

# Challenges and Opportunities for Intelligent Transportation Systems

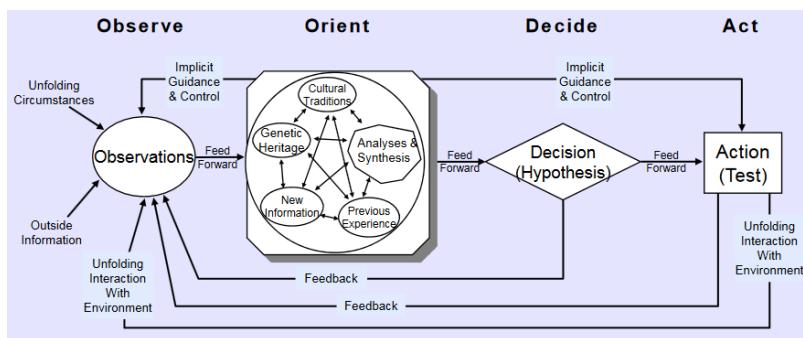
Akshay Rajhans, PhD

Senior Research Scientist  
Advanced Research and Technology Office  
MathWorks  
<https://arajhans.github.io>

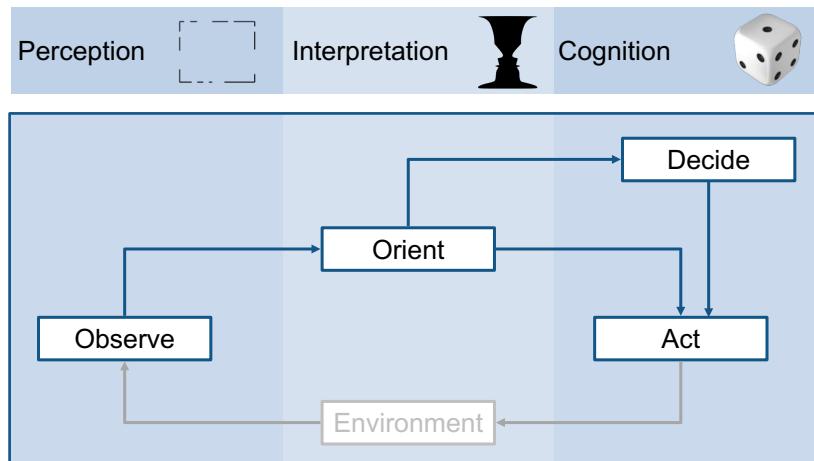
Invited talk in the session on Intelligent Transportation Systems at Robotica 2017  
June 15, 2017

© 2017 The MathWorks, Inc.

## The Observe-Orient-Decide-Act (OODA) loop

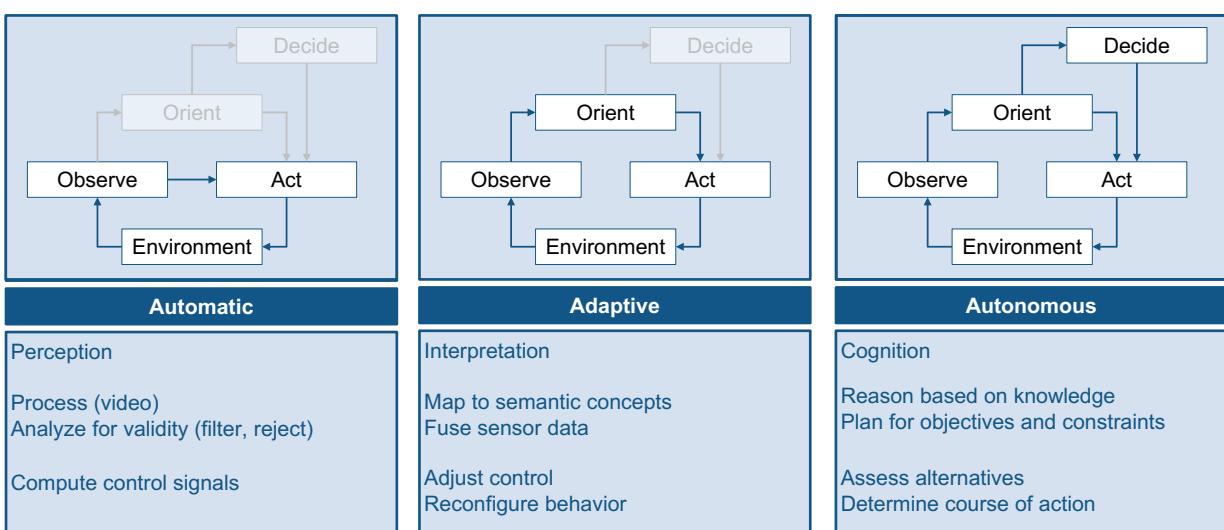


## OODA and the stages of cognition

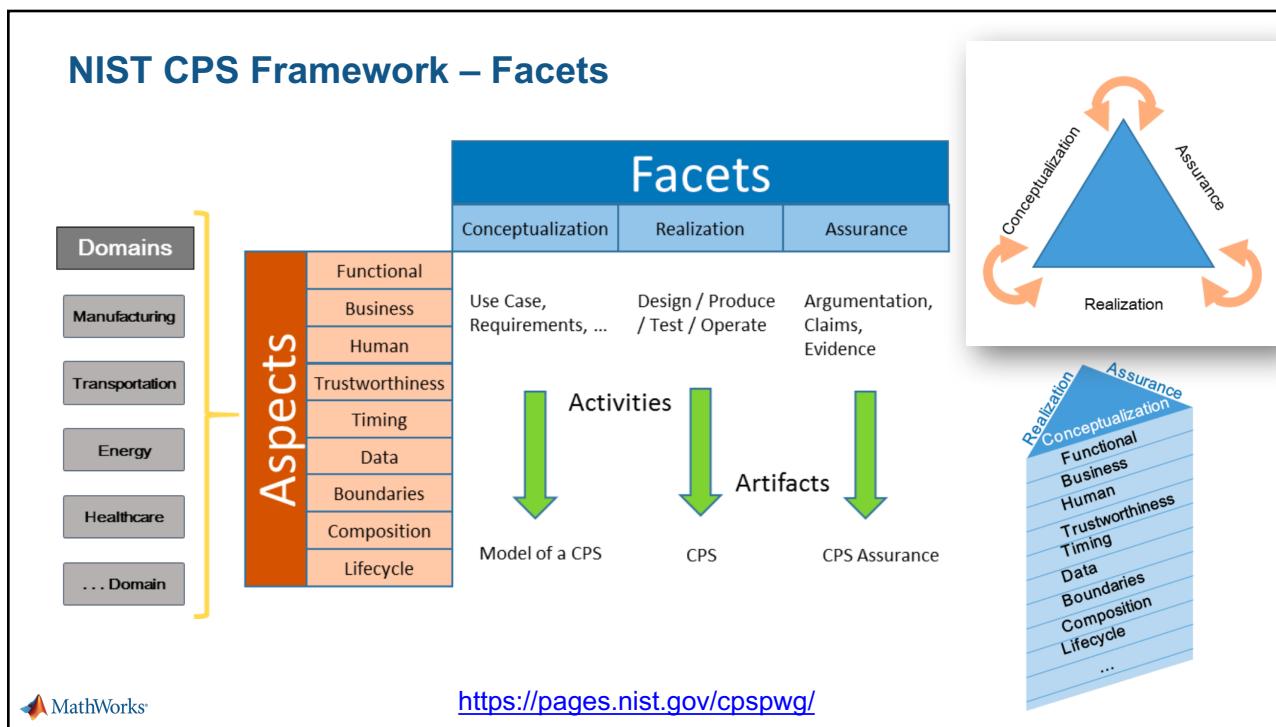
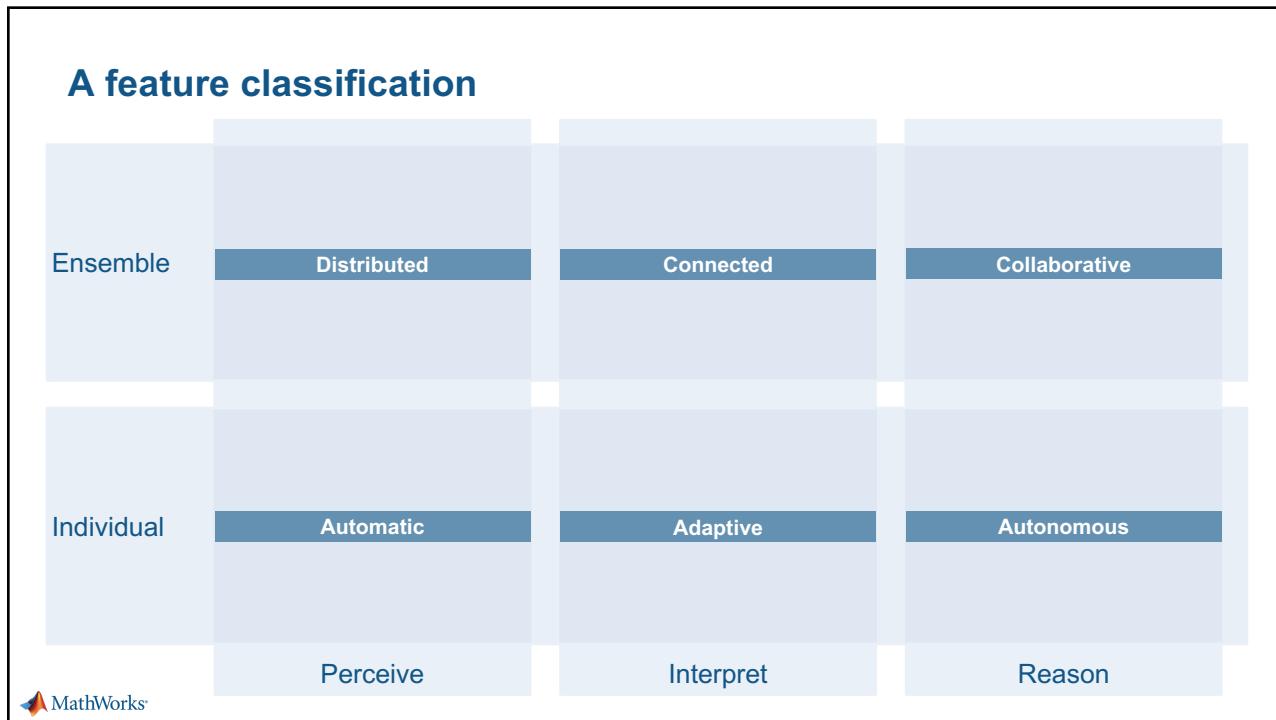


MathWorks

## Engineered systems and levels of cognition



MathWorks



## Adaptive

**Conceptualize**

- How to limit learning to safe behavior?

**Realize**

- What sensory system has sufficient richness?
  - How to prevent over interpretation?
- Robustness against interpretation edge case?
- Correctly fuse sensor data that is misaligned in time and space?

**Assure**

- How to test a self-changing artifact?
  - If regimes are not pre enumerated?
- Ensure successful and correct online calibration?



<https://www.theverge.com/2016/3/24/11297050/tay-microsoft-chatbot-racist>

“Unfortunately, in the first 24 hours of coming online, a **coordinated attack** by a subset of people **exploited a vulnerability** in Tay. Although we had prepared for many types of abuses of the system, we had made a critical **oversight for this specific attack.**”

<http://blogs.microsoft.com/blog/2016/03/25/learning-tays-introduction>

## Adaptive

**Conceptualize**

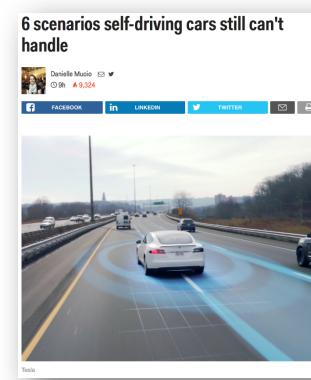
- How to limit learning to safe behavior?

**Realize**

- What sensory system has sufficient richness?
  - How to prevent over interpretation?
- Robustness against interpretation edge case?
- Correctly fuse sensor data that is misaligned in time and space?

**Assure**

- How to test a self-changing artifact?
  - If regimes are not pre enumerated?
- Ensure successful and correct online calibration?



**6 scenarios self-driving cars still can't handle**

“Because **bridges don't have many environmental cues** like surrounding buildings, it's hard for the Uber car to figure out where it is. GPS helps the car position itself, but not to the accuracy Uber wants.”

<http://www.businessinsider.com/autonomous-car-limitations-2016-8>

## Adaptive

**Conceptualize**

- How to limit learning to safe behavior?

**Realize**

- What sensory system has sufficient richness?
  - How to prevent over interpretation?
- Robustness against interpretation edge case?
- Correctly fuse sensor data that is misaligned in time and space?

**Assure**

- How to test a self-changing artifact?
  - If regimes are not pre enumerated?
- Ensure successful and correct online calibration?

 MathWorks

**6 scenarios self-driving cars still can't handle**

**2. Cars struggle in inclement weather**

"Heavy snow and rain tend to confuse LiDAR sensors and also cameras," John Dolan, principle systems scientist at Carnegie Mellon's Robotics Institute, told Business Insider. "So you end up having some problems."

<http://www.businessinsider.com/autonomous-car-limitations-2016-8>

## Adaptive

**Conceptualize**

- How to limit learning to safe behavior?

**Realize**

- What sensory system has sufficient richness?
  - How to prevent over interpretation?
- Robustness against interpretation edge case?
- Correctly fuse sensor data that is misaligned in time and space?

**Assure**

- How to test a self-changing artifact?
  - If regimes are not pre enumerated?
- Ensure successful and correct online calibration?

 MathWorks

**6 scenarios self-driving cars still can't handle**

**3. Cars struggle without clear lane markings**

"When driverless cars [can't distinguish the lanes](#), it makes it nearly impossible for them to drive or change lanes safely."

<http://www.businessinsider.com/autonomous-car-limitations-2016-8>

## Autonomous

**Conceptualize**

- Models of environment with sufficient predictive quality?
- Safe but nontrivial interaction with humans?
  - What are safe level of aggressiveness?

**Realize**

- Robust operation in an exceedingly complex environment?
- Fail safely with loss of minimum information?
- Know a planned action is safe?
- Assess risk online?

**Assure**

- Turing test for cars?
- Ensure the reasoning is always safe?
- Degraded safety (there is no perfect safety)?

**6 scenarios self-driving cars still can't handle**



**4. City driving is much harder than highway**

“Cities are a **mess of pedestrians, cars, potholes, traffic cones** — you get the point.”

“...you get into areas where there are a lot of tall buildings it's hard to receive the GPS signal and **you'll have drop outs**”

<http://www.businessinsider.com/autonomous-car-limitations-2016-8>

 MathWorks

## Autonomous

**Conceptualize**

- Models of environment with sufficient predictive quality?
- Safe but nontrivial interaction with humans?
  - What are safe level of aggressiveness?

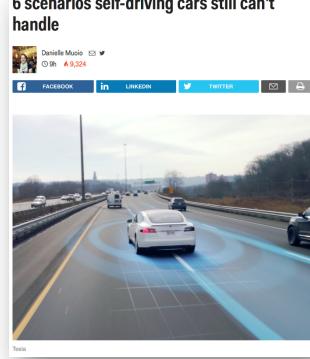
**Realize**

- Robust operation in an exceedingly complex environment?
- Fail safely with loss of minimum information?
- Know a planned action is safe?
- Assess risk online?

**Assure**

- Turing test for cars?
- Ensure the reasoning is always safe?
- Degraded safety (there is no perfect safety)?

**6 scenarios self-driving cars still can't handle**



**5. Robot cars can't interact like humans can**

“... more times than not, **we rely on waving** to let someone know it's ok to go. Driverless cars don't have that luxury”

<http://www.businessinsider.com/autonomous-car-limitations-2016-8>

 MathWorks

## Autonomous

**Conceptualize**

- Models of environment with sufficient predictive quality?
- Safe but nontrivial interaction with humans?
  - What are safe level of aggressiveness?

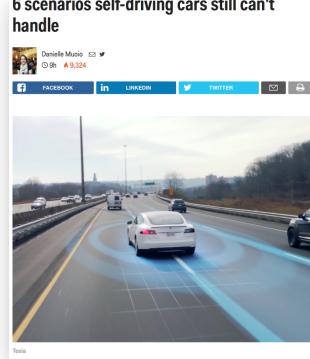
**Realize**

- Robust operation in an exceedingly complex environment?
- Fail safely with loss of minimum information?
- Know a planned action is safe?
- Assess risk online?

**Assure**

- Turing test for cars?
- Ensure the reasoning is always safe?
- Degraded safety (there is no perfect safety)?

**6 scenarios self-driving cars still can't handle**



<http://www.businessinsider.com/autonomous-car-limitations-2016-8>

## Autonomous

**Conceptualize**

- Models of environment with sufficient predictive quality?
- Safe but nontrivial interaction with humans?
  - What are safe level of aggressiveness?

**Realize**

- Robust operation in an exceedingly complex environment?
- Fail safely with loss of minimum information?
- Know a planned action is safe?
- Assess risk online?

**Assure**

- Turing test for cars?
- Ensure the reasoning is always safe?
- Degraded safety (there is no perfect safety)?

**HACKADAY**



<http://hackaday.com/2016/04/18/the-predictability-problem-with-self-driving-cars/>

When we want to know what another car is going to do, we think about the driver of the car, [...] We then think about what we'd do in their place,

If people can't read your car's AI's mind, you're gonna get your fender bent.

7

## Autonomous

**Conceptualize**

- Models of environment with sufficient predictive quality?
- Safe but nontrivial interaction with humans?
  - What are safe level of aggressiveness?

**Realize**

- Robust operation in an exceedingly complex environment?
- Fail safely with loss of minimum information?
- Know a planned action is safe?
- Assess risk online?

**Assure**

- Turing test for cars?
- Ensure the reasoning is always safe?
- Degraded safety (there is no perfect safety)?

SAE “levels of autonomy”

Learn more about SAE J3016 or purchase the standard document: [www.sae.org/autodrive](http://www.sae.org/autodrive)

[https://www.sae.org/misc/pdfs/automated\\_driving.pdf](https://www.sae.org/misc/pdfs/automated_driving.pdf)

→
We are here

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
<b>Human driver monitors the driving environment</b>						
<b>0</b>	<b>No Automation</b>	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
<b>1</b>	<b>Driver Assistance</b>	the <i>driving mode</i> -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 <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes
<b>2</b>	<b>Partial Automation</b>	the <i>driving mode</i> -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 <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes
<b>Automated driving system (“system”) monitors the driving environment</b>						
<b>3</b>	<b>Conditional Automation</b>	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver	Some driving modes
<b>4</b>	<b>High Automation</b>	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	System	Some driving modes
<b>5</b>	<b>Full Automation</b>	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	All driving modes

MathWorks

[https://www.sae.org/misc/pdfs/automated\\_driving.pdf](https://www.sae.org/misc/pdfs/automated_driving.pdf)

Copyright © 2014 SAE International. The summary table may be freely copied and distributed provided SAE International and J3016 are acknowledged as the source and must be reproduced AS-IS.

8

## Autonomous

**Conceptualize**

- Models of environment with sufficient predictive quality?
- Safe but nontrivial interaction with humans?
  - What are safe level of aggressiveness?

**Realize**

- Robust operation in an exceedingly complex environment?
- Fail safely with loss of minimum information?
- Know a planned action is safe?
- Assess risk online?

**Assure**

- Turing test for cars?
- Ensure the reasoning is always safe?
- Degraded safety (there is no perfect safety)?

MathWorks


The New York Times

TECHNOLOGY

**Robot Cars Can't Count on Us in an Emergency**

By JOHN MARKOFF JUNE 7, 2017



“...most drivers required [more than five seconds](#) to regain control of a car when — while playing a game on a smartphone — they were abruptly required to return their attention to driving.”

<https://www.nytimes.com/2017/06/07/technology/google-self-driving-cars-handoff-problem.html>

## Autonomous

**Conceptualize**

- Models of environment with sufficient predictive quality?
- Safe but nontrivial interaction with humans?
  - What are safe level of aggressiveness?

**Realize**

- Robust operation in an exceedingly complex environment?
- Fail safely with loss of minimum information?
- Know a planned action is safe?
- Assess risk online?

**Assure**

- Turing test for cars?
- Ensure the reasoning is always safe?
- Degraded safety (there is no perfect safety)?

MathWorks


The New York Times

TECHNOLOGY

**Robot Cars Can't Count on Us in an Emergency**

By JOHN MARKOFF JUNE 7, 2017



“Taking back control of a car is a very different experience at a high speed than at a low one, and [adapting to the feel of the steering](#) took a significant amount of time even when the test subjects were prepared for the handoff.”

<https://www.nytimes.com/2017/06/07/technology/google-self-driving-cars-handoff-problem.html>

## Autonomous

**Conceptualize**

- Models of environment with sufficient predictive quality?
- Safe but nontrivial interaction with humans?
  - What are safe level of aggressiveness?

**Realize**

- Robust operation in an exceedingly complex environment?
- Fail safely with loss of minimum information?
- Know a planned action is safe?
- Assess risk online?

**Assure**

- Turing test for cars?
- Ensure the reasoning is always safe?
- Degraded safety (there is no perfect safety)?

The New York Times TECHNOLOGY

**Robot Cars Can't Count on Us in an Emergency**

By JOHN MARKOFF JUNE 7, 2017

I believe that Level 3 autonomous driving is unsolvable, said John Leonard, a mechanical engineering professor at [MIT].

"The notion that a human can be a reliable backup is a fallacy."

<https://www.nytimes.com/2017/06/07/technology/google-self-driving-cars-handoff-problem.html>

## Connected

**Conceptualize**

- How to interpret data safely
  - Which data to corroborate information?

**Realize**

- Safely operate in the face of communication challenges
  - Degradation, loss
  - Corruption
- Timeliness and responsiveness guarantees?
  - Service discovery time out, DoS

**Assure**

- Is closed loop verification possible?
- How do you obtain failure probabilities?

news.com.au

National | World | Lifestyle | Travel | Entertainment | Technology | Finance | Sport | Video

Probe to dive into Jupiter's atmosphere   Facebook to automate news feed   Garage collector's job now scary   Freaky fanged spiders discovered

**gadgets**

**Woman follows GPS into lake**

MAY 16, 2016 8:09PM

A 23-year-old woman managed to drive into a lake during a foggy Canadian night

RIGHT NOW IN TECHNOLOGY

277 READERS	Great Pyramid of Cholula, Mexico: World's largest pyramid is... <a href="#">Read more</a>
148 READERS	Car park chaos solved? Researchers discover link to... <a href="#">Read more</a>
176 READERS	Super recognition: London police... <a href="#">Read more</a>
92 READERS	Cycling from NSW: No helmet, no belt, no brakes leads to... <a href="#">Read more</a>
87 READERS	NASA probe to dive into Jupiter's atmosphere

the woman was following a route on her car's GPS while driving in the dark on a foggy night in Ontario when it directed her to drive onto a boat launch, and she ended up in a lake.

<http://www.news.com.au/technology/gadgets/woman-follows-gps-into-lake/news-story/a7d362dfc4634fd094651afc63f853a1>

10

## Connected

**Conceptualize**

- How to interpret data safely
  - Which data to corroborate information?

**Realize**

- Safely operate in the face of communication challenges
  - Degradation, loss
  - Corruption
- Timeliness and responsiveness guarantees?
  - Service discovery time out, DoS

**Assure**

- Is closed loop verification possible?
- How do you obtain failure probabilities?

 MathWorks

<div style="border: 1px solid

## Connected

**Conceptualize**

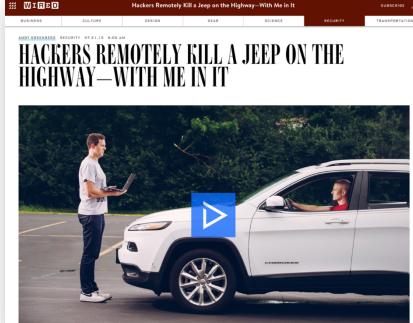
- How to interpret data safely
  - Which data to corroborate information?

**Realize**

- Safely operate in the face of communication challenges
  - Degradation, loss
  - Corruption
- Timeliness and responsiveness guarantees?
  - Service discovery time out, DoS

**Assure**

- Is closed loop verification possible?
- How do you obtain failure probabilities?



"Uconnect's cellular connection also lets anyone who knows the car's IP address gain access from anywhere in the country."

"From that entry point, the attack pivots to an adjacent chip [...] rewriting the firmware [...] capable of sending commands through the CAN bus, to its physical components like the engine and wheels."

<https://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/>

 MathWorks

## Collaborative

**Conceptualize**

- Cross-organization failure effect analysis?
- How to identify and prevent race conditions?
- Robust conflict resolution across an ensemble?
- How to trade off system vs. ensemble safety?

**Realize**

- Safety of ad hoc rules in collaboration?
- How to perform online safety analysis?
- How much risk to assign to a collaboration?
- How to gracefully enter/exit a collaboration?
- How to ensure ample resources to be safe?
- Can you assign probability to reliance?

**Assure**

- How do you test? Measure coverage?
- Work outside nominal regions (online derating)?
- Assumptions about collaborating systems?



The way humans often deal with these situations is that "they make eye contact. On the fly, they make agreements about who has the right of way," said John Lee, a professor of industrial and systems engineering and expert in driver safety and automation at the University of Wisconsin.

<http://www.nytimes.com/2015/09/02/technology/personaltech/google-says-its-not-the-driverless-cars-fault-its-other-drivers.html>

 MathWorks

## Collaborative

### Conceptualize

- Cross-organization failure effect analysis?
- How to identify and prevent race conditions?
- Robust conflict resolution across an ensemble?
- How to trade off system vs. ensemble safety?

### Realize

- Safety of ad hoc rules in collaboration?
- How to perform online safety analysis?
- How much risk to assign to a collaboration?
- How to gracefully enter/exit a collaboration?
- How to ensure ample resources to be safe?
- Can you assign probability to reliance?

### Assure

- How do you test? Measure coverage?
- Work outside nominal regions (online derating)?
- Assumptions about collaborating systems?



## GIZMODO

### What Google's Self-Driving Car Team Learned From Hitting That Bus

Alessa Walker · 3/19/17 10pm · Filed to AUTONOMOUS VEHICLES · 161 · 12 · 0 · 0



The Google car's prediction didn't come true when it struck a bus on Valentine's Day

'Our car was [making an assumption](#) about what the other car was going to do,' said Chris Urmson

<http://gizmodo.com/what-googles-self-driving-car-team-learned-from-hitting-1764409297>

## Opportunities

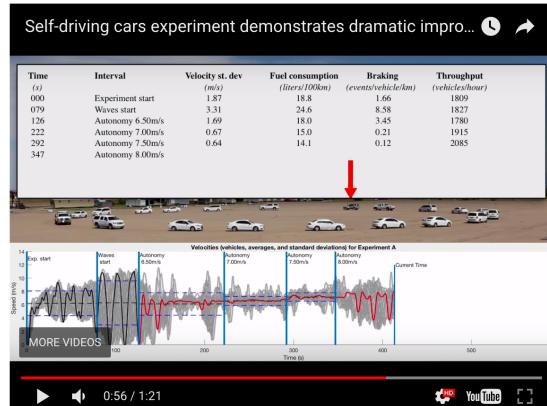


## Even one autonomous vehicle can make a big impact!

Experiments show that a few self-driving cars can dramatically improve traffic flow



"Before we carried out these experiments, I did not know how straightforward it could be to positively affect the flow of traffic," Sprinkle said. "I assumed we would need sophisticated control techniques, but what we showed was that controllers which are staples of undergraduate control theory will do the trick."



<https://phys.org/news/2017-05-self-driving-cars-traffic.html>

<https://www.youtube.com/watch?v=2mBjYZTeaTc>



Jonathan Sprinkle  
Litton Industries John M. Leonis Distinguished Associate Professor  
Office: ECE 456N  
Phone: 520.626.0737  
Email: sprinkle@ece.arizona.edu  
Research/Lab Website



**MathWorks®** Products Solutions Academia Support Community Events

Student Home | MATLAB Student | Tutorials | Examples | Student Competitions | Books | Hardware Support

**CAT Vehicle Challenge**

The CAT Vehicle CPS Challenge 2017 brings together 30 teams, comprised of over 80 students, to use Model-Based Design to develop a software component for controlling a real self-driving car—the University of Arizona's CAT Vehicle. The teams will create ROS software components prototyped using Simulink using real-world data from the CAT Vehicle to compete for tasks such as obstacle identification using fewest sensors possible, velocity computation for trajectory following, and generation of 3D simulation virtual world files in Gazebo from simulation trajectories and actual driving data. Top-performing teams will have an opportunity to see their validated software running on the CAT Vehicle in Tucson, AZ, over a period of 2-3 days.

**Getting Started**

See all the videos of the CAT Vehicle Simulator in action

- » Visualizing the CAT Vehicle
- » Taking a Hard Left Turn
- » Following a Circular Path
- » Generating Code from a ROS Simulink Model

CAT Vehicle Challenge official website (on the CPS Virtual Organization)

**Complimentary Software**

MathWorks provides complimentary software for this competition. If your team is participating in this competition and would like to request software contact us.

Request Software

<https://www.mathworks.com/academia/student-competitions/catvehiclechallenge.html>





DARYL DAVIDSON  
Executive Director, AUVSI Foundation

[Feedback](#)

Student Teams Use MATLAB and Simulink in the AUVSI Foundation RoboBoat Competition

Daryl Davidson, AUVSI Foundation

See how students design fully autonomous boats using Model-Based Design with MATLAB and Simulink in the AUVSI Foundation's RoboBoat Competition.

<https://www.mathworks.com/videos/student-teams-use-matlab-and-simulink-in-the-ausvi-foundation-roboboat-competition-98693.html>



