CAP 6635 – Artificial Intelligence

Lecture 3 : Self-driving vehicles

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@ProfessorOge

ProfessorOgeMarques

Why this topic?

Short answer:

Because, as a case study, **it has it all!**

Key ideas

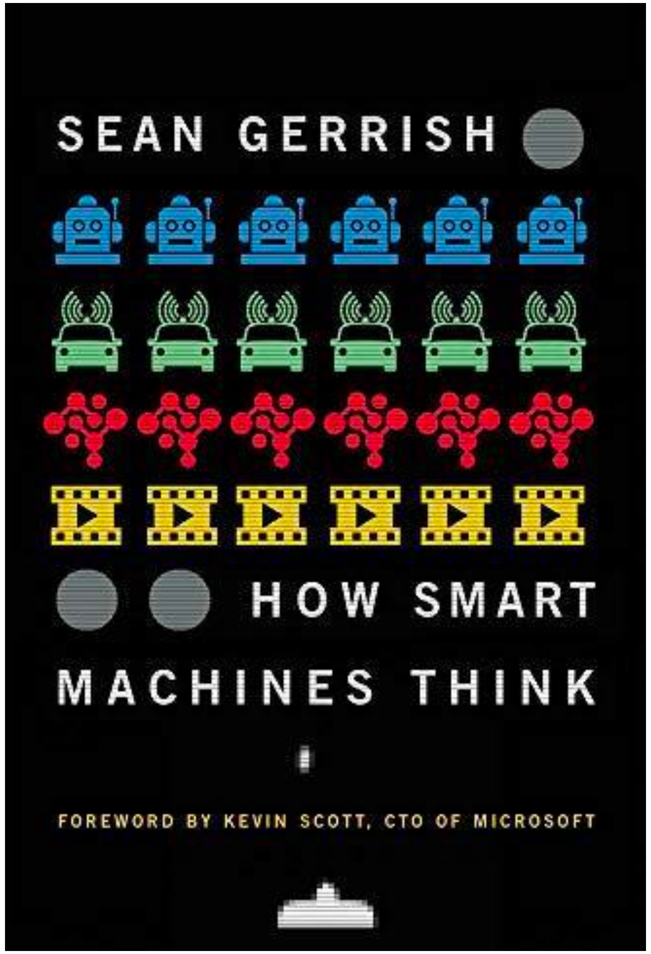
- One of the greatest Engineering / AI achievements of our time (hardware, software, control, etc.)
- Inherently complex (real-time, real-world, multiple sensors, safety considerations, etc.)
  - Teamwork is essential
  - Simulation played a big part
  - Divide-and-conquer
  - Sebastian Thrum’s “genius move”: turning it into a software / ML problem

Key ideas

- Huge market / ecosystem (trillions of USD?)
  - Big names -- Waymo (Google), Tesla, Uber, automakers – attracting top-notch talent
  - Many other players at all levels
  - Market shifts and market niches
- Hype cycle, ups and downs, buzzwords (“disruptive”)
- Bold executive/engineering decisions (e.g., Tesla’s ”no Lidar”)
- Real products / real world / millions of logged miles / model updates

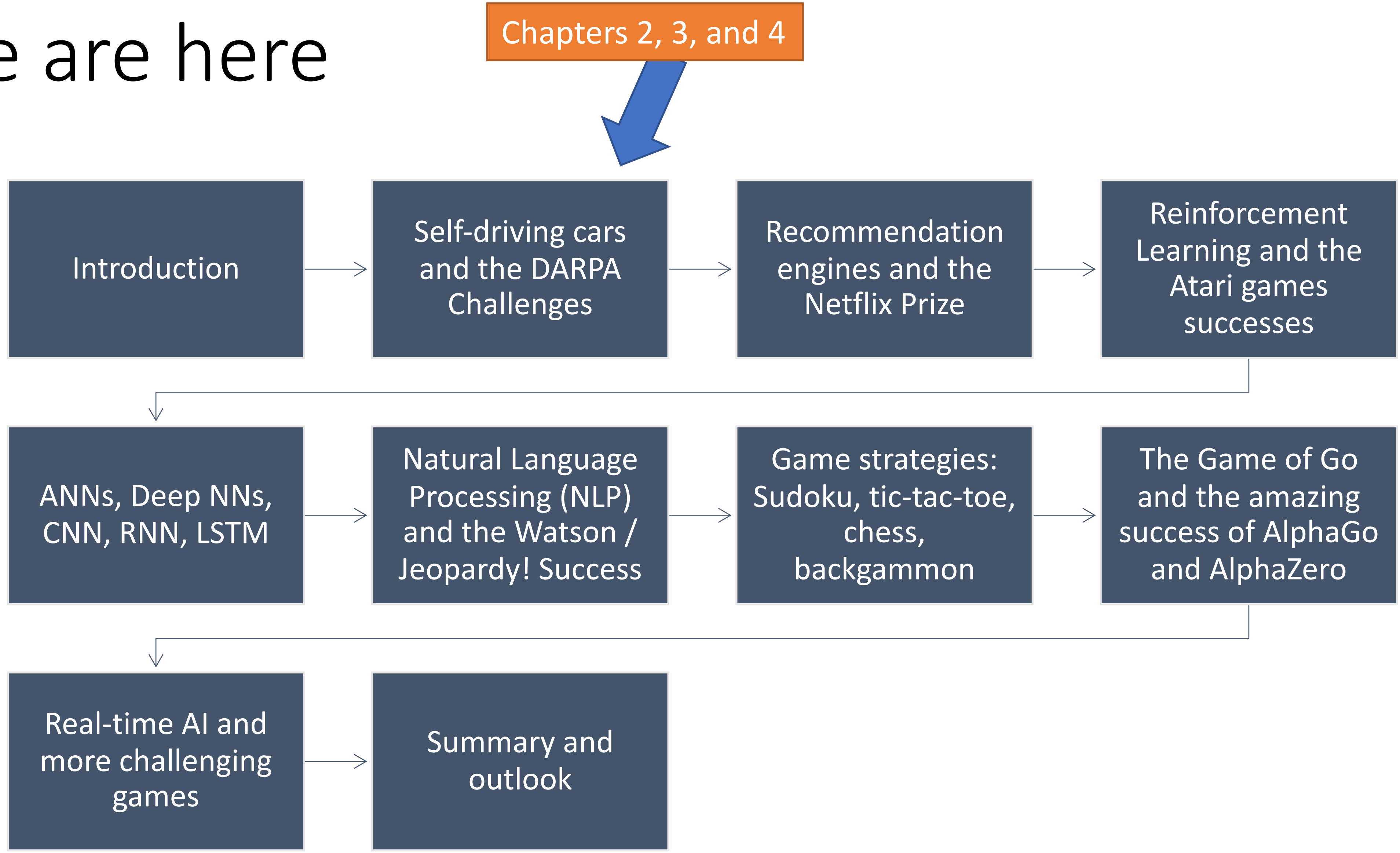
Key ideas

- Human-computer interaction issues
- Socioeconomic questions, e.g., truck drivers’ job losses
- Utopian vs. dystopian views: headlines vs. statistics
- Moral questions: the (infamous) trolley problems
- FATE (Fairness, Accountability, Transparency, Ethics) aspects
- Plenty of learning opportunities



How smart machines think (by Sean Gerrish)

We are here


Chapters 2, 3, and 4
Introduction
Self-driving cars and the DARPA Challenges
Recommendation engines and the Netflix Prize
Reinforcement Learning and the Atari games successes
ANNs, Deep NNs, CNN, RNN, LSTM
Natural Language Processing (NLP) and the Watson / Jeopardy! Success
Game strategies: Sudoku, tic-tac-toe, chess, backgammon
The Game of Go and the amazing success of AlphaGo and AlphaZero
Real-time AI and more challenging games
Summary and outlook

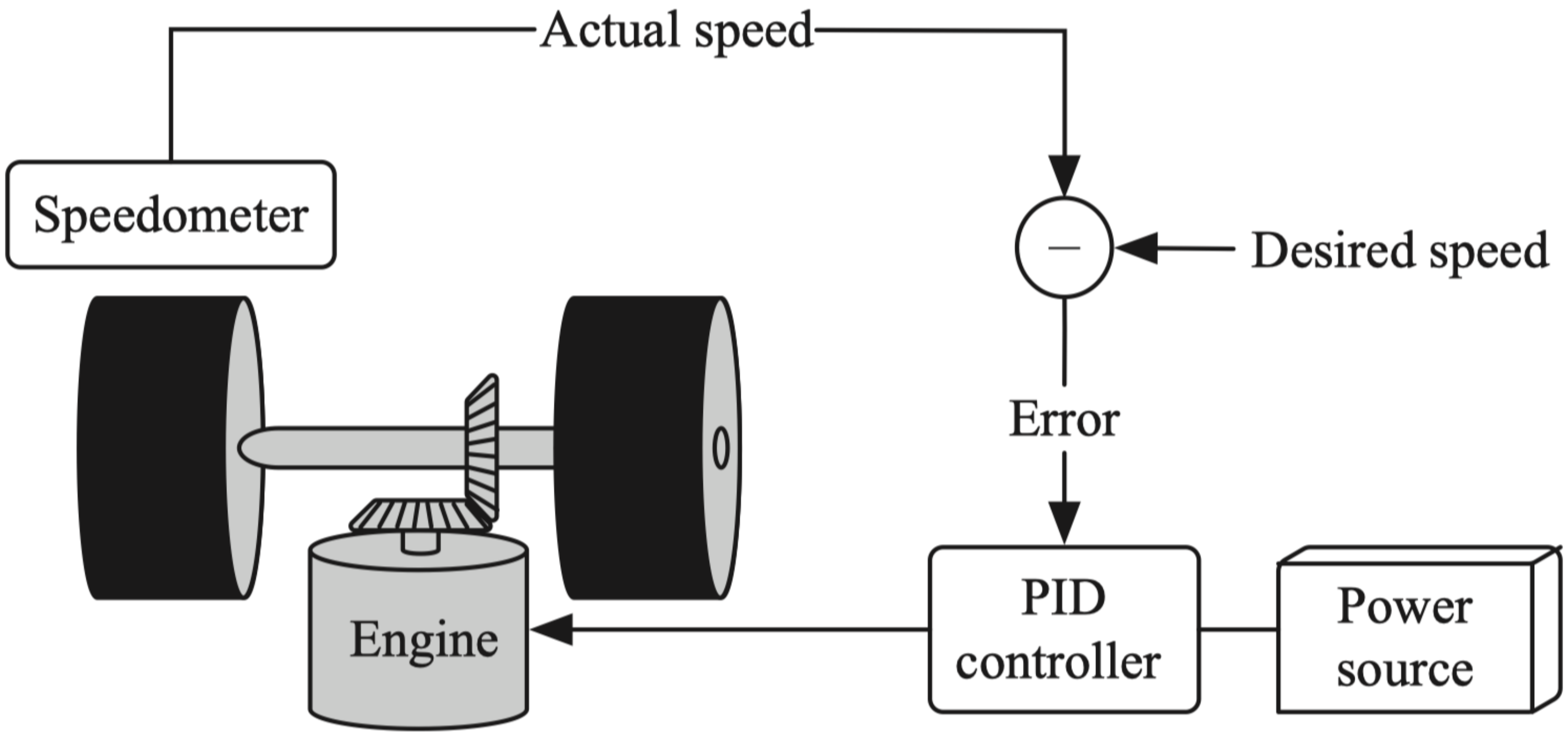
Key idea:

Self-driving cars are one the greatest Engineering achievements of all time

One of the greatest technological achievements of our time

- Multidimensional
  - Hardware
  - Software
  - Control
- Inherently complex
  - real-time
  - real-world
  - multiple sensors
  - safety considerations
- Teamwork is essential
- Simulation played a big part
- Divide-and-conquer
- Sebastian Thrum’s “genius move”: turning it into a software / ML problem

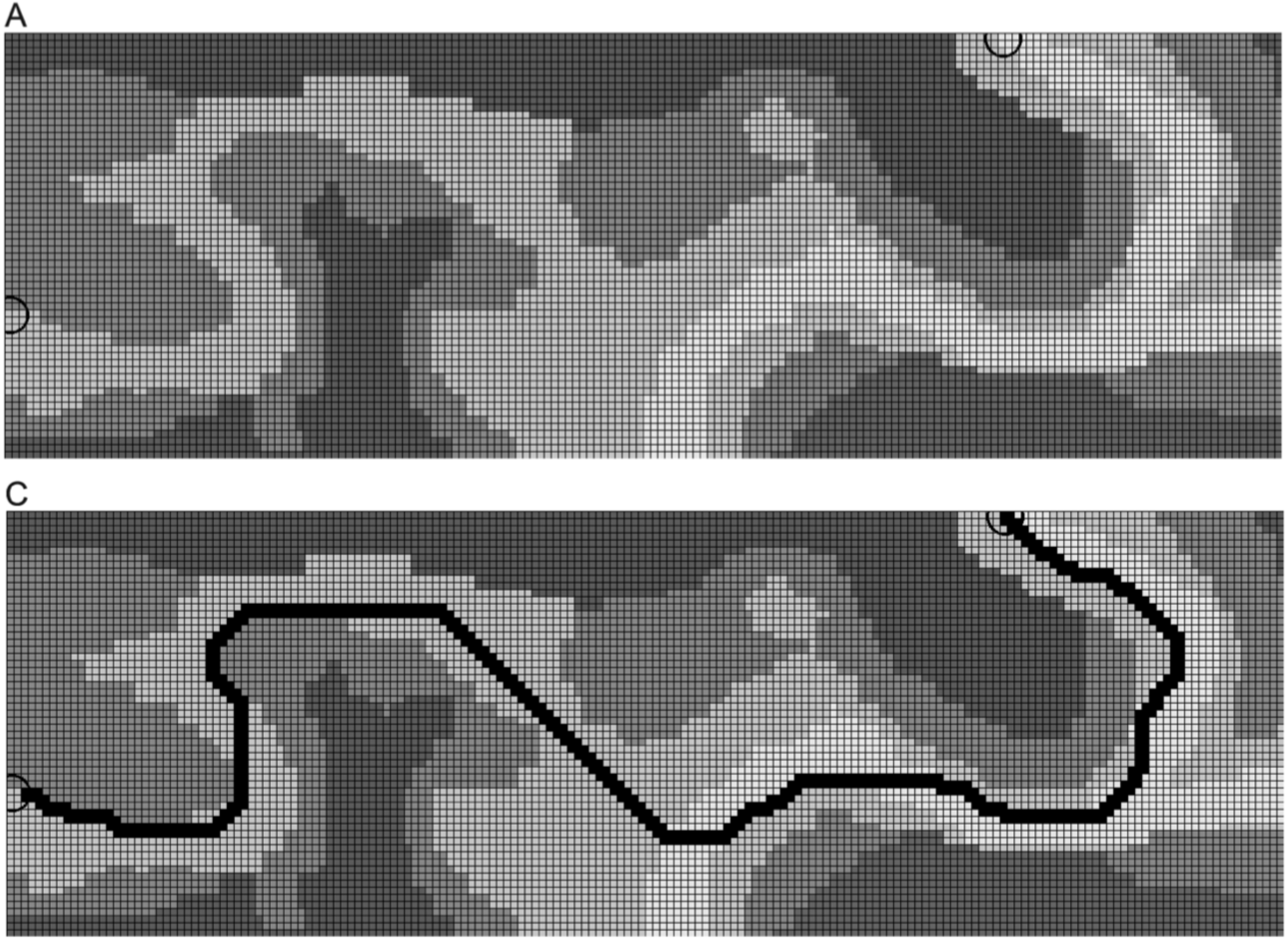
PID controller



Path planning

- Path planning: searching for the *least cost* path

- Popular algorithm: Dijkstra's



Navigation

- GPS
- Accelerometers
- Gyros
- Kalman filter
- LIDAR (Light Detection And Ranging) (aka *laser scanners*)

Keeping within the lanes: perception in self-driving cars

Key idea:

It all started with a DARPA Challenge (or two…)

Self-driving cars and the DARPA Grand Challenge (2004-2005)

2004

($ 1M prize):
no winner!

2005

($ 2M prize):
CMU vs. Stanford

2004-05

DARPA DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

The Grand Challenge

Self-driving cars and the DARPA Grand Challenge (2004-2005)

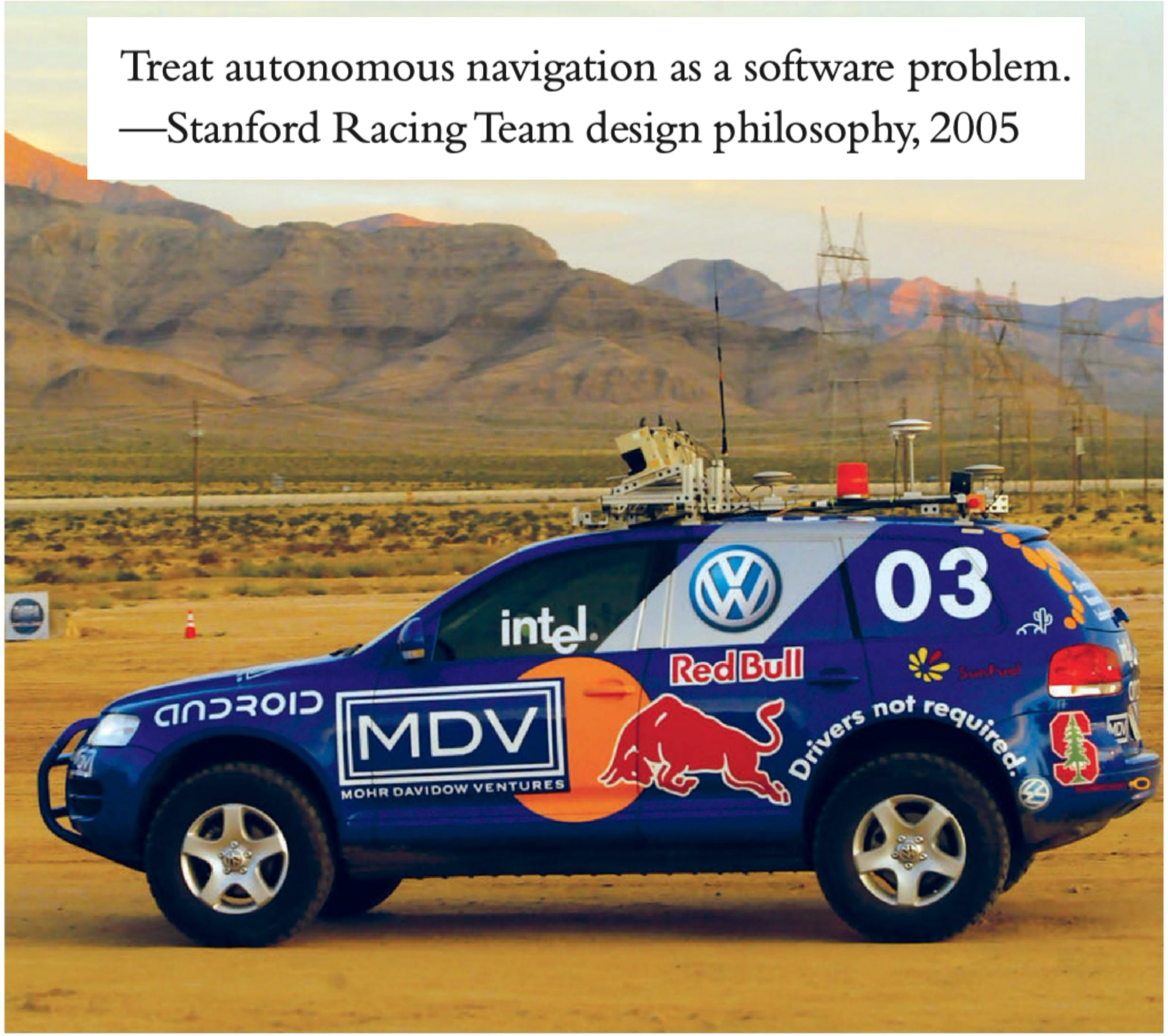
CMU’s H1ghlander

Self-driving cars and the DARPA Grand Challenge (2004-2005)

CMU's H1ghlander

Self-driving cars and the DARPA Grand Challenge (2004-2005)

Stanford's Stanley: winner of the 2005 Grand Challenge
($ 2M prize)

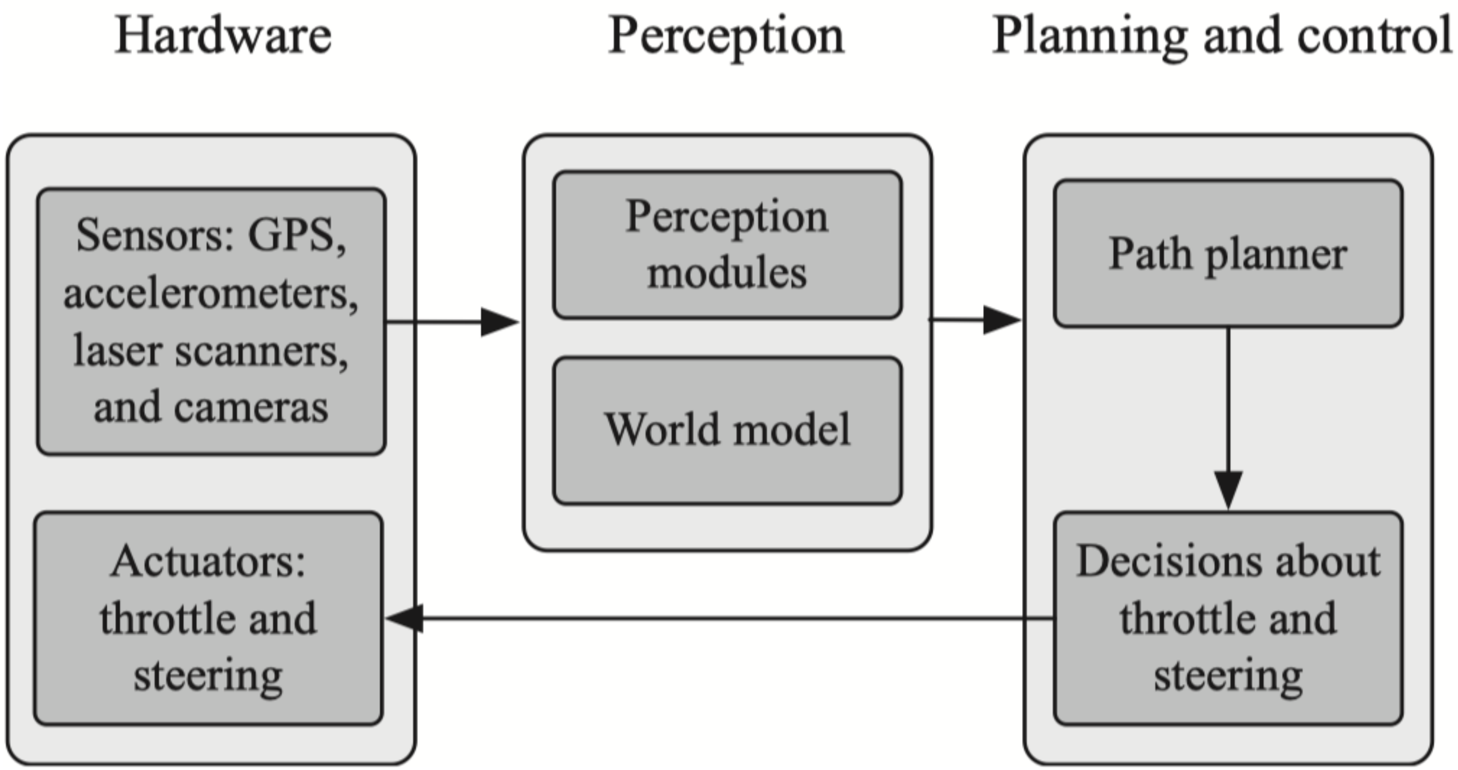


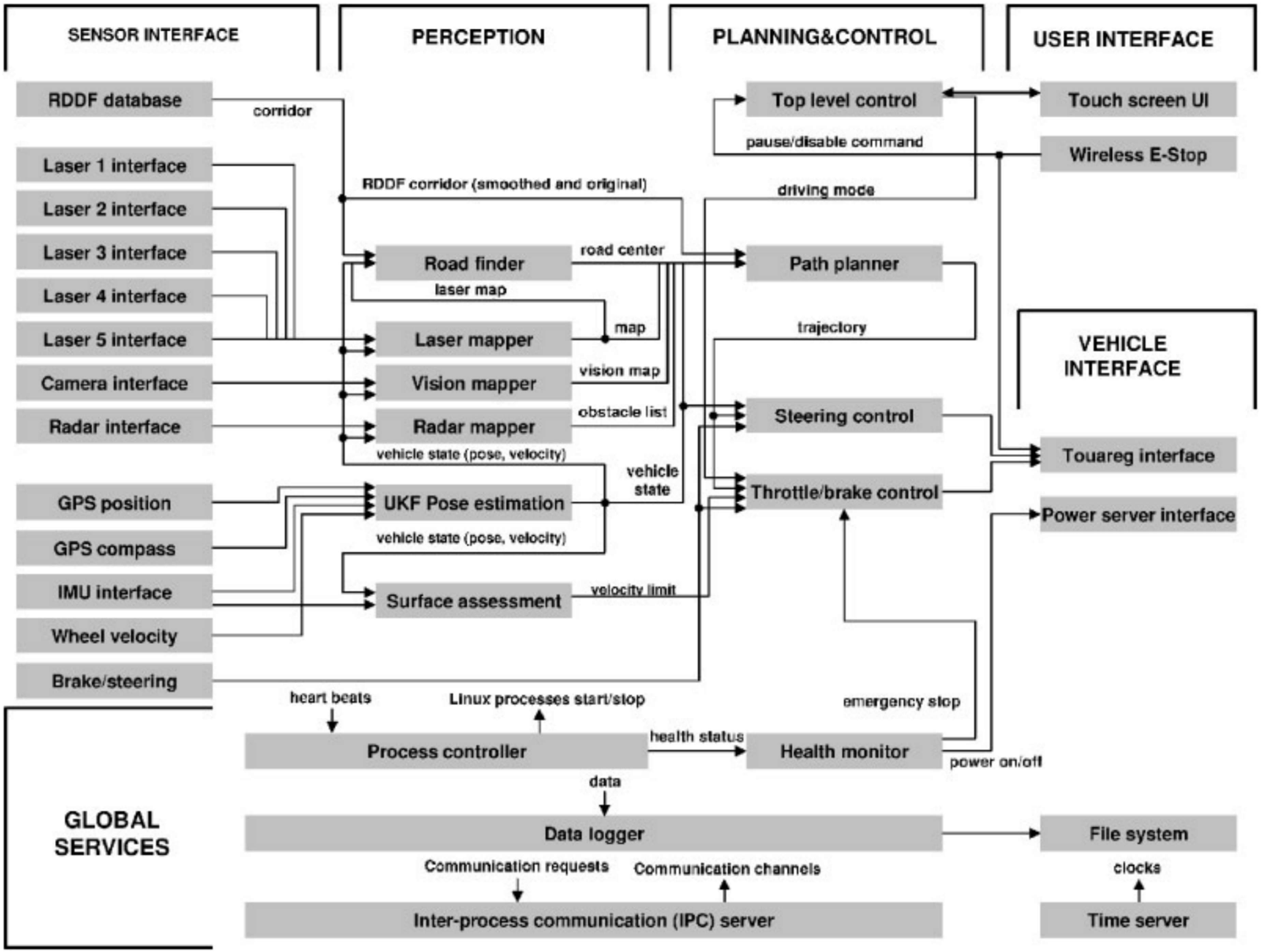
What made Stanley so successful in the race?

- The Stanford Racing Team had the insight that placing so much emphasis on mapping and navigation at the expense of *sensing* the environment was a mistake.
- They converged on a different design philosophy: *treat autonomous navigation as a software problem*.
- They were one of the first modern self-driving car teams to take a full bet on machine learning, embracing its role in self-driving cars nearly a decade before it became a buzzword in the mainstream media.

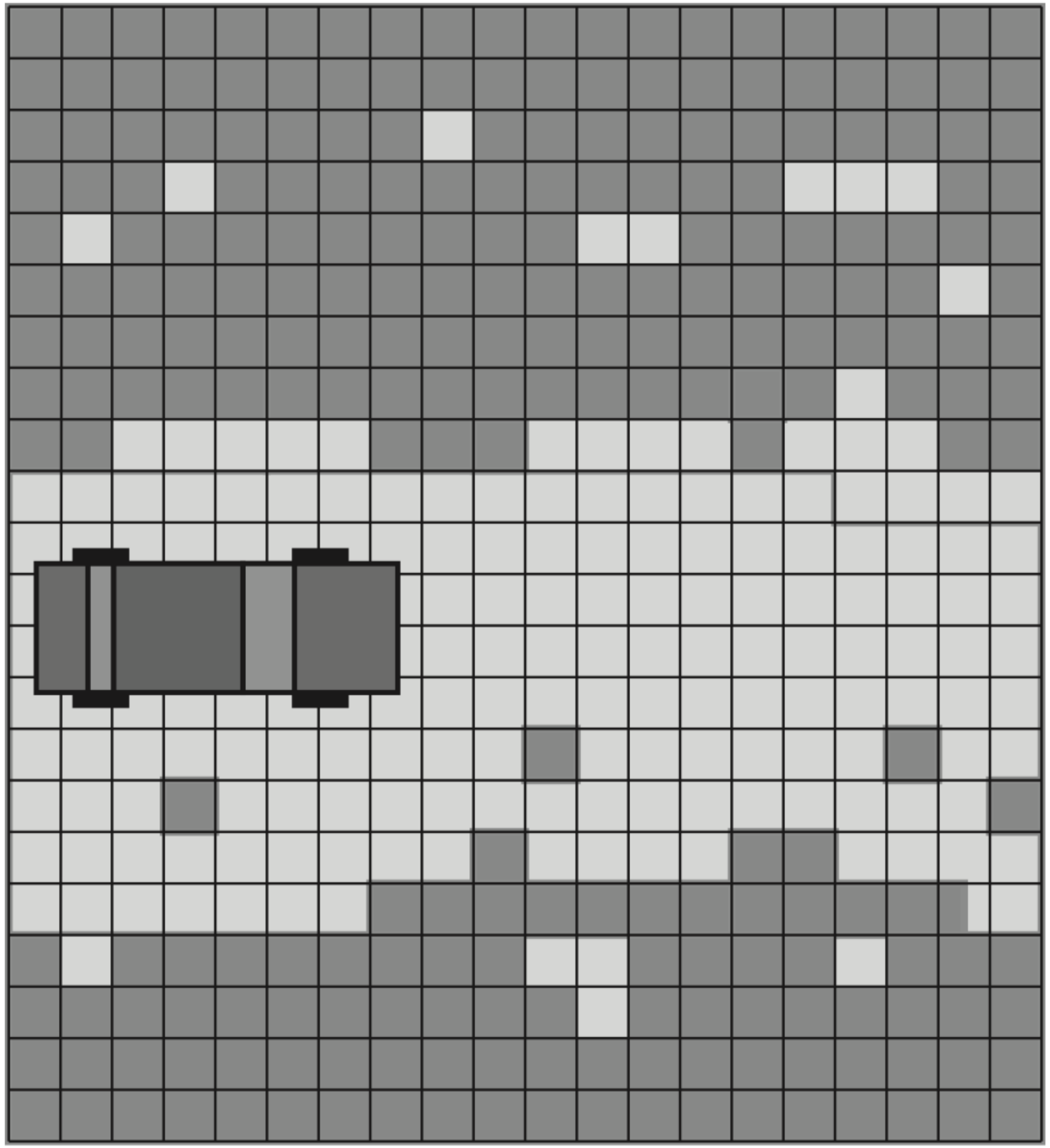
> The pervasive use of machine learning, both ahead [of] and during the race, made Stanley robust and precise. We believe that those techniques, along with the extensive testing that took place, contributed significantly to Stanley's success in this race.[20]

Stanley's simplified architecture



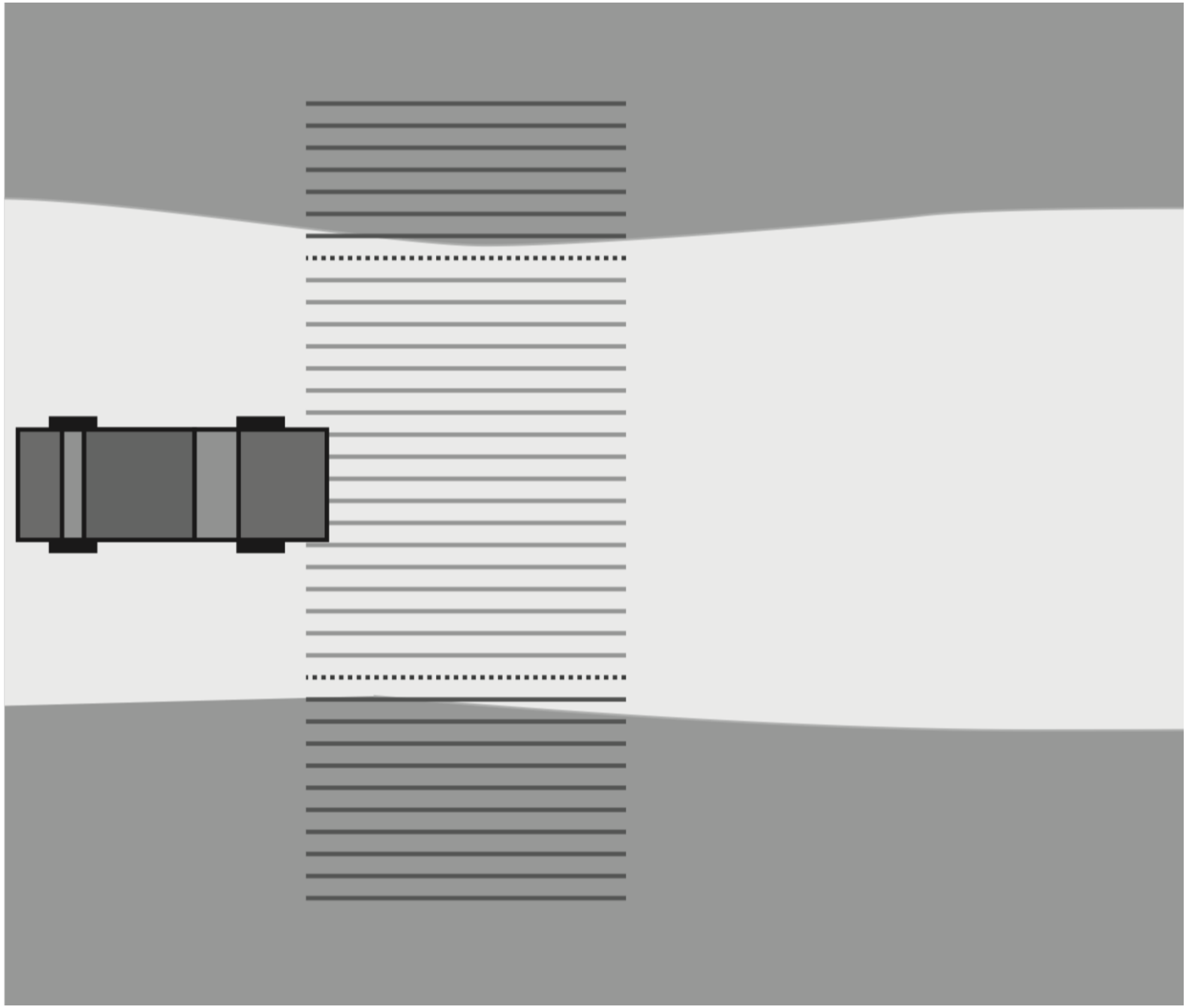

SENSOR INTERFACE
PERCEPTION
PLANNING&CONTROL
USER INTERFACE
RDDF database
corridor
Laser 1 interface
Laser 2 interface
Laser 3 interface
Laser 4 interface
Laser 5 interface
Camera interface
Radar interface
GPS position
GPS compass
IMU interface
Wheel velocity
Brake/steering
RDDF corridor (smoothed and original)
Road finder
road center
laser map
map
Laser mapper
Vision mapper
vision map
Radar mapper
obstacle list
vehicle state (pose, velocity)
UKF Pose estimation
vehicle state
vehicle state (pose, velocity)
Surface assessment
velocity limit
Top level control
pause/disable command
driving mode
Path planner
trajectory
Steering control
Throttle/brake control
Touch screen UI
Wireless E-Stop
VEHICLE INTERFACE
Touareg interface
Power server interface
heart beats
Linux processes start/stop
Process controller
health status
Health monitor
emergency stop
power on/off
data
Data logger
File system
Communication requests
Communication channels
clocks
Inter-process communication (IPC) server
Time server
GLOBAL SERVICES

Stanley: avoiding obstacles



Stanley: finding the road’s edges

Combining laser scanners with color camera



Stanley: putting it all together

- In the self-driving car, the GPS and accelerometers estimated the car’s position and orientation, “published” them with the current timestamp, and continued to take and publish updated position information for the rest of the race: that was their only job.
- The pixel-clustering, road-finding module fetched camera and laser scanner data, found roads, and then published this information so the speed controller and path planner could use them at their convenience.
- Meanwhile, the path-finding module estimated the best path for the robot given its current position and obstacles, repeating itself ten times per second—and so on, for a total of about 30 modules.

What made Stanley so successful in the race?

- Phenomenal teamwork and leadership!
- Amazing talent!
- Freedom to create, be bold, innovate!
- Resources (including $$$)
- Learn more about it!
  - See papers on Canvas
  - Watch Sebastian’s interview with Lex Fridman on the AI Podcast

The DARPA Urban Challenge (2007)

2007

DARPA

DEFENSE ADVANCED
RESEARCH PROJECTS AGENCY

URBAN CHALLENGE

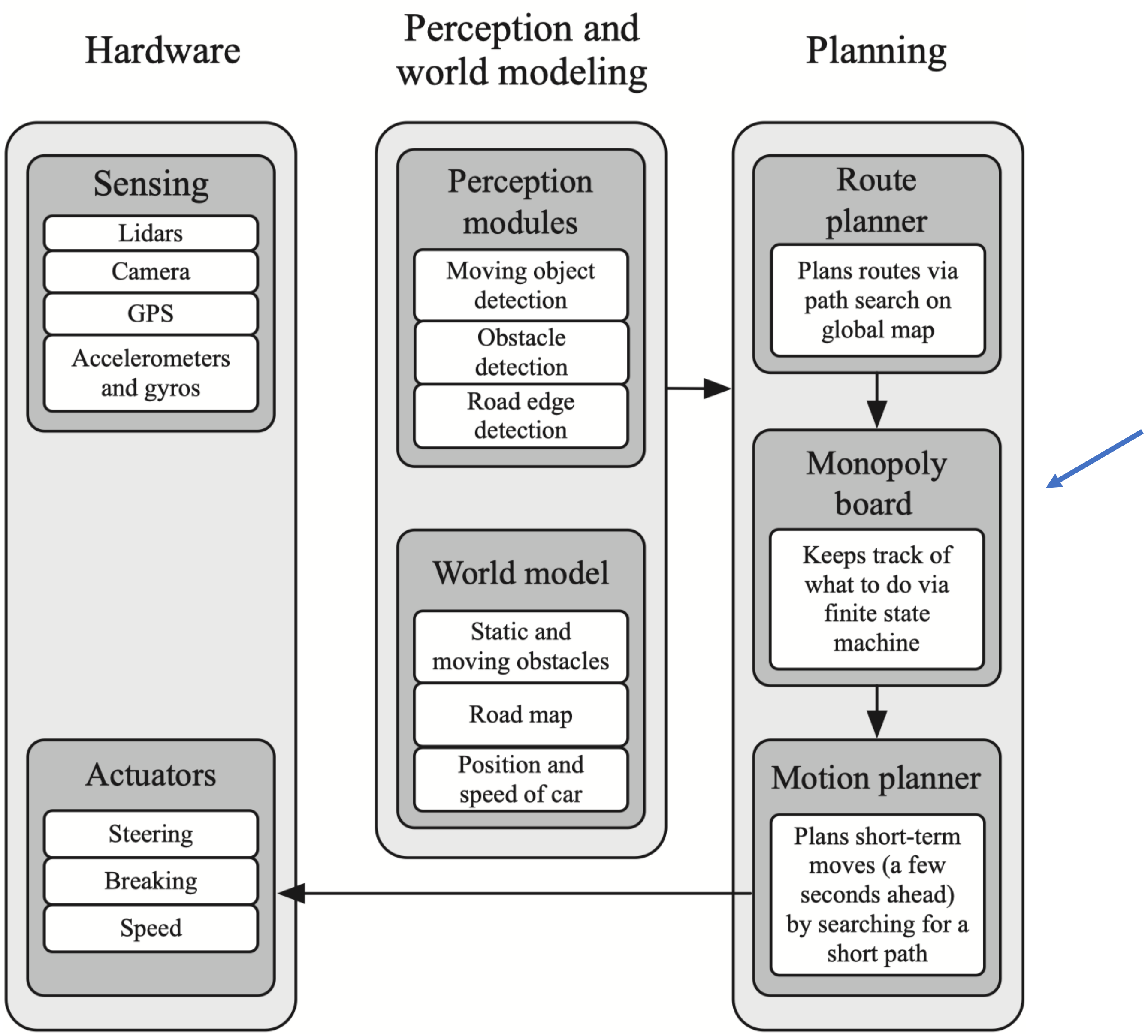
Tartan Racing – Pittsburgh, PA
1st Place

Stanford Racing – Stanford, CA
2nd Place

The DARPA Urban Challenge (2007)

Boss (CMU)

Boss's architecture (simplified)



The Monopoly board layer: Finite State Machines (FSMs)

A FSM provides a way for a computer program to reason about the world by limiting the things it needs to worry about.

- It works a lot like the game Monopoly: you have a piece that can move around on a board, and at any given time, your piece can be in exactly one "state" (that is, position) on the board.
- This position determines what you're allowed to do now and where you're allowed to move next.

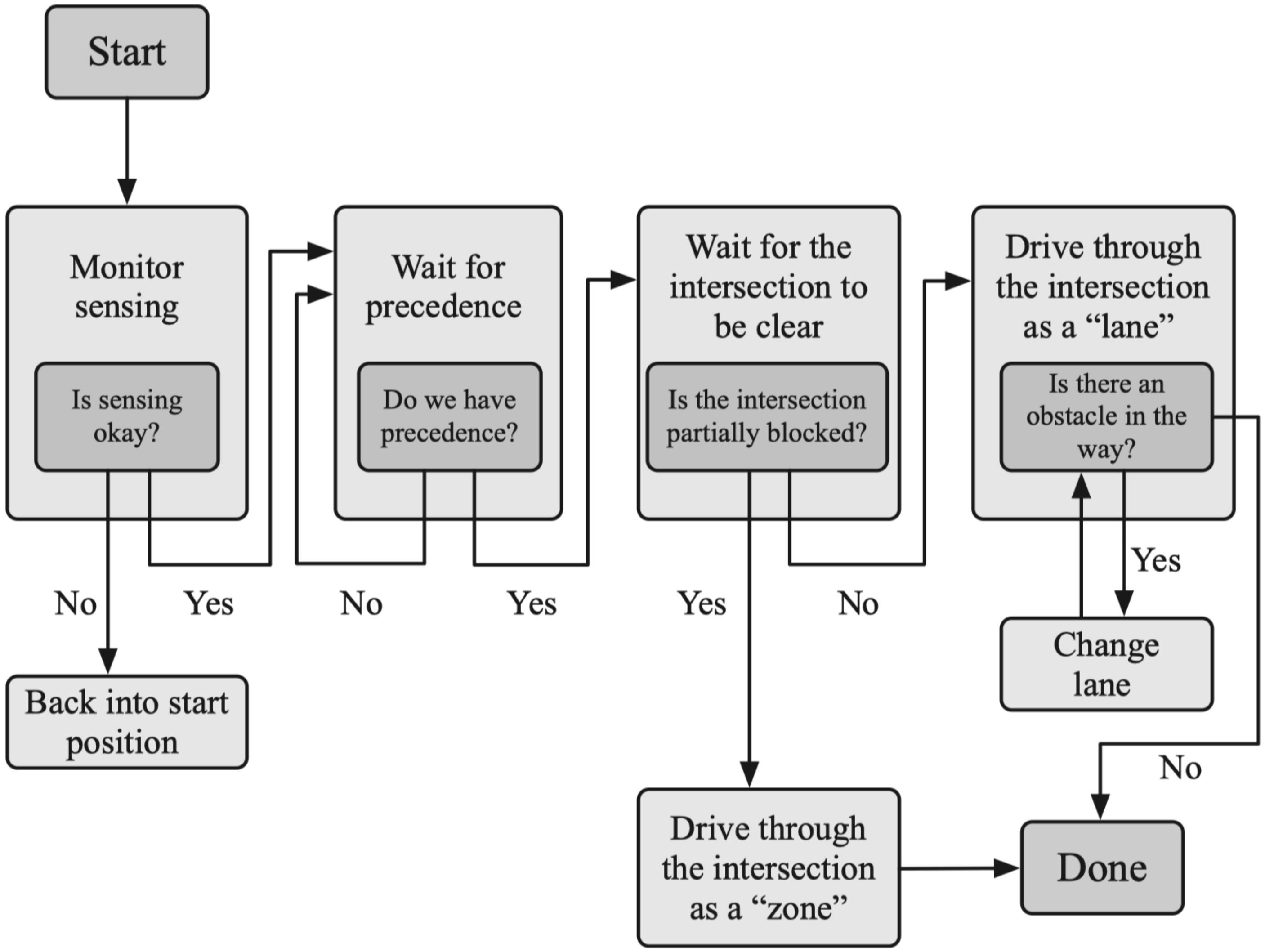
When Tartan Racing designed Boss, they created a variety of finite state machines for the Monopoly board module: one for each type of environment Boss might find itself in.

- As Boss drove along, its Monopoly board module moved a virtual Monopoly piece around its finite state machine in order to keep track of what the car was doing and what it needed to do to achieve its next goal.

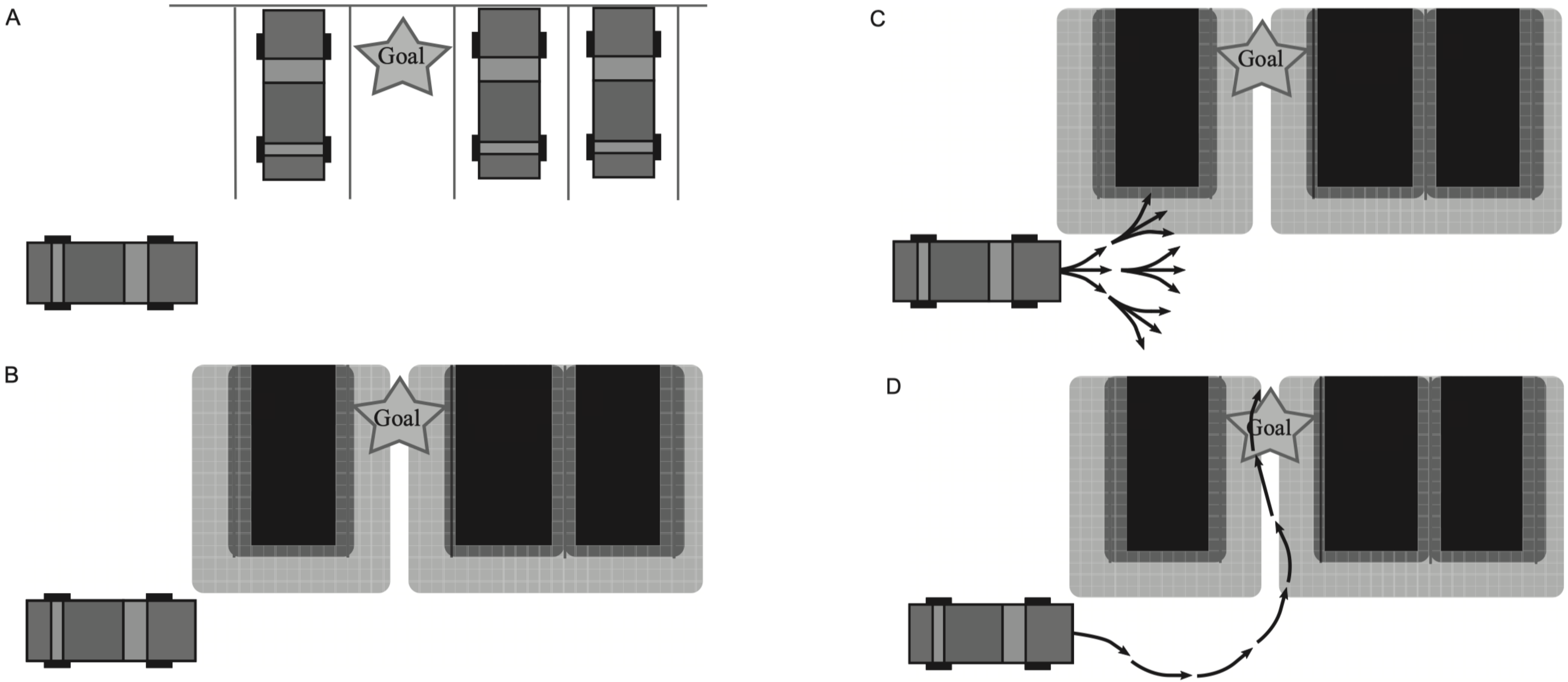
FSMs

- Depending on Boss's current situation, its Monopoly board used one of three finite state machines:
  - one to drive down the road, keeping track of whether it needed to change lanes, for example;
  - one to handle intersections (*see next slide*); and
  - one to maneuver itself into a specific position, such as a parking spot or the other side of a crowded intersection.
- Each of these finite state machines outlined a set of simple rules the module should follow to achieve its goal.
- Wherever it was, Boss's Monopoly board module kept track of the world and its goals with its virtual piece on the board.

Boss's FSM to handle intersections



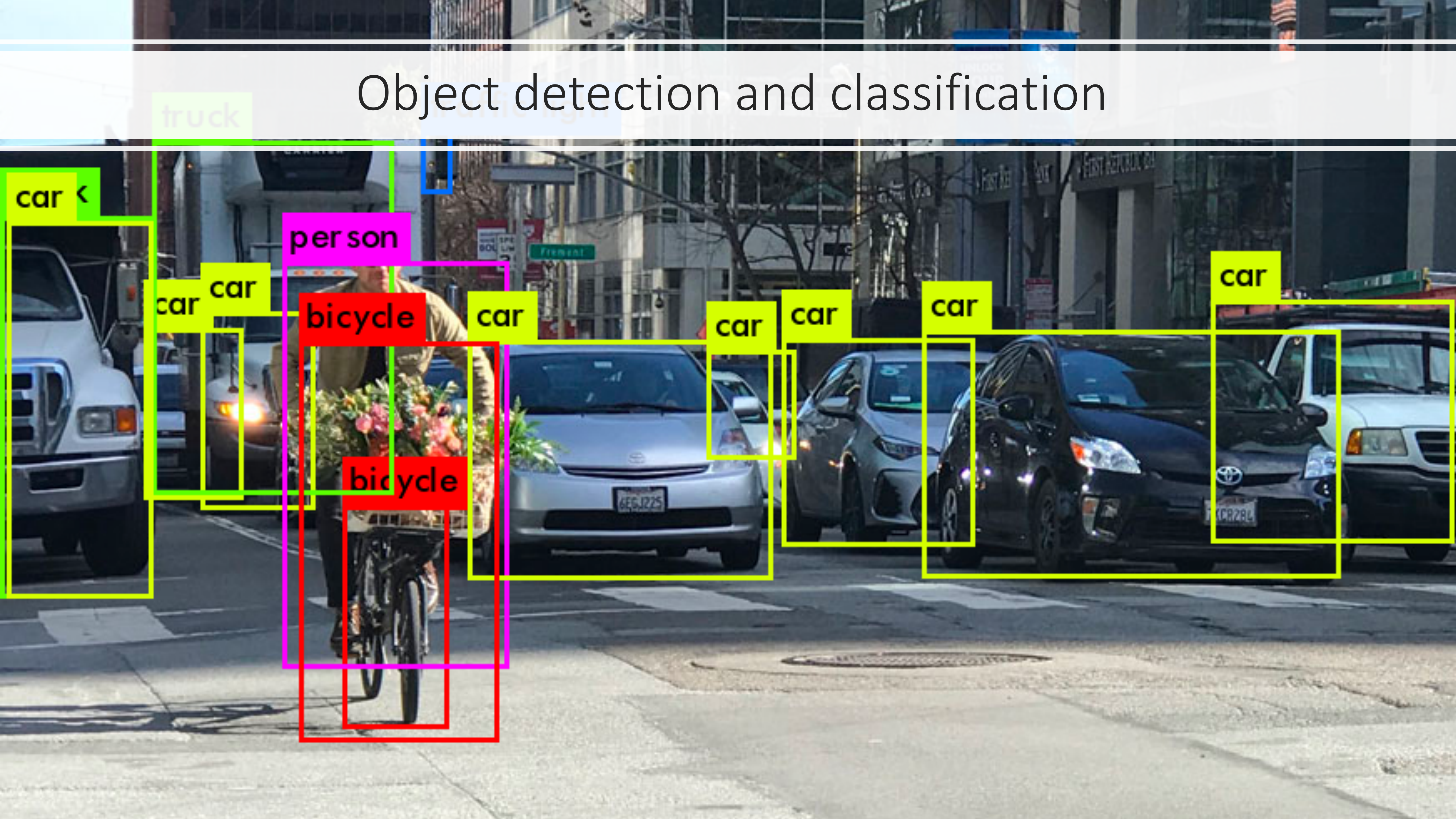
Boss's motion planner



The three-layer architecture

- Deliberator
- Sequencer
- Control layer

Object detection and classification



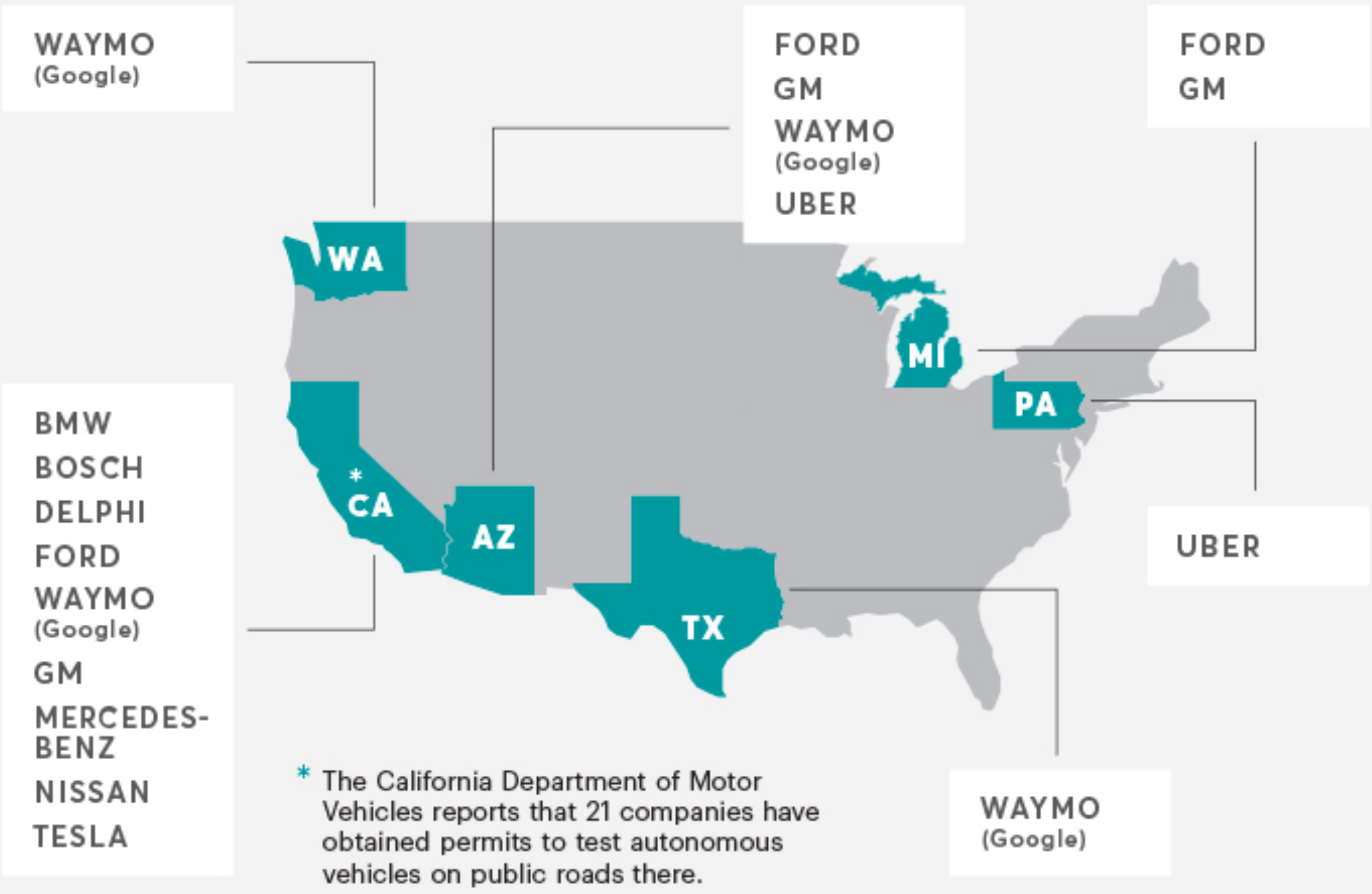
WAYMO 360° EXPERIENCE

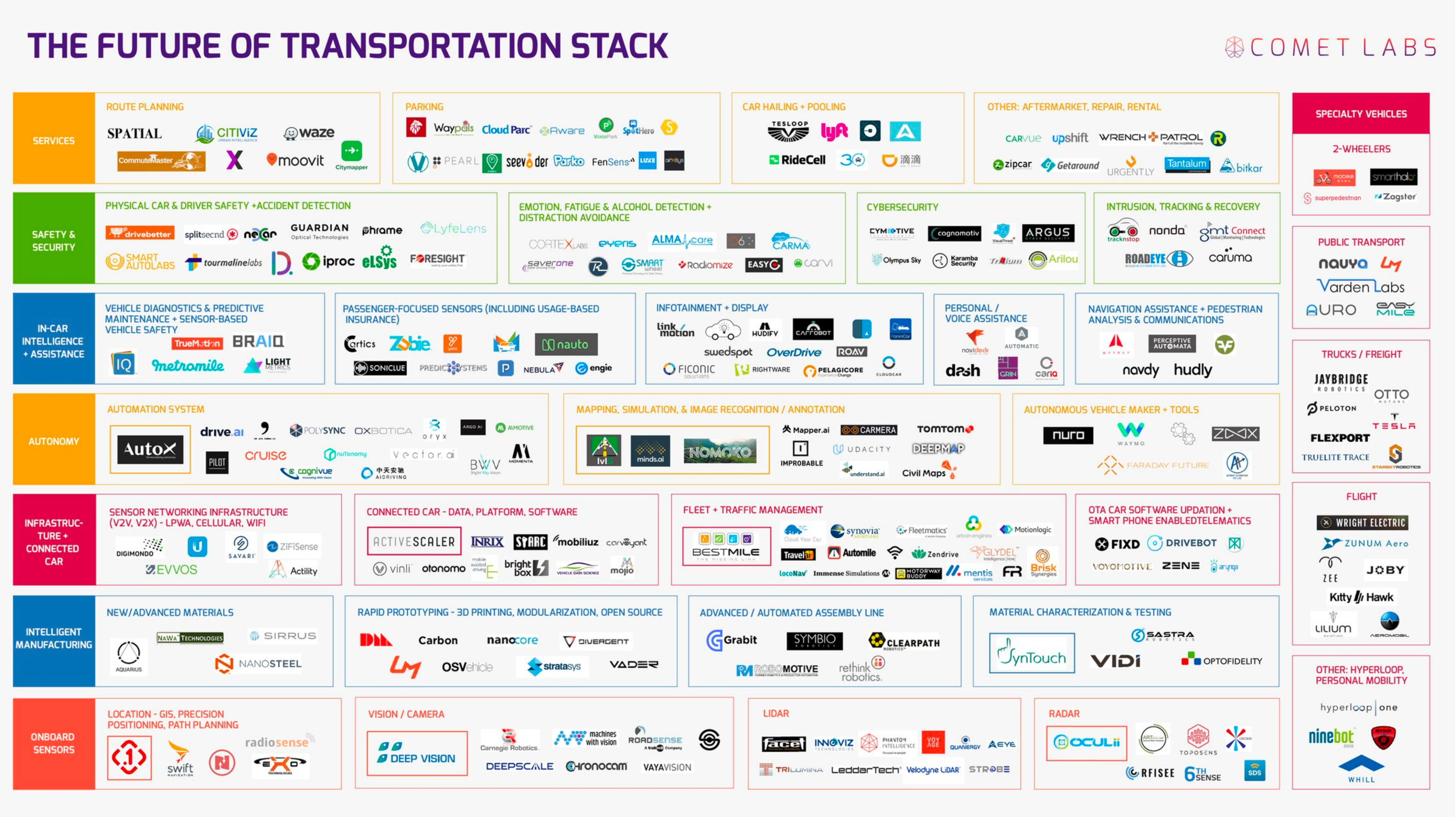
Key idea:

It is a huge market

Where the Driverless Cars Are

Here are some of the states where automated prototype cars are already being tested on roads, usually with humans at the ready as backup.





263 companies! (as of May 2017)

https://www.wired.com/2017/05/mapped-top-263-companies-racing-toward-autonomous-cars/

The Building Blocks of Autonomy

Prepared by VISION SYSTEMS INTELLIGENCE

Level of Integration

AUTONOMOUS SOLUTIONS

TOYOTA, TESLA, Ford, GM, HYUNDAI, KIA MOTORS, GEELY, Google, NVIDIA, Continental, nauyo, ZMP Robot of Everything, Audi, BMW, CHANGAN, HONDA, VOLVO, Mercedes-Benz, UBER, Baidu 百度, VisLab Extend Your Vision, OTTO, nuTonomy, PSA PEUGEOT CITROËN, NISSAN, BAIC, SAIC, CHERY, DELPHI, BOSCH, RENESAS, drive.ai, ZOOX

PROCESSING

RENESAS, NVIDIA, MOBILEYE, NXP, TOSHIBA Leading Innovation, CEVA, cadence, Imagination, ARM, ANALOG DEVICES, intel, XILINX, videantis passion for video, ALTERA, TEXAS INSTRUMENTS, MARVELL, QUALCOMM, Movidius, ST

SENSORS

BOSCH, DELPHI, MITSUBISHI ELECTRIC, NXP, Continental, ibeo, Valeo, ZF, TRW, HITACHI, OmniVision, Pioneer, HYUNDAI MOBIS, POINT GREY Innovation in Imaging, Autoliv, TOSHIBA Leading Innovation, KOSTAL, DENSO, LG Innotek, Panasonic, MAGNA, HARMAN, FUJITSU TEN, Visteon, QUANERGY, Melexis Microelectronic Integrated Systems, Mando Corporation, applanix A TRIMBLE COMPANY, FLIR SYSTEMS, ON Semiconductor, OSRAM, LeddarTech, Neusoft, infineon, SONY, PEPPERL+FUCHS, TRILUMINA, ublox, Velodyne LiDAR, PHANTOM INTELLIGENCE

CONNECTIVITY

HITACHI, RENESAS, Peloton, Continental, NXP, BOSCH, DELPHI, intel, CohdaWireless Mobile Broadband, QNX, TTTech, DENSO, HARMAN, infineon, Mentor Graphics

MAPPING

TOMTOM, here, Google, NAVINFO, mapscape, HARMAN, NVIDIA, GeoDigital, Increment P FEEL THE SPACE, EXONAV MAPPING AUTOMATION, ZENRIN, applanix A TRIMBLE COMPANY, sanborn, Civil Maps, 'AND

ALGORITHMS

MOBILEYE, NVIDIA, MITSUBISHI ELECTRIC, Elektrobit, dSPACE, AdasWorks, Neusoft, ETAS, LUXOFT, KPIT, VECTOR

SECURITY/SAFETY

HITACHI, RENESAS, Mentor Graphics, BOSCH, Continental, DELPHI, NXP, WIND, ARGUS CYBER SECURITY, Elektrobit, intel, QNX, ETAS, DENSO, Green Hills SOFTWARE, HARMAN, infineon, KPIT, VECTOR

DEVELOPMENT TOOLS

BASELABS, IAR SYSTEMS, LDRA, MathWorks, SYNOPSYS, VECTOR software, automotive engineering iav, Elektrobit, KPIT, LUXOFT, Mentor Graphics, HARBRICK, KISHONTI INFORMATICS, INTEMPORA MULTISENSOR SOFTWARE SOLUTIONS, tass international, TTTech, dSPACE, ETAS, VECTOR, QNX

AARIAN MARSHALL TRANSPORTATION 06.03.17 08:00 AM

ROBOCARS COULD ADD $7 TRILLION TO THE GLOBAL ECONOMY

STRATEGY ANALYTICS
Research, Experts, and Analytics

Autonomous Vehicle Service

Accelerating the Future: The Economic Impact of the Emerging Passenger Economy

June 2017

Roger Lanctot
Tel: +1 617 614 0714
Email: rlanctot@strategyanalytics.com

US$7 Trillion Opportunity

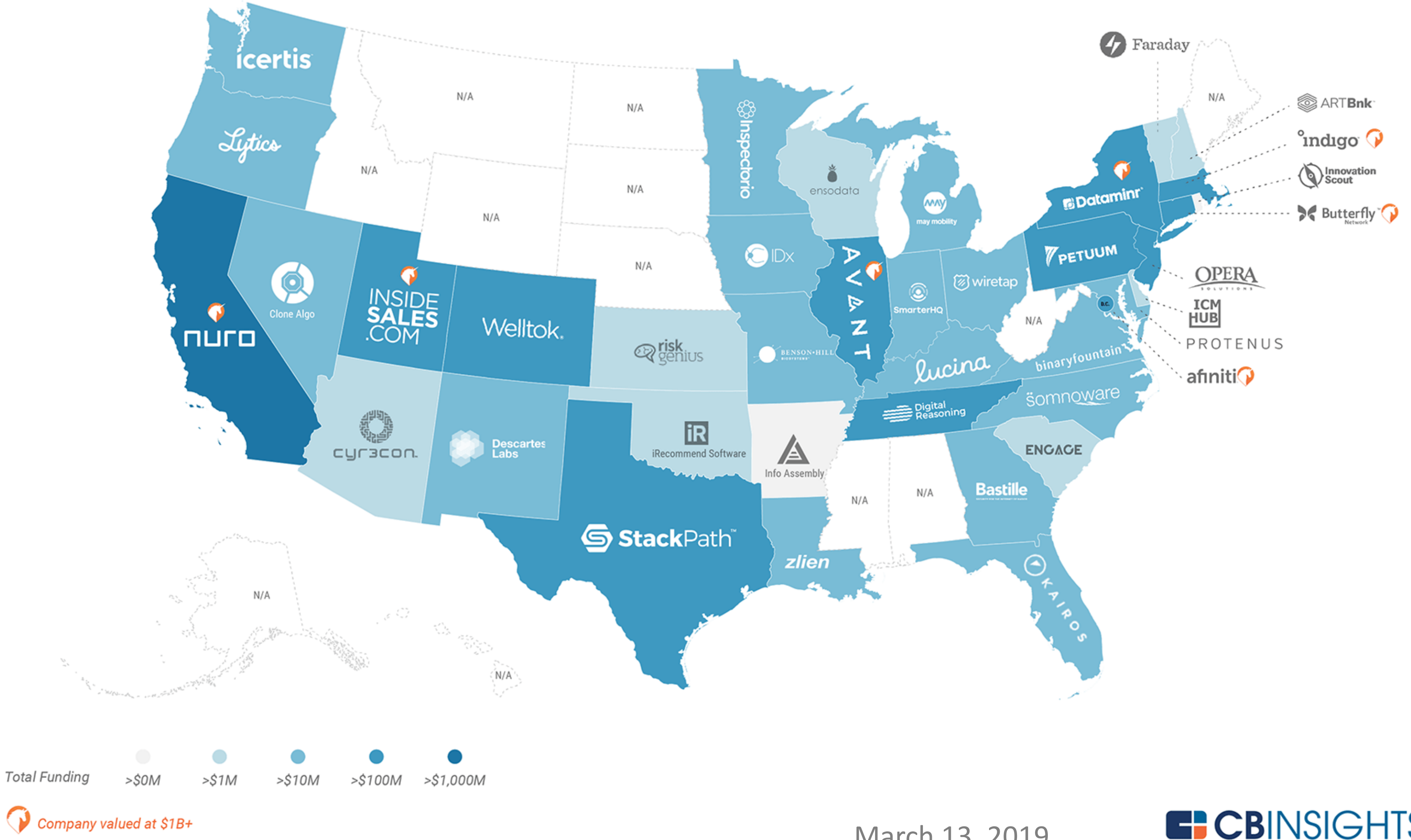
Autonomous driving technology will enable a new "Passenger Economy" worth US$7 trillion – more than the projected 2017 GDPs of Japan and Brazil combined.

Key idea:

It is a moving target

THE UNITED STATES OF ARTIFICIAL INTELLIGENCE

The most well-funded AI startups by state.
Only companies that have raised equity funding since January 2014 were considered.
Excludes debt and lines of credit.



March 13, 2019

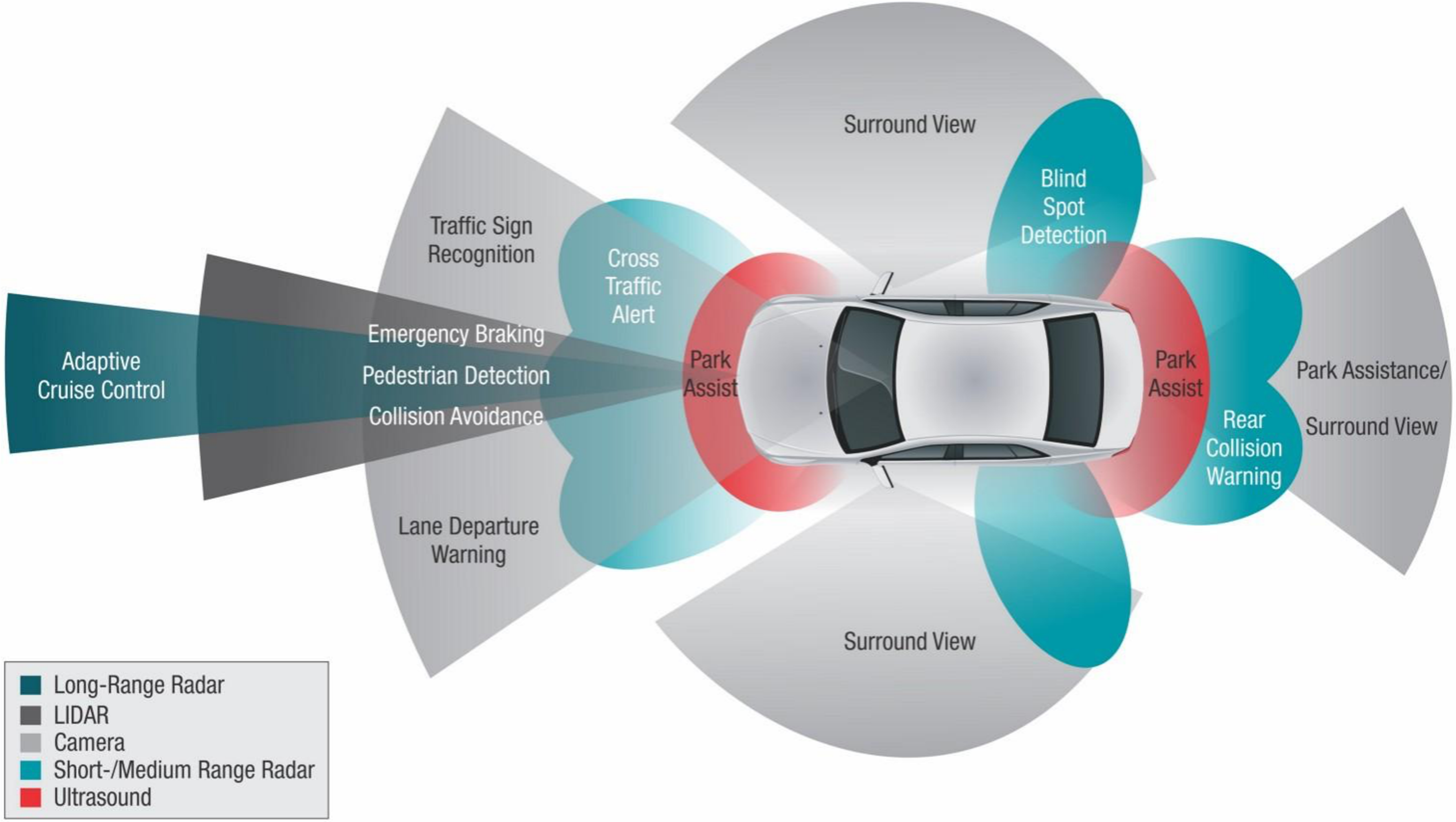
CBINSIGHTS

Nuro is developing autonomous vehicles for local commerce, with a focus on last-mile delivery of goods.

Nuro's vehicles aim to be small, efficient, and can be packed for users or merchants to load with groceries, packages, gifts, or other goods for transport over short distances.

Source: https://www.cbinsights.com/company/nuro-ai

Self-driving vehicles: different levels of automation



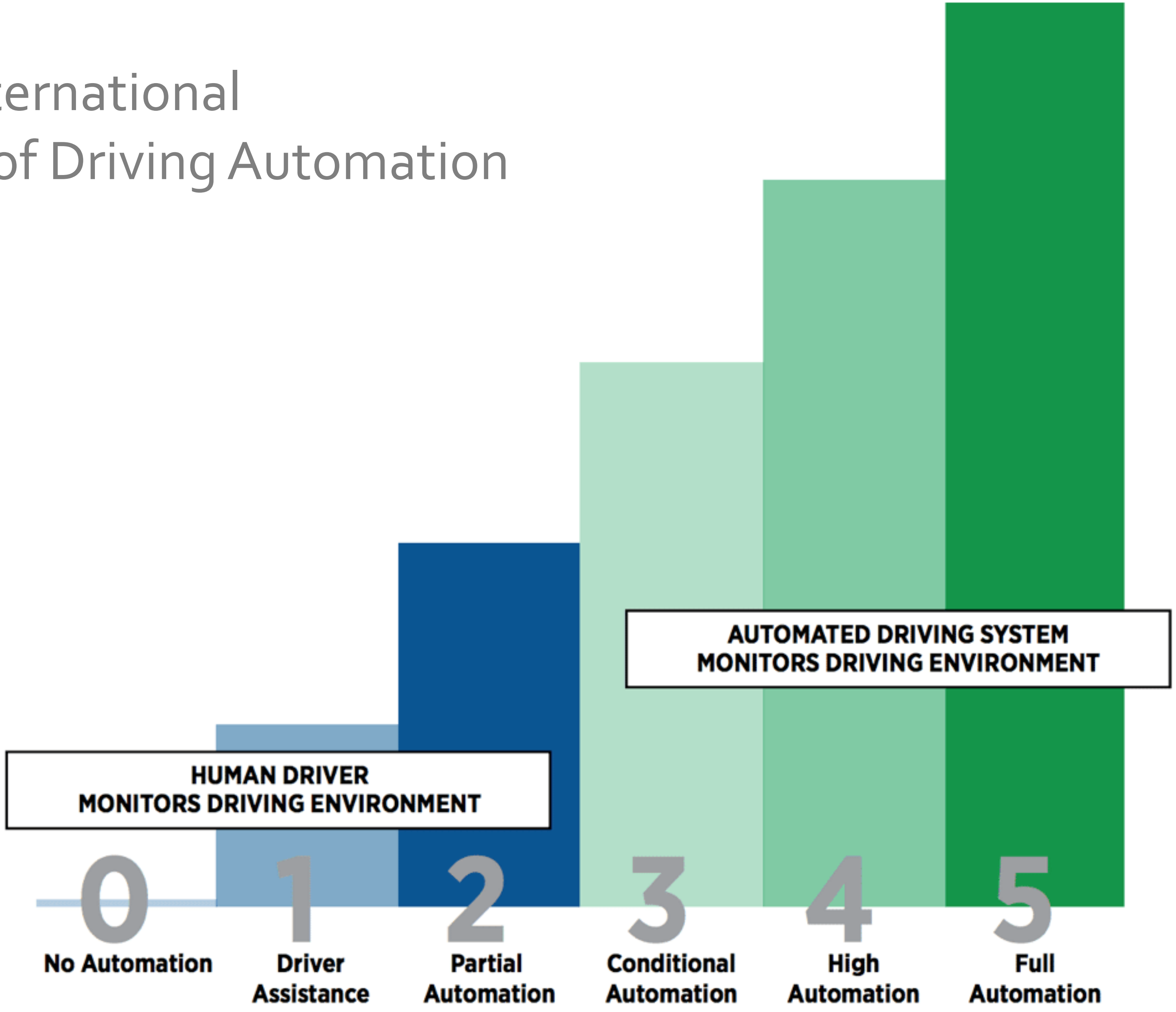
Surround View
Blind Spot Detection
Traffic Sign Recognition
Cross Traffic Alert
Adaptive Cruise Control
Emergency Braking
Pedestrian Detection
Collision Avoidance
Park Assist
Park Assist
Park Assistance/
Surround View
Rear Collision Warning
Lane Departure Warning
Surround View
Long-Range Radar
LIDAR
Camera
Short-/Medium Range Radar
Ultrasound

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) AUTOMATION LEVELS

Full Automation

0	1	2	3	4	5
No Automation	**Driver Assistance**	**Partial Automation**	**Conditional Automation**	**High Automation**	**Full Automation**
Zero autonomy; the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

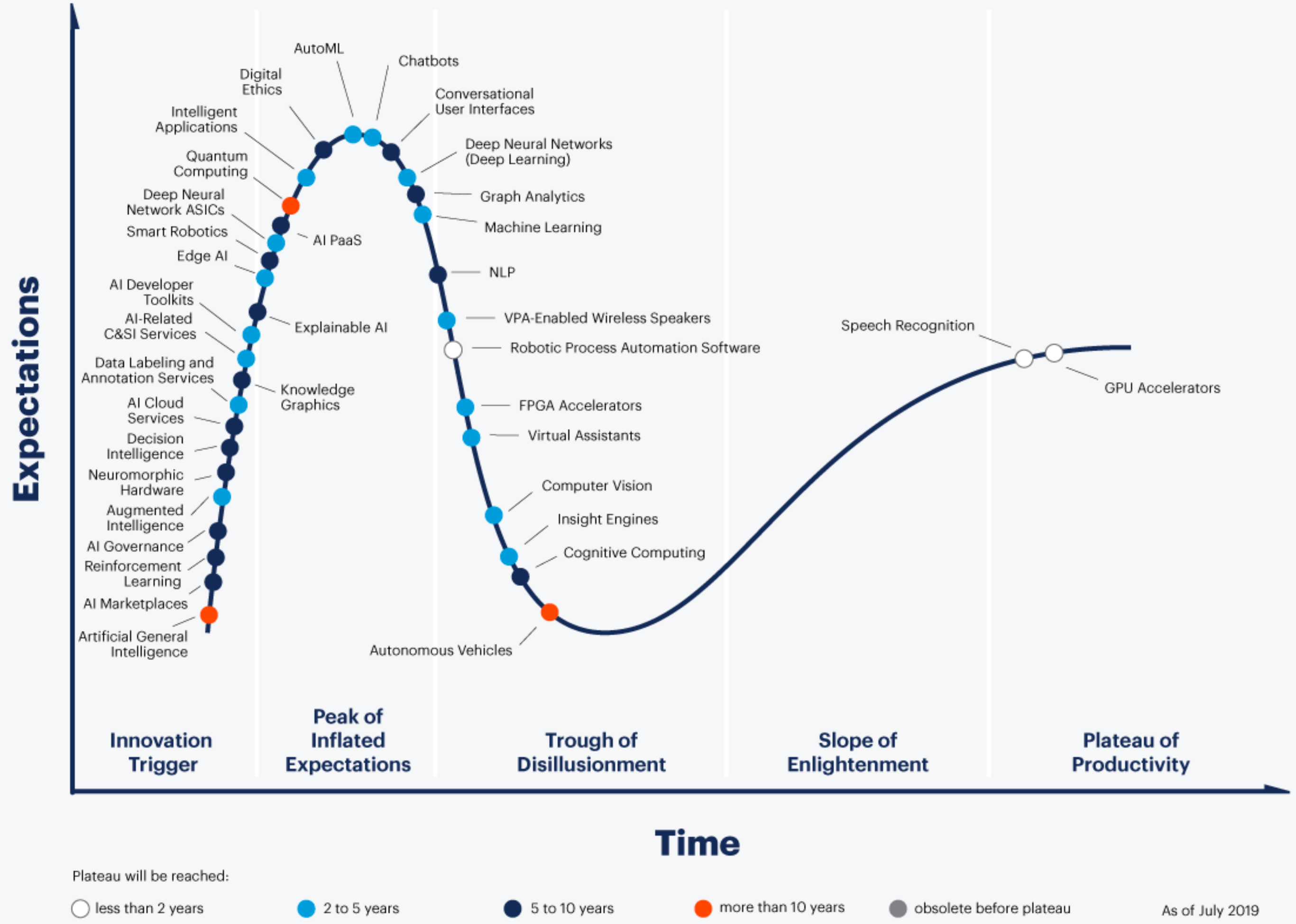
SAE International
Levels of Driving Automation



Key idea:

It is filled with buzzwords and subject to the hype cycle

Gartner Hype Cycle for Artificial Intelligence, 2019



gartner.com/SmarterWithGartner

Source: Gartner

Gartner

Gartner Hype Cycle for Emerging Technologies, 2019

gartner.com/SmarterWithGartner

Source: Gartner

Gartner

Key idea:

Not everyone is thrilled with the idea

61%

The proportion of adult internet users who say they are **not inclined to ride in a self-driving car**, according to a survey by the Brookings Institution.

54%

The proportion of respondents to a recent Northeastern University/Gallup survey who said they are **unlikely to use fully self-driving cars** when they arrive on the roads.

57%

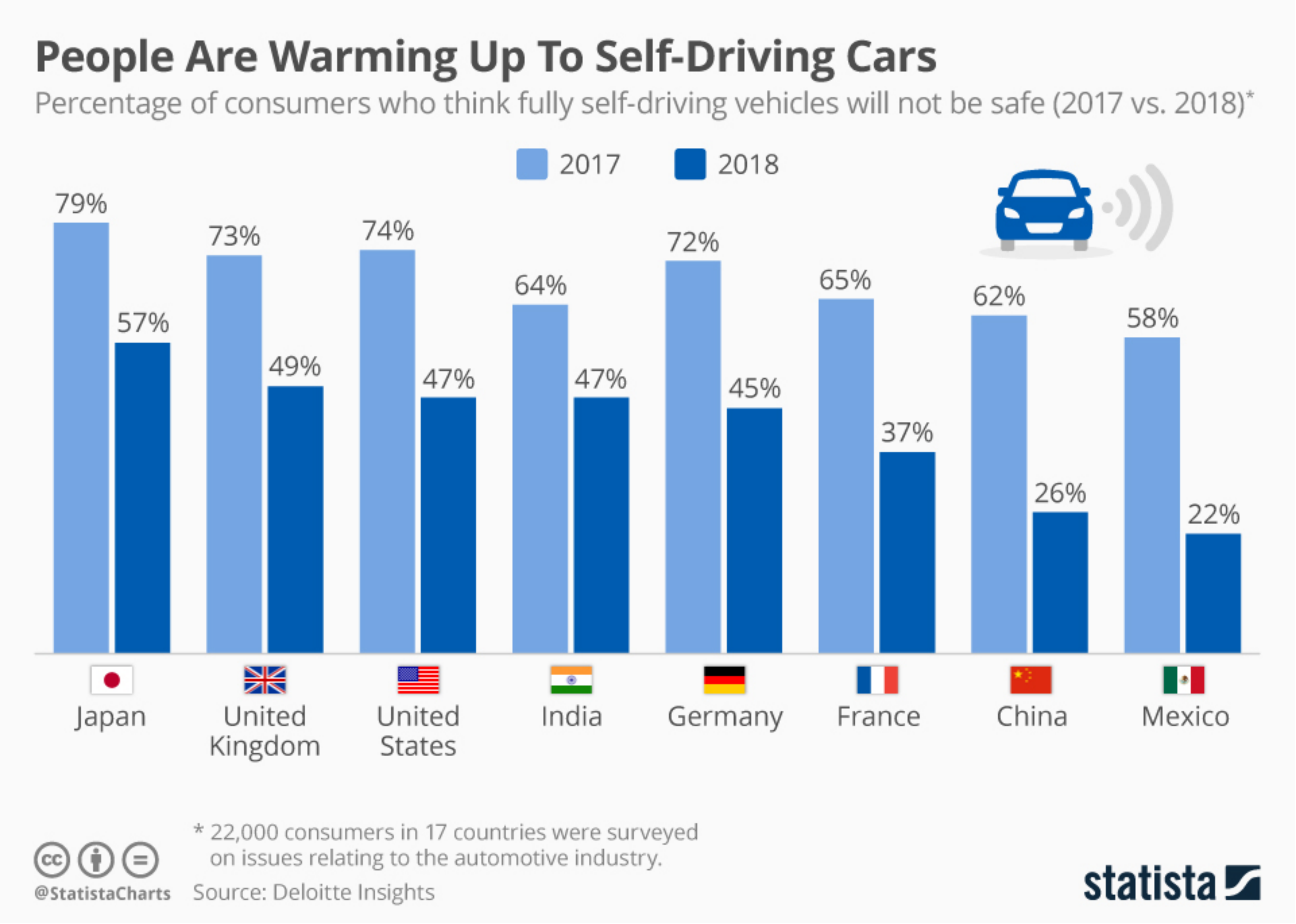
The proportion of connected car drivers in a recent survey who said they **would not buy a self-driving car**, even if cost was no issue.

56%

The proportion of US adults who say they **would not want to ride in a driverless vehicle** if given the opportunity, according to a new survey.

Source: Pew Research Center, *Automation in Everyday Life*

Source: https://www.driverlessguru.com/self-driving-cars-facts-and-figures/


People Are Warming Up To Self-Driving Cars
Percentage of consumers who think fully self-driving vehicles will not be safe (2017 vs. 2018)*
2017
2018
79%
57%
73%
49%
74%
47%
64%
47%
72%
45%
65%
37%
62%
26%
58%
22%
Japan
United Kingdom
United States
India
Germany
France
China
Mexico
* 22,000 consumers in 17 countries were surveyed on issues relating to the automotive industry.
@StatistaCharts
Source: Deloitte Insights
statista

Jan 15, 2019

The New York Times

TECHNOLOGY

Self-Driving Uber Car Kills Pedestrian in Arizona, Where Robots Roam

By DAISUKE WAKABAYASHI MARCH 19, 2018

Nationwide, there are an estimated **5 million crashes** every year, according to the National Highway Traffic Safety Administration.

In **California**, in 2018, there were **75** reported crashes involving self-driving vehicles, according to the state's Department of Motor Vehicles.

The world around us

WAYMO

1.25 million

deaths worldwide due to vehicle crashes in 2014

32,675

deaths in the United States due to vehicle crashes in 2014

6%

increase in traffic fatalities in 2016, reaching the highest point in nearly a decade

WAYMO

94%

of crashes involve human choice or error in the US.

WAYMO

U.S. fatalities associated with human choice or error (2014)

9,262
Speeding

9,967
Alcohol

3,179
Distraction

846
Drowsiness

- Utopian view
  - Save lives (1.3 million die every year in manual driving)
    - 4D’s of human folly: drunk, drugged, distracted, drowsy driving
  - Eliminate car ownership
    - Increase mobility and access
    - Save money
  - Make transportation personalized, efficient, and reliable

---

- Dystopian view
  - Eliminate jobs in the transportation sector
  - Failure (even if much rarer) may not depend on factors that are human interpretable or under human control
  - Artificial intelligence systems may be biased in ways that do not coincide with social norms or be **ethically grounded**
  - Security

Source: https://selfdrivingcars.mit.edu/

Self-Driving Cars: Grain of Salt

- Carefully differentiate between:
  - **Doubtful:** Promises for future vehicles (in 2+ years)
  - **Skeptical:** Promises for future vehicles (in 1 year)
  - **Possible:** Actively testing vehicles on public roads at scale
  - **Real:** Available for consumer purchase today

Source: https://selfdrivingcars.mit.edu/

Key idea:

The most flawed assumption behind self-driving cars

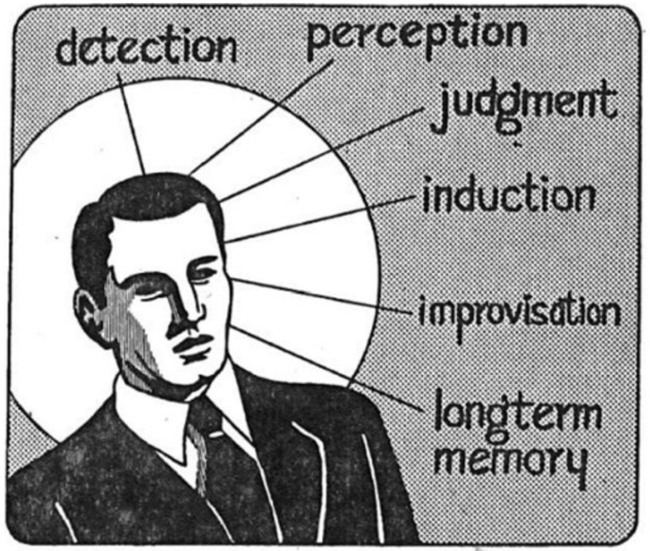
Plans for self-driving cars have pitfall: the human brain

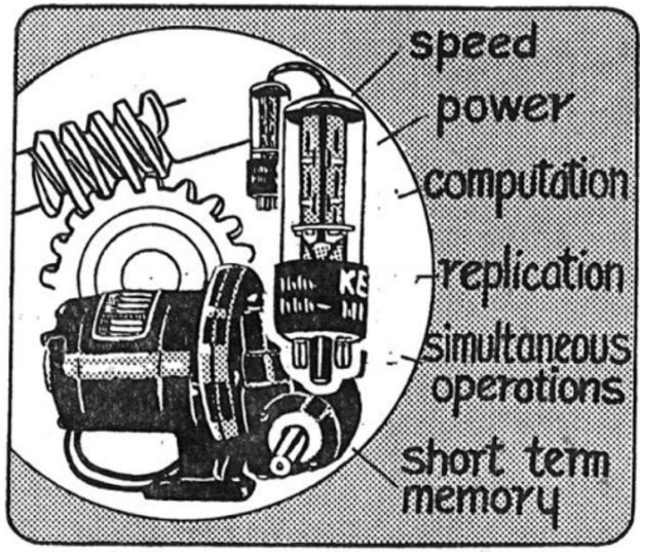
AP

Experts say the development of self-driving cars over the coming decade depends on an unreliable assumption by many automakers:

that the humans in them will be **ready** to step in and take control if the car's systems fail.

https://apnews.com/78a716f8c4474a36bf97a33e4c207b7b





- Ability to detect small amount of visual or acoustic energy.
- Ability to perceive patterns of light or sound.
- Ability to improvise and use flexible procedures.
- Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time.
- Ability to reason inductively.
- Ability to exercise judgment.

- Ability to respond quickly to control signals, and to apply great force smoothly and precisely.
- Ability to perform repetitive, routine tasks.
- Ability to store information briefly and then to erase it completely.
- Ability to reason deductively, including computational ability.
- Ability to reason handle highly complex operations, i.e., to do many different things at once.

Fitts PM, *ed (1951) Human Engineering for an Effective Air Navigation and Traffic Control System (National Research Council, Washington, DC).*

Self-driving vehicles: job losses

PBS Frontline – Nov 2019

Key idea:

There are entire courses and certificates in the area

THIS PROGRAM

Intro to Self-Driving Cars

NANODEGREE PROGRAM

Get on the road to a Self-Driving Car career

●●○ INTERMEDIATE

Best Deal!

4 MONTHS ACCESS

$1436 ~~$399~~ $359 per month

Pay up-front and save! Switch to the monthly price afterwards if more time is needed.

ENROLL NOW

MIT 6.S094: Deep Learning for Self-Driving Cars

Lecture 1

Deep Learning

[Slides] - [Lecture Video]

Lecture 2

Self-Driving Cars

[Slides] - [Lecture Video]

Lecture 3

Deep Reinforcement Learning

[Slides] - [Lecture Video]

Lecture 4

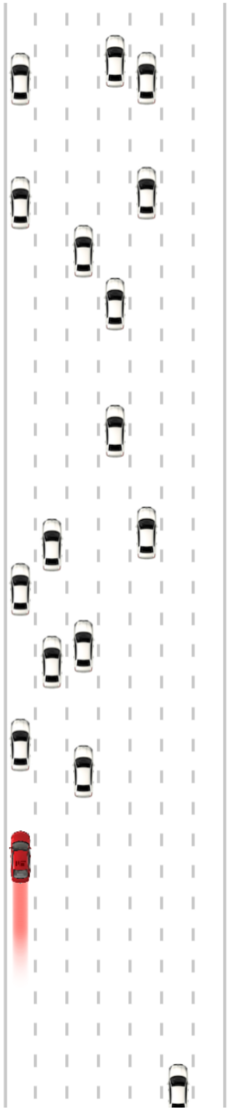
Computer Vision

[Slides] - [Lecture Video]

Lecture 5

Deep Learning for Human Sensing

[Slides] - [Lecture Video]



Speed:

46 mph

Cars Passed:

12

Road Overlay:

None

Simulation Speed:

Normal

DeepTraffic

Main Page - Leaderboard - About DeepTraffic

Americans spend 8 billion hours stuck in traffic every year.

Deep neural networks can help!

```
brain = new deepqlearn.Brain(num_inputs, num_actions, opt);

learn = function (state, lastReward) {
brain.backward(lastReward);
var action = brain.forward(state);

draw_net();
draw_stats();

```

Apply Code/Reset Net | Save Code/Net to File | Load Code/Net from File

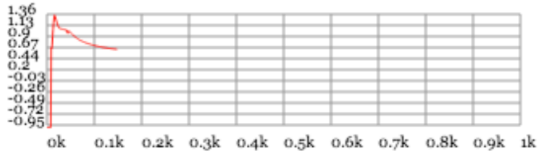
Submit Model to Competition

Load Custom Image

Red

Request Visualization

Vehicle Skins



Run Training | Start Evaluation Run

Value Function Approximating Neural Network:

Flying Cars, Autonomous Vehicles, and Education

Sebastian Thrun

Kitty Hawk, Udacity, Waymo

Concluding remarks