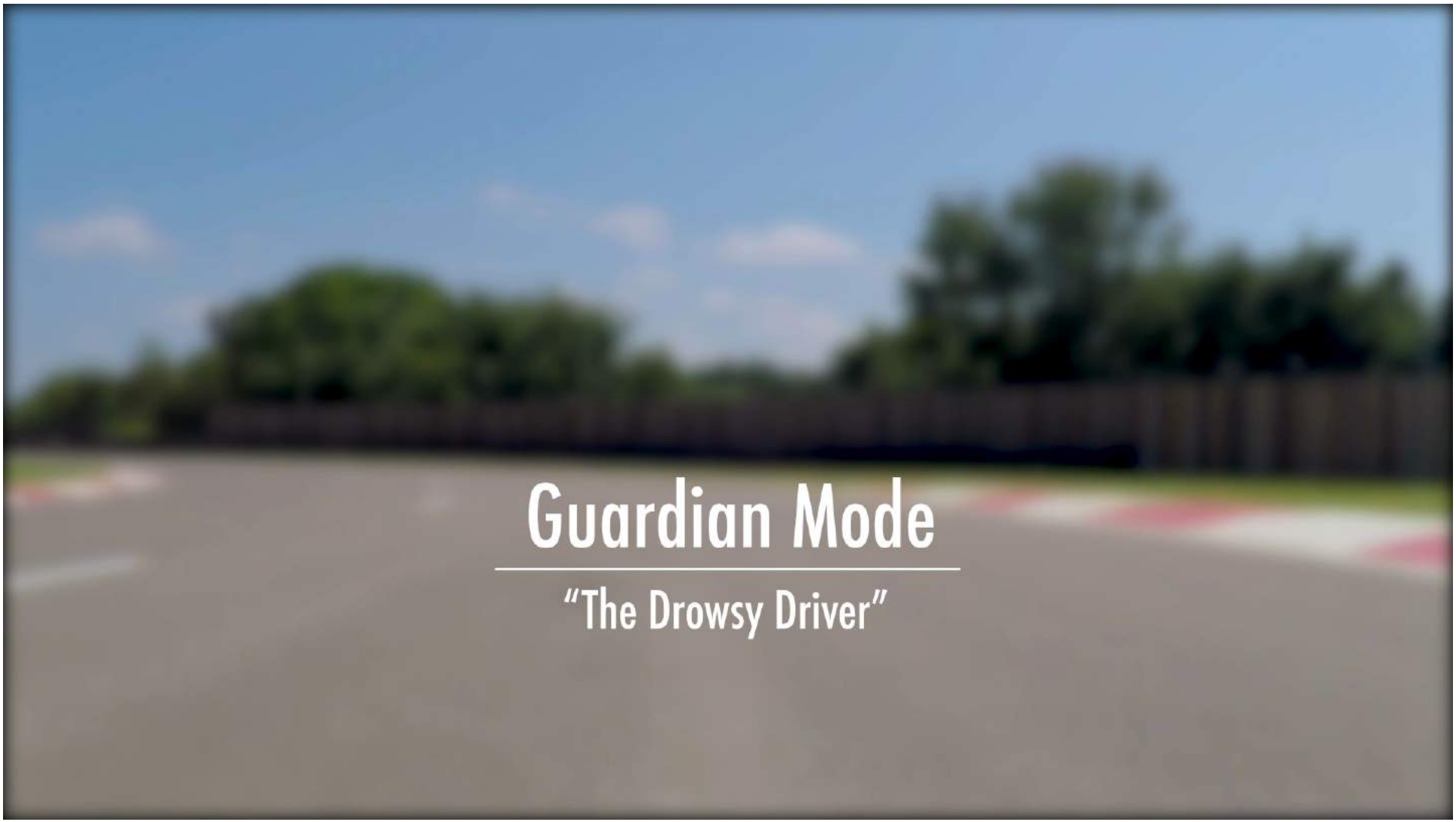
Dual Steering Prototype – TRI Platform 2 (2017)


Guardian Mode
"The Drowsy Driver"

Conclusion

- Excited to have had a chance to be part of the automated driving team at TRI
- Working with AUVs is a great training for self-driving
- Developing a unified technology stack to address both Guardian and Chauffeur
- Conducting research across the entire spectrum of automated driving, to exploit Toyota's data advantage to achieve unprecedented levels of safety and mobility
- Many great fundamental research challenges remain to be investigated