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

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
Autonomous Driving in the News
Left Turn Across Traffic
Why did a Rhode Island police officer pull over a self-driving shuttle on its first day?

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 Perll 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
Connecting the world with autonomy
Robust Range Only Beacon Localization

Olson et al., IEEE AUV 2004
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)
With David Barrett, Seth Teller, and Jonathan How
Meeting Room
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

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CMU 1st place
Stanford 2nd place
Virginia Tech 3rd place
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CMU 1st place
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MIT 4th place
2007 DARPA Urban Challenge – Collision between MIT and Cornell
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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

Karl Iagnemma
Co-Founder of Nutonomy

Ed Olson
May Mobility

Sertac Karaman
Co-Founder of Optimus Ride

Emilio Frazzoli
Co-Founder of Nutonomy

Albert Huang
Co-Founder of Optimus Ride

Toyota
Google Cars Drive Themselves, in Traffic

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.
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

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:
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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 question for Level 4 approaches?
• Can near-perfect detection be obtained in a wide variety of demanding settings?
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 Erica Guizzo and Evan Ackerman
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

- 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:
  - Stanford
  - University of Michigan
  - MIT
Ryan Eustice (WHOI, U. Michigan, Toyota Research Institute) and Chris Roman (WHOI, University of Rhode Island)
## Automated Driving Team

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<thead>
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<th>Driver Risk Assessment</th>
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<td>Vehicle Software</td>
<td>Machine Learning</td>
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<td>Safety &amp; System Engineering</td>
<td>Simulation</td>
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<td>Cloud Data Processing</td>
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<tr>
<td>Perception and Prediction</td>
<td>User Experience</td>
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<td>Planning and Control</td>
<td>Vehicle Operations</td>
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Automated Driving Approach: One System, Two Modes

**GUARDIAN**
- Driver always engaged, but vehicle monitors and intervenes to help prevent collisions
- Builds on similar hardware and software development as fully-autonomous Chauffeur

**CHAUFFEUR**
- Fully autonomous driving system engaged at all times
- Staged commercial release, likely beginning with shared mobility fleets
Guardian First – “AI Guards the Human”

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