“Does your car have any idea why my car pulled it over?”

DRIVERS ED FOR AVS
Leilani H Gilpin (MIT), Matias Aranguiz (SJTU)
MOTIVATION
# MOTIVATION - TECHNOLOGY

<table>
<thead>
<tr>
<th>Trend</th>
<th>Current and future enabling forces</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrification</strong></td>
<td>- Desirable products</td>
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<tr>
<td></td>
<td>- Battery technology/cost (&lt;USD 200/kWh, 2020)</td>
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<td></td>
<td>- Charging stations (1,200% global increase, 2014-20)</td>
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<td></td>
<td>- Emission/efficiency regulation (EU 95 g\text{CO}_2 /km, 2021; US 54.5 mpg, 2025, CA 15% ZEV 2025)</td>
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<td><strong>Connectivity</strong></td>
<td>- Connected lifestyle extending to the car</td>
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<td>- Vehicle safety communication mandate (US vehicle-to-vehicle, expected by 2020)</td>
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<td>- Communication network growing (5G, 2020)</td>
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<td></td>
<td>- Tech giants and start-ups discover the remaining piece in connected world</td>
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<td><strong>Autonomous driving</strong></td>
<td>- Sensor and processing solutions</td>
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<td>- Communication/legal infrastructure (currently 4 states in the US, more expected)</td>
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<td>- Public demonstrations of autonomous driving show benefit</td>
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<td>- Tech giants and start-ups discover automated cars &quot;interesting playground&quot;</td>
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<td><strong>Diverse mobility</strong></td>
<td>- Consumers prefer access over ownership (600% global car sharing revenue increase, 2013-20)</td>
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<td>- Smartphone makes scheduling convenient</td>
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<td>- Incentives for corporations and consumers</td>
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<td></td>
<td>- Urban congestion (30% of traffic for parking)</td>
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<td>- Shared mobility providers offer trendy products</td>
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MOTIVATION

GOALS

• Big technical weaknesses: physicality of the car
  • Machine perception
  • Communication (security)
  • Ethics (the trolley problem)

• Implementation
  • Regulation

• The “people”
## 5 Levels of Autonomy

<table>
<thead>
<tr>
<th>SAE Level</th>
<th>Name</th>
<th>Narrative Definition</th>
<th>Execution of Steering and Acceleration/Deceleration</th>
<th>Monitoring of Driving Environment</th>
<th>Fallback Performance of Dynamic Driving Task</th>
<th>System Capability (Driving Modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
</tr>
</tbody>
</table>
THE PROBLEMS WITH MACHINE VISION

TO COMPLETE YOUR REGISTRATION, PLEASE TELL US WHETHER OR NOT THIS IMAGE CONTAINS A STOP SIGN:

NO  YES

ANSWER QUICKLY—OUR SELF-DRIVING CAR IS ALMOST AT THE INTERSECTION.

SO MUCH OF "AI" IS JUST FIGURING OUT WAYS TO OFFLOAD WORK ONTO RANDOM STRANGERS.

Source: XKCD
THE PROBLEMS WITH MACHINE VISION

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alt text: “Crowdsourced steering” doesn’t sound quite as appealing as self-driving.

Source: XKCD
VEHICLE SIGHT

• LIDAR - light based radar
  • Car can see how far it is from the object or person.

• Standard cameras

• “Seeing through walls”
SO WHAT DOES THIS LOOK LIKE?

Source: Ranft and Stiller: The Role of Machine Vision for Intelligent Vehicles
SOME RISKS

- Training data matters
- Changing cities
- How to engage the human?

Volvo's self-driving cars are thrown off by kangaroos

Their hopping confuses the cars’ detection system.
SOME RISKS

Exhibit 12  Aircraft and Automobile Software Code Compared (GAO 2016)

Vehicles have more complex computer systems than aircraft, due to complex roadway interactions.
AV SECURITY
WHY IS THE MODERN VEHICLE NOT SECURE?

- The modern car contains two (newer) units
  - Electronic Control Unit
  - Controller Area Network (CAN)
- The CAN network can contain over 80 ECUs and 100 sensors.
- Projected sensors could double in the next year.

Image courtesy of Toyota Costa Rica
CAR LAYOUT

(C) PEI TECHNOLOGIES
ACCESSING THE CAN

• The early CANs were wired (considered a closed network)

• Could “hack” into these CAN buses by plugging in a device to the car’s **federally mandated** universal OBD-II diagnostics port

• Messages are
  
  • Unencrypted
  
  • Not authenticated

  • All messages are broadcast to the entire system

• Now, more recent CANs contain wireless components which have massive security implications
WIRELESS CAN ACCESS

• On the freeway, two “hackers” were able to control radio, windshield wipers, air conditioner and accelerator

• They can track GPS coordinates, measure speed, and even drop pins on a map

• Read the article, “Hackers Remote Kill a Jeep on the Freeway—With Me in It” - Wired

copyright Andy Greenberg-Wired
SO WHY THE CAN BUS?

• Adopted early

• Works well when exchanging data because it’s reliable and works well in noisy, environment.

• (Also scary: CAN bus is used in a lot of aerospace automation)

• How can we help?
CAN BUS : EASY TO EMULATE

- Easy to hack
- Simple schema
- Schema: time stamp, CAN bus code, extra information
- Connects to all aspects of a car
- Car manufacturers are unwilling to change the standard
- How do we stop it?
CAN MESSAGE FORMAT
THE TROLLEY PROBLEM
for Autonomous Vehicles
WHAT IS THE TROLLEY PROBLEM?
RESULTS

• Approximately 90% choose to kill one and save the five.

• Situation greatly differs if one of the 5 is a relative or a romantic partner.
VARIATIONS

• The fat man
• The fat villain
• The transplant
• The man in the yard
MORAL MACHINE

• A platform to get a human perspective on moral decisions made by autonomous machines

• Can judge moral dilemmas and can design your own scenarios
WHAT DO YOU THINK?
OTHER PROBLEMS

• Instincts are quick (disagree with the Media Lab)

• Model would need to be fast

• Currently do ex post facto analysis (after the fact)
  
• This would need to be able to be run in real time
IMPLEMENTATION ISSUES
EXISTING REGULATIONS

Here and abroad.
IN SUMMARY

• There is not much useful regulation (now).

• Most says if you can have self-driving cars (and insurance)…or not

• Liability is a BIG issue.
WHO?

• In US

• Department of Transportation (DOT)

• National Highway Traffic Safety Administration (NHTSA)

• Currently regulates the manufacturing safety standard of vehicles, where state government regulate the operation of vehicles.
WHAT HAS NHTSA DONE?

• Mandated installation of event data recorders (EDRs) in all new vehicles
  • To help a court determine if the human driver, computer driver, or a particular automated feature of a car caused a crash or traffic incident.
  • Problem: not easy to know the cause

• Federal Motor Vehicle Safety Standards (FMVSSs), which sets performance and testing standards for the safety components of a vehicle.
  • cover crash-avoidance, crashworthiness, and post-crash features of vehicles.
  • prohibit third-party modifications that interfere with safety
  • cannot control owners modifications.
SOME EXISTING STATE RULES

- District of Columbia, Michigan, Florida, and Washington, D.C. all require a driver to be present to manually override the self-driving mode to prevent crashes.

- California, Florida, and Nevada require drivers to submit an insurance instrument, surety bond, or proof of self-insurance in the amount of five million dollars.

- California’s and Florida’s statutes also include a clause expressly stating that federal law preempts any section where the states’ laws are in conflict.

- Nevada and Florida crafted a licensing framework that requires operators of self-driving cars to obtain a certificate of compliance for the vehicle and a driver’s license.

- California was planning to require a licensed operator to be inside the vehicle. But, Google wants: no steering wheel, pedals, or person required.
TWO CHALLENGES WITH REGULATION

1. Liability rules
2. How to best define insurance (with AVs)
LIABILITY

• (Prob. of an accident) × (average damage) + insurance fee

• If the driver doesn’t drive
  • Who is responsible
    • Manufacturer
    • Maintenance
    • Street mapping
    • Infrastructure to vehicle (city or PPP)
LIABILITY (CONTINUED)

- If the driver does not drive....
  - Data event recorders
  - Proof of negligence or causation will need an expert
  - What happens with different traffic regulations?
  - \((\text{Lower probability of an accident}) \times (? \text{ damage})\)
INSURANCE

• Insurance premiums will reduce?

• Liability will be transferred to manufacturers
  • Musk said if he do now get insure he will create his own

• Car prices will include the manufacturer expects to spend in insurance premiums.

• Manufacturer’s liability makes more likely that the cars will be leased, rather than sold.

• Ridesharing businesses such as Uber or Lyft own the vast majority of autonomous vehicles and provide transportation for private parties on an individual-ride basis
THE BIG PROBLEM WITH SELF-DRIVING CARS

the people
Joan is part way across the street on the way to deliver her finished report. While thinking about what to say at the meeting, she hears a sound and turns her head — and sees a quickly oncoming car. Uncertain whether to cross or retreat, but uneasy about arriving late, she decides to sprint across the road. She later remembers her injured knee and reflects upon her impulsive decision. “If my knee had failed, I could have been killed. Then what would my friends have thought of me?”
JOAN CROSSING THE STREET

Reaction: Joan reacted quickly to that sound.

Identification: She recognized it as being a sound.

Characterization: She classified it as the sound of a car.

Attention: She noticed certain things rather than others.

Imagining: She envisioned two or more possible futures.

Indecision: She wondered whether to cross or retreat.

Decision: She chose one of several alternative actions.

Recollection: She retrieved descriptions of prior events.

Reconsideration: Later she reconsidered this choice.

Selection: She selected a way to choose among options.

Apprehension: She was uneasy about arriving late.

**Planning: She constructed a multi-step action-plan.**

Embodiment: She tried to describe her body’s condition.

Emotion: She changed major parts of her mental state.

Representation: She interconnected a set of descriptions.

Language: She constructed several verbal expressions.

Narration: She heard them as dialogs in her mind.

Anticipation: She expected certain future condition.
**Layered System of Human Reasoning**

- **Inborn, Instinctive Reactions:** Joan hears a sound and turns her head. All animals are born equipped with ‘instincts’ that help them to survive.

- **Learned Reactions:** She sees a quickly oncoming car. Joan had to learn that conditions like this demand specific ways to react.

- **Deliberative Thinking:** To decide what to say at the meeting, she considers several alternatives, and tries to decide which would be best.

- **Reflective Thinking:** Joan reflects upon what she has done. She reacts, not just to things in things in the world, but also to recent events in her brain.

- **Self-Reflective Thinking:** Being “uneasy about arriving late” requires her to keep track of the plans that she’s made for herself.
LAYERED SYSTEM OF HUMAN REASONING

Values, Censors, Ideals and Taboos

- Self-Conscious Reflection
- Self-Reflective Thinking
- Reflective Thinking
- Deliberative Thinking
- Learned Reactions
- Instinctive Reactions

Human analogy

Operator
  - Mapping
  - Route planning
  - Sensing Surroundings
  - Driving Tactics
  - Traffic Monitoring
  - Power
  - Steering
  - Braking
  - Safety
NOW, RODNEY BROOKS

• Technology has unintended consequences
• Highlights different problems
  • Dynamics of interaction
    • pedestrian
    • pedestrian to car (even car to car)
• Bullying

Source: IEEE Spectrum. Illustration by Bryan Christie Design
DYNAMICS OF INTERACTION

- Reading body language
- Signifying to the pedestrian
- Interactions with different levels of autonomy

Source: IEEE Spectrum. Illustration by Bryan Christie Design
BULLYING

• Block others with self-driving cars (adding another line).

• Use multiple AVs to wait in line early.

• Using AVs early in the market...

Source: IEEE Spectrum. Illustration by Bryan Christie Design
OTHER PROBLEMS

- Infrastructure
- Restricted environments
- Autonomous subways

Autonomous subway in Copenhagen
WHAT’S NEXT?
TESTING STILL “BAD”

<table>
<thead>
<tr>
<th>Company</th>
<th>Autonomous miles</th>
<th>Disengagements</th>
<th>Rate per 1000 miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google</td>
<td>635868</td>
<td>124</td>
<td>0.20</td>
</tr>
<tr>
<td>Cruise</td>
<td>10015</td>
<td>284</td>
<td>28.36</td>
</tr>
<tr>
<td>Nissan</td>
<td>4099</td>
<td>28</td>
<td>6.83</td>
</tr>
<tr>
<td>Delphi</td>
<td>3125</td>
<td>178</td>
<td>56.95</td>
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<tr>
<td>Bosch</td>
<td>983</td>
<td>1442</td>
<td>1466.94</td>
</tr>
<tr>
<td>Mercedes</td>
<td>673</td>
<td>336</td>
<td>498.95</td>
</tr>
<tr>
<td>BMW</td>
<td>638</td>
<td>1</td>
<td>1.57</td>
</tr>
<tr>
<td>Ford</td>
<td>590</td>
<td>3</td>
<td>5.08</td>
</tr>
<tr>
<td>Tesla</td>
<td>550</td>
<td>182</td>
<td>330.91</td>
</tr>
<tr>
<td>Honda</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>VW</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
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*Source: California DMV. Image - Mark Harris*
Subject to progress on the technical, infrastructure, and regulatory challenges, up to 15% of all new vehicles sold in 2030 could be fully autonomous.

**New vehicle market share of fully autonomous vehicles**

<table>
<thead>
<tr>
<th>Percent</th>
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<tbody>
<tr>
<td>100</td>
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<tr>
<td>90</td>
</tr>
<tr>
<td>80</td>
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<td>20</td>
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<tr>
<td>10</td>
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**High-disruption scenario entails**
- Regulatory challenges overcome in key markets
- Safe and reliable technical solutions fully developed
- Consumers enthusiastic and willing to pay

**Commercial introduction of full autonomy by new tech players and premium OEMs**
- Manufacturing capacity for tech players ramps up gradually
- Mass market leaders introduce full autonomy
- Ramp-up as AV availability spreads across popular consumer models
- Technical and regulatory barriers delay commercial scale introduction of autonomous vehicles
- Slow consumer uptake driven by low perceived value proposition or negative publicity following critical incidents

**SOURCE:** McKinsey

**OEM** - original-equipment manufacturers
Today consumers use their vehicles for all purposes; in the future, they will choose an optimal mobility solution for each specific purpose.

Today:
One vehicle for every trip purpose

2030:
A solution for each specific purpose

Avg. share of annual driving time

Exhibit 3

1 Only showing automobile based mobility, alternative options like walking, biking, and public transportation are also included in optimal mobility solutions.

SOURCE: McKinsey