Road Vehicle Automation Challenges

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What are we talking about?

- What are the goals? What problem(s) are we trying to solve?
- Need precise terminology and operational concepts in order to understand each other
  - Not "driverless", "self driving" or "unmanned"
- Automation vs. autonomy
- Definitions of driver vs. "system" roles
- Automation under what operating conditions/environmental complexity?
- Technical challenges

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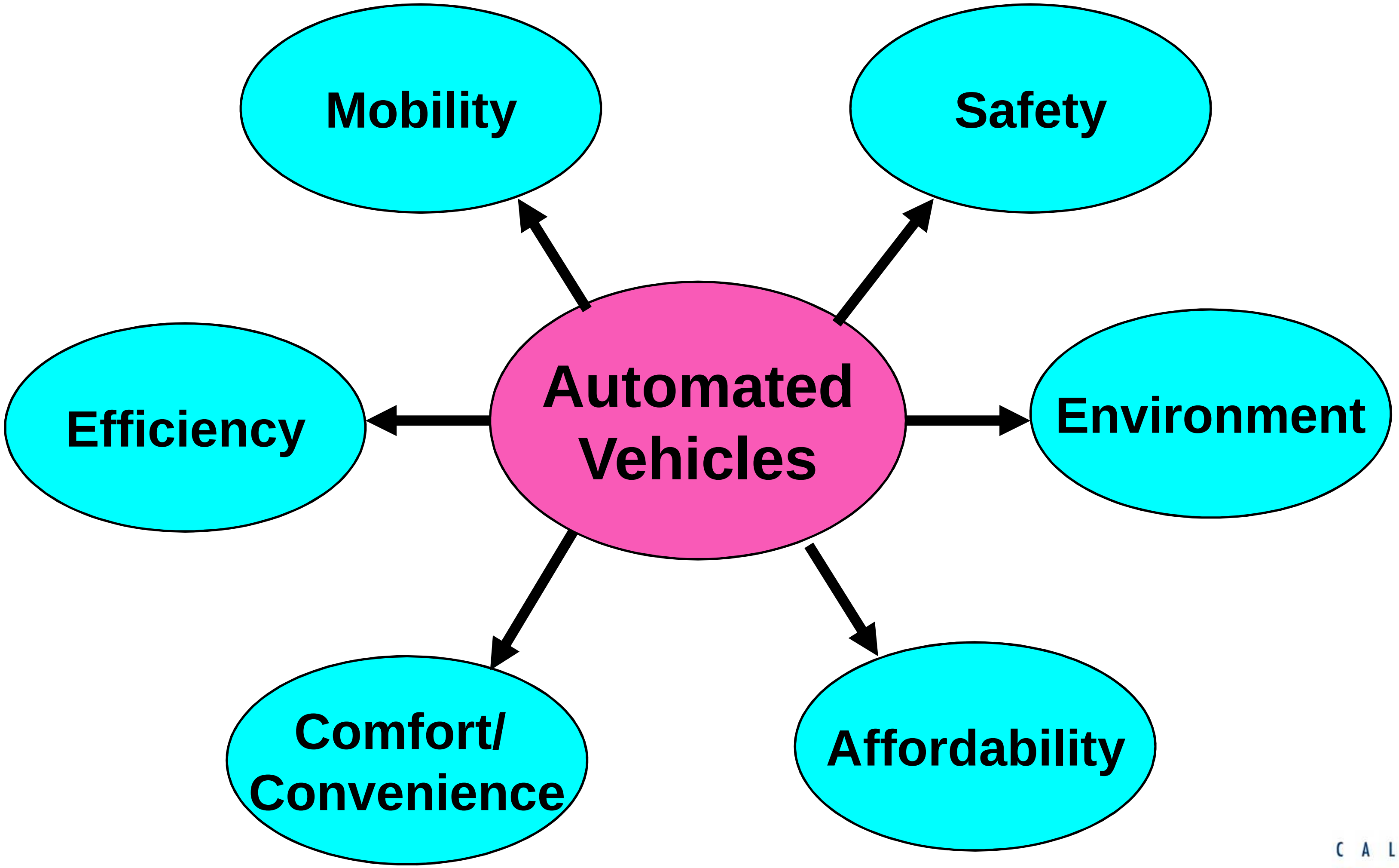
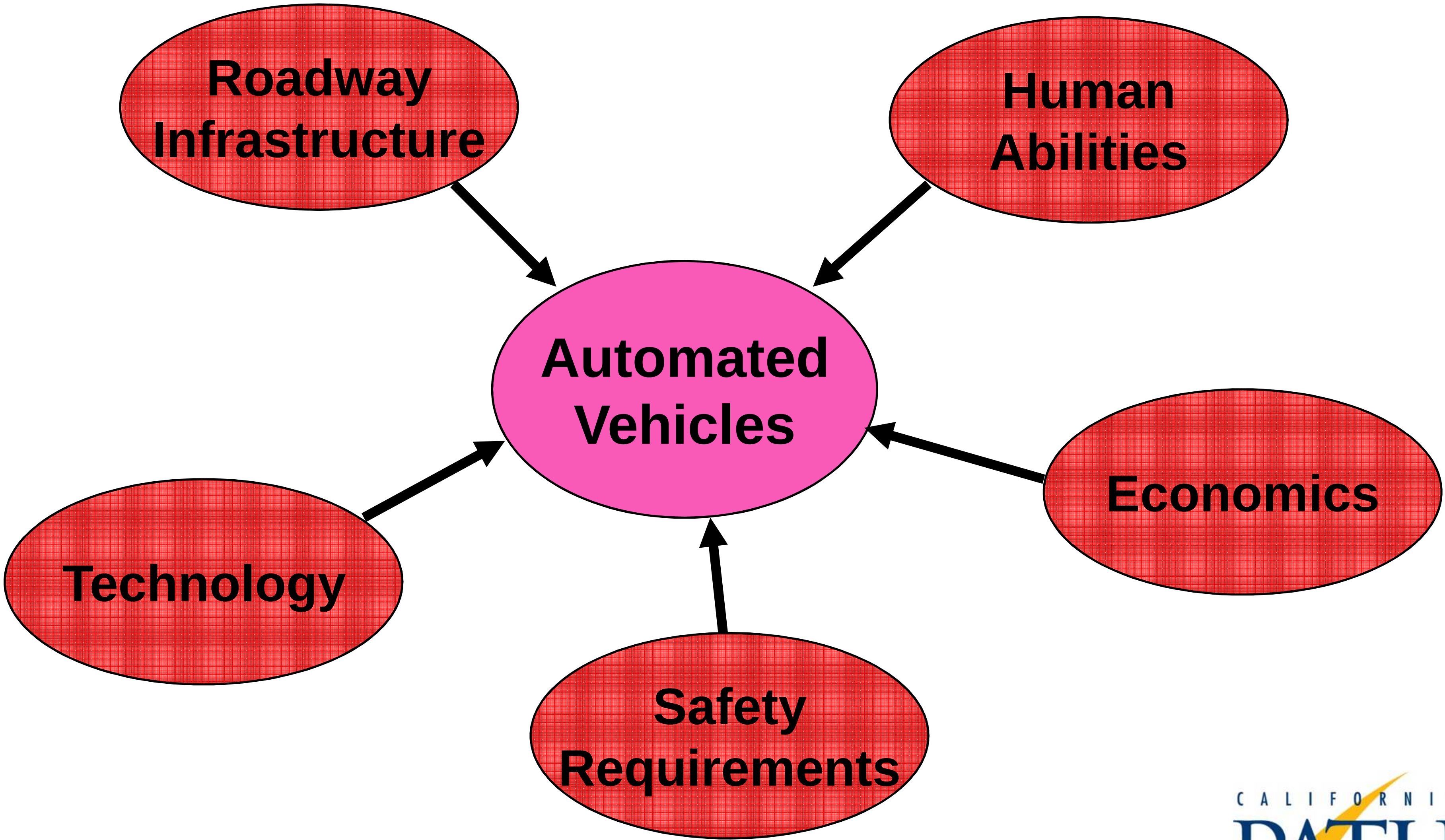
Potential Goals



Constraints



Definitions
(per Oxford English Dictionary)

- **autonomy:**
  1. *(of a state, institution, etc.)* the right of self-government, of making its own laws and administering its own affairs
  2. *(biological)* (a) the condition of being controlled only by its own laws, and not subject to any higher one; (b) organic independence
  3. a self-governing community.

  autonomous:
  1. of or pertaining to an autonomy
  2. possessed of autonomy, self governing, independent
  3. *(biological)* (a) conforming to its own laws only, and not subject to higher ones; (b) independent, i.e., not a mere form or state of some other organism.

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- <u>automate</u>: to apply automation to; to convert to largely automatic operation

  <u>automation</u>: automatic control of the manufacture of a product through a number of successive stages; the application of automatic control to any branch of industry or science; by extension, <u>the use of electronic or mechanical devices to replace human labour</u>

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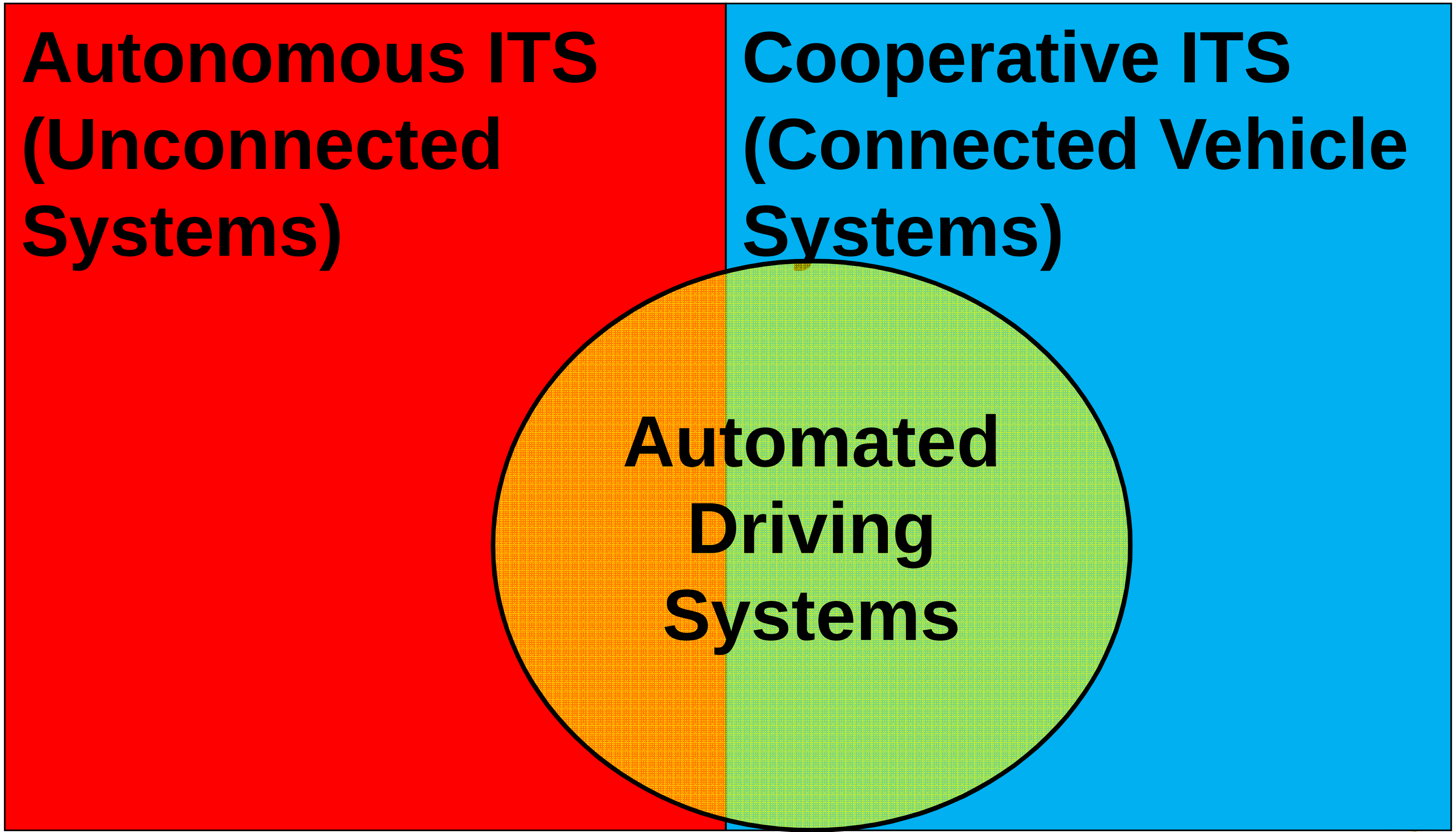
Autonomous and Cooperative ITS



SAE J3016 Definitions

SAE Level	Name	Narrative Definition	Execution of Steering/ Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability (*Driving Modes*)
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	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*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	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*	**System**	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	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*	System	**System**	Human driver	Some driving modes
4	High Automation	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*	System	System	**System**	Some driving modes
5	Full Automation	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*	System	System	System	**All driving modes**

Example Systems at Each Automation Level

Level	Example Systems	Driver Roles
1	Adaptive Cruise Control OR Lane Keeping Assistance	Must drive <u>other</u> function and monitor driving environment
2	Adaptive Cruise Control AND Lane Keeping Assistance Traffic Jam Assist (Mercedes)	Must monitor driving environment (system nags driver to try to ensure it)
3	Traffic Jam Pilot Automated parking	May read a book, text, or web surf, but be prepared to intervene when needed
4	Highway driving pilot Closed campus driverless shuttle Driverless valet parking in garage	May sleep, and system can revert to minimum risk condition if needed
5	Automated taxi (even for children) Car-share repositioning system	No driver needed

How to manage driver interaction?

- **Can't redesign the driver → must design the system to be usable by the driver**

- **Force driver to stay engaged? (nuisance)**
- **Disregard driver? (system must take full responsibility)**
- **Re-engage driver when system is disabled? (how much time needed to guarantee arousing a sleeping or texting driver?)**

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Safety Requirements

- Not an “unmanned” vehicle, but a safety-of-life critical system
- “Significantly” safer than today’s driving to gain public acceptance and provide benefits
  - Fatal crashes MTBF > 3.3 million vehicle hours
  - Injury crashes MTBF > 65,000 vehicle hours
- What software-intensive consumer electronic product can approach these MTBF levels?
- How to PROVE that an automated driving system is better than this?
  - To trust this vehicle to carry your family
  - To get affordable insurance
  - To manage risk of the system vendor

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Driving Environment Diversity (1/2)

- **Existing infrastructure, unchanged**
  - Off-road
  - All roads
  - All paved roads
  - Well-marked paved roads
  - Urban and suburban arterials
  - Rural highways
  - Residential streets
  - Limited-access highways (freeways)
  - Parks or low-speed pedestrian zones
  - Enclosed parking facilities

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Driving Environment Diversity (2/2)

- **Existing infrastructure, augmented for automation**
  - **Dedicated lanes within limited-access highway**
  - **Special markings or electronics added**
- **Separate new infrastructure**
  - **Dedicated, protected lanes on limited-access highways**
  - **Fully automated parking facilities**
  - **Physically separated guideways (PRT)**

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Driving Environment Complexity

- **Cluttered, highly dynamic environment**
  - **Vehicles, pedestrians, bikes, kids, pets**
  - **Scofflaw and aggressive drivers**
  - **Adverse weather and visibility**
  - **Poorly maintained markings and signs**
- **How to replicate defensive driving skills, including use of subtle visual cues and eye contact?**
- **Murphy's Law is unavoidable**

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Orders of Magnitude Harder than Commercial Aircraft Automation

- Positioning accuracy ~ 10 cm
- Many simultaneous threats to track and avoid
  - Relative locations of targets ~10 cm
  - Relative speeds of targets ~1 m/s
- Threat response needed in <100 ms
- Fault recovery needed in <100 ms
- No operator (driver) training
- No preventive maintenance, >10 year lifetime
- Unit capital cost target ~ $3 K

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Need for Communication/Cooperation to Gain Transportation Benefits

- **Infrastructure must provide traffic signal status, variable speed limits, dynamic restrictions on lane use (work zones)**
- **Extremely beneficial to have other vehicles providing:**
  - **Maneuver intentions**
  - **Message/condition acknowledgments**
  - **Advance alerts about hazards**
  - **Cooperation to improve efficiency, enable close clustering to reduce drag**
- **By contrast, autonomous vehicles are deaf-mute drivers**

Technological Challenges

- Sensor performance and cost
- Logic and data processing
- Software complexity and safety

Sensor Challenges for Autonomous Automation in Mixed Traffic

- **High-performance, costly sensors are needed (accuracy, field of regard, discriminant capability)**
- **Sensors cannot detect subtle cues from other vehicles and drivers like experienced drivers**
- **No single sensor technology can satisfy all needs, so fusion of multiple sensors with complementary faults and vulnerabilities is necessary**
  - **Cost and complexity concerns**
- **Filtering is necessary, but introduces serious lags**
- **Remote sensors are slower and more uncertain than onboard sensors (speed, acceleration, driver actions)**

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Logic and Data Processing Challenges

- **Sensor signal processing (e.g., distinguishing hazardous from benign obstacles)**
  - **Any object large enough to cause harm**
  - **BUT, ignore innocuous “soft” targets**
  - **“Zero” missed detections (false negatives)**
  - **“Near-zero” false alarms (false positives)**
- **Predicting future actions of other vehicles**
- **General driving threat assessment (defensive driving)**
- **Decision making in ethically ambiguous threat situations (truck vs. motorcycle)**
- **Moore’s Law does not provide salvation**

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Software Challenges for Fully Automated Driving

- **Complexity – cannot test all combinations of conditions**
- **Cannot <u>prove</u> safety of software for safety-critical applications**
- **Need comprehensive fault detection, identification and reconfiguration – self-healing**

- **How many hours of testing are needed to <u>prove</u> safety better than human driving?**
- **How many hours of <u>continuous, unassisted</u> automated driving has anybody achieved in real traffic?**

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Where to go from here?

- Simplify, simplify, simplify… to focus on tractable problems to solve
  - Protected environments
  - Commercial vehicles, professional drivers
  - Use all available data (including V2V, I2V)
  - Limited levels of automation (retaining driver as safety backup)
- Automation of buses on busways
- Automation of trucks in truck lanes and terminals
- Parking in enclosed garages

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