IEEE-CNSV
Consultants' Network of Silicon Valley

Autonomous Driving: Anticipating Human Behavior Is The Hardest Problem

+ The Possible Impact of COVID-19 on Autonomous Driving

James Gowers
VP Strategy & Business Development
Perceptive Automata

May 12, 2020

TODAY'S AGENDA

1. Autonomous Vehicles - Brief History
2. The Complex Social Act of Driving
3. Human Intuition For Machines
4. Autonomous Vehicles - Where Next?

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DISCLAIMER

- Sole purpose for showing publicly available drive recordings featuring test vehicles from full-stack AV companies during this talk is **to educate and inform**, to help make AV technology development challenges accessible to a broader audience.

- These recordings are NOT meant to explicitly or implicitly criticize those companies. The teams are working very hard to progress the development of the technology in a professional, scalable, and safe manner.

- Nor am I making any claims about the state-of-the-art at those companies. We should assume that their state-of-the-art is almost certainly more advanced than what a single recording at a specific point in time shows.

- We don't have access to the vehicle logs to know with certainty what the root causes of the observed driving behaviors are.

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THE DREAM OF AUTOMATED VEHICLES STARTED 100 YEARS AGO (!) AND FICTION KEPT IT ALIVE

1980

The most capable fictional robot car in the 1980s was the vehicle KITT in the TV series **Knight Rider**. KITT had the ability to drive itself and possessed a scanner that allowed the vehicle to "see" the environment.

1983 Christine

1989 Batman

1990 Total Recall

1993 Demolition Man

1997 The Fifth Element

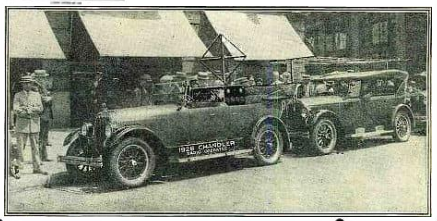
2004 I, Robot

1918

Scientific American "a motorist's dream: a car that is controlled by a set of push buttons."

1925

A radio-controlled vehicle was shown in 1926 on Fifth Avenue in New York.



1938

Popular Science in the article "Highways of the Future" predicted that in 50 years, collisions would be impossible, car to car communication would work with infrared light, and electric cables would control the car's speed and eventually would also take over the car's steering.

1939

1939 World Fair in New York, General Motors presented in the Futurama exhibit their vision for 1960, which showed automated vehicles on multi-lane highways to visitors.

1953

Mechanix Illustrated asked, "Why Don't We Have … Crash-Proof Highways … with automatic pilots to take the wheel for trip-weary, accident-prone drivers?"

1962

Firebird III on display at the Century 21 Exposition, Seattle. The car would be guided along a road cable, and car to infrastructure communication would control the car's longitudinal movement.

1967

Popular Science reported that "a U.S.-backed $100,000 study at a world-famous lab is working out the design of a commuter's car of tomorrow–and it's electric-tracked guideway to the city and back."

1921

A radio-controlled car was shown for the first time in October 1921 in Dayton, Ohio by RCA.

1935

The film "The Safest Place," Chevrolet predicted that "if the manufacturer could equip every car with an automatic driving mechanism, the car would always do just what it should do when it got out on the road …"

1950

Walt Disney took imagination to the next level in the episode "Magic Highway U.S.A." of the 1950s TV series "The Magical World of Disney," predicting radar sensors, night vision, traffic guidance systems, and other futuristic vehicle features.

1956

For the 1956 Motorama auto show, General Motors produced this musical short, "Key to the Future," which predicted self-driving cars in the far-off future of 1976.

1968

Disney created Herbie, the Love Bug, a vehicle that had "a mind of his own and [was] capable of driving himself."

Source: Jan Becker, Apex.AI

PHASES OF AUTONOMOUS DRIVING DEVELOPMENT

From ~1960-2000
Fundamental
Pioneering Research

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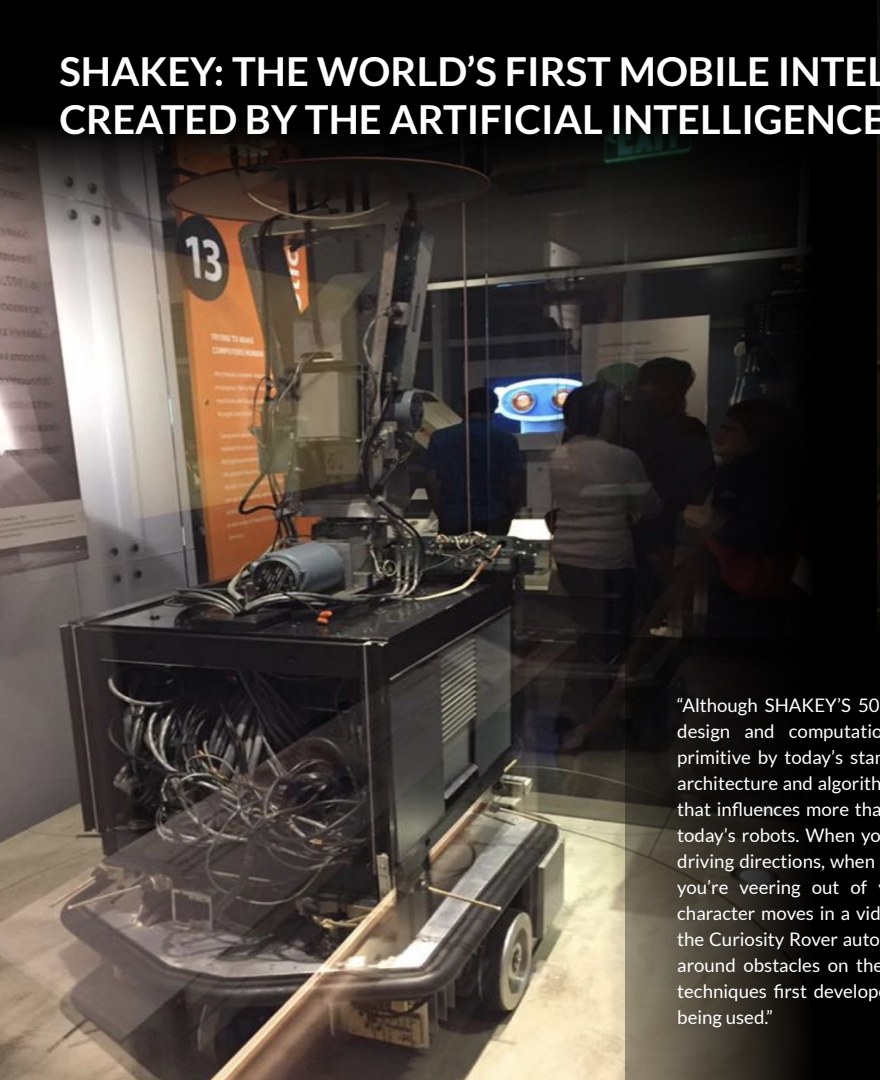
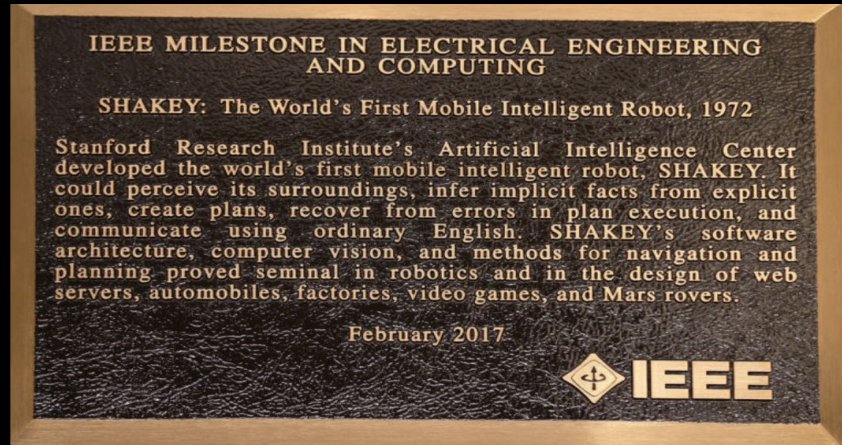
SHAKEY: THE WORLD'S FIRST MOBILE INTELLIGENT ROBOT - 1966-72
CREATED BY THE ARTIFICIAL INTELLIGENCE CENTER AT STANFORD RESEARCH INSTITUTE



"Although SHAKEY'S 50-year old hardware design and computational resources are primitive by today's standards, its software architecture and algorithms created a legacy that influences more than just the design of today's robots. When your phone computes driving directions, when your car warns that you're veering out of your lane, when a character moves in a video game, and when the Curiosity Rover autonomously navigates around obstacles on the Martian surface – techniques first developed for SHAKEY are being used."



EARLY AUTONOMOUS DRIVING RESEARCH VAMORS - ERNST DICKMANNS IN GERMANY (~1986)

“The other drivers wouldn’t have noticed anything unusual as the two sleek limousines with German license plates joined the traffic on France’s Autoroute 1.

But what they were witnessing - on that sunny, fall day in 1994 - was something many of them would have dismissed as just plain crazy.

It had taken a few phone calls from the German car lobby to get the French authorities to give the go-ahead. But here they were: two gray Mercedes 500 SELs, accelerating up to 130 kilometers per hour, changing lanes and reacting to other cars — autonomously, with an onboard computer system controlling the steering wheel, the gas pedal and the brakes.”

Janosch Delcker
“The man who invented the self-driving car (in 1986)”
Politico, July 19, 2018

EARLY AUTONOMOUS DRIVING RESEARCH @CMU NAVLAB5/PANS - FIRST USE OF NEURAL NETS (~1995)

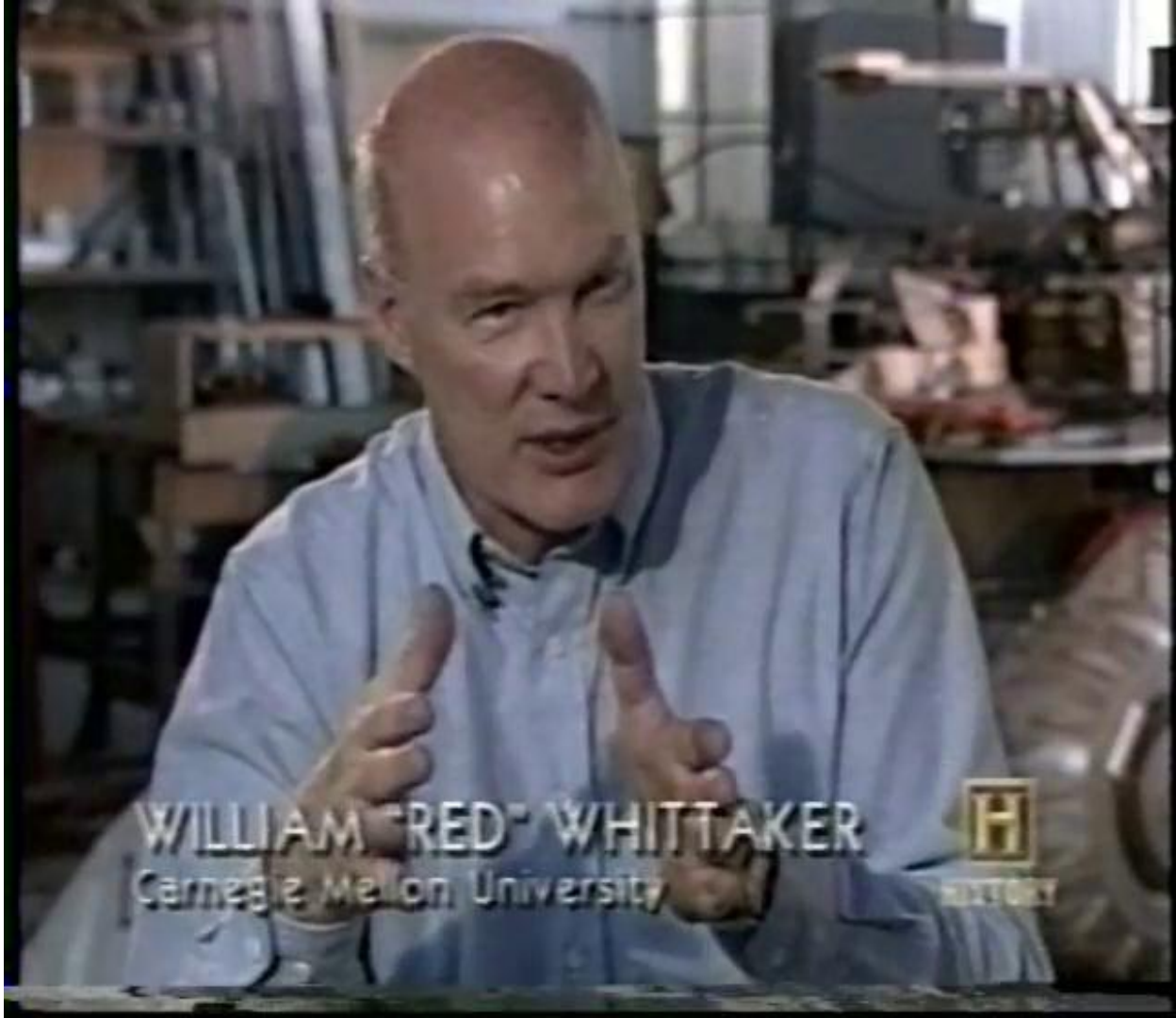
"In the early 90s, Carnegie Mellon researcher Dean Pomerleau writes a PhD thesis describing how **neural networks** could allow a self-driving vehicle to take in raw images from the road and output steering controls in real time.

In 1995, Pomerleau and fellow researcher Todd Jochem drive their Navlab5 autonomous minivan (they have to control speed and braking) on a 3,000-mile trip (~98% 'autonomously') from Pittsburgh to Washington, D.C. to San Diego in a journey the pair dubs "No Hands Across America.""

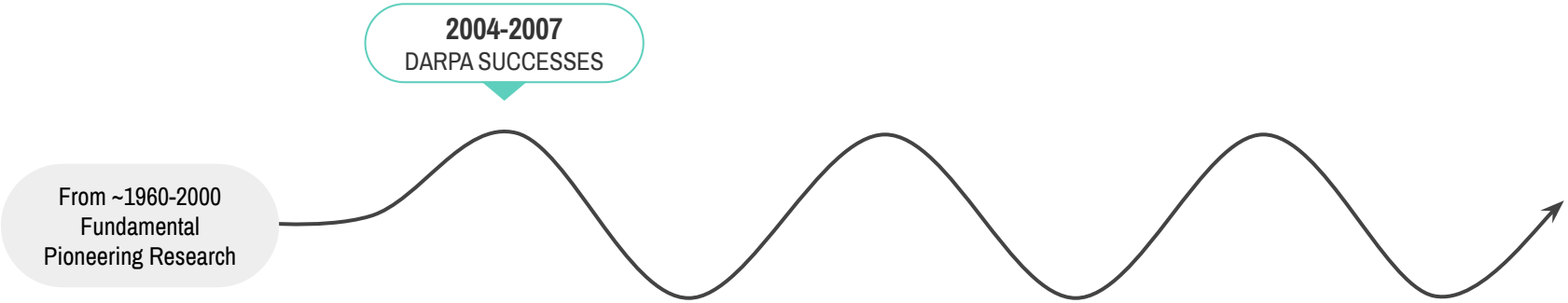
Compute: Sparc LX class portable computer, 50MHz MicroSparc CPU, 32 MB of RAM, 970 MB HD, running UNIX SunOS 4.1.

Camera: 0.38 MP Sony DXC-151A RGB Color

CMU, The Robot Hall of Fame
Digital Trends, "Sit back, relax, and enjoy a ride through the history of self-driving cars"



PHASES OF AUTONOMOUS DRIVING DEVELOPMENT



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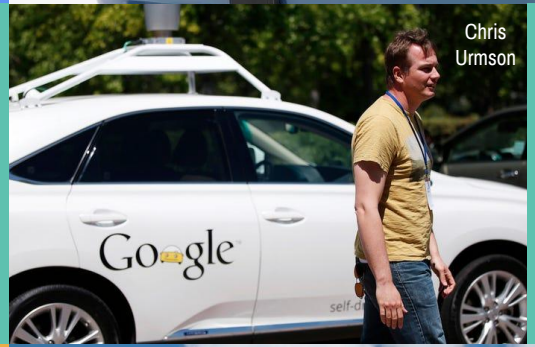
DARPA GRAND CHALLENGE CONTESTS IN 2004, 2005, AND 2007 KICK-STARTED DEVELOPMENT EFFORTS AT GOOGLE FROM 2009 ONWARDS

"BOSS" (CMU/GM) - 2007 Winner

"STANLEY" (Stanford) - 2005 Winner

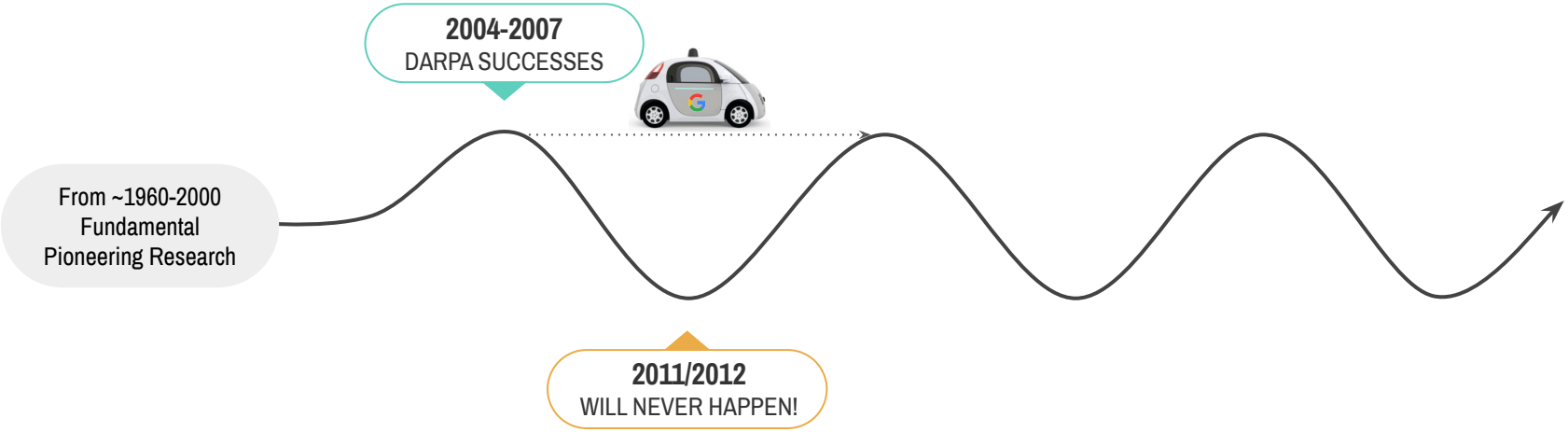
PRIUS
2009-2010



LEXUS SUV
2011-2018

FIREFLY
2014-2016

PHASES OF AUTONOMOUS DRIVING DEVELOPMENT



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EARLY AUTOMOTIVE INDUSTRY REACTIONS

> “I went to meet with carmakers and suppliers after we publicly announced our self-driving efforts in 2011, and literally got laughed at. They told me it's a waste of time, reckless, and will never happen. There was utter disinterest. Self-driving technology didn’t make sense to them, and it seemed so far out of the playbook that it wasn’t even addressable.”

Chris Urmson
CEO & Co-Founder of Aurora
Head of Google Self-Driving, 2009-2016

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LYFT CO-FOUNDER'S EXPERIENCE IN 2012

> We got feedback in 2012 that we would be laughed out of the room, that we sound crazy.

Logan Green
CEO & Co-Founder, Lyft

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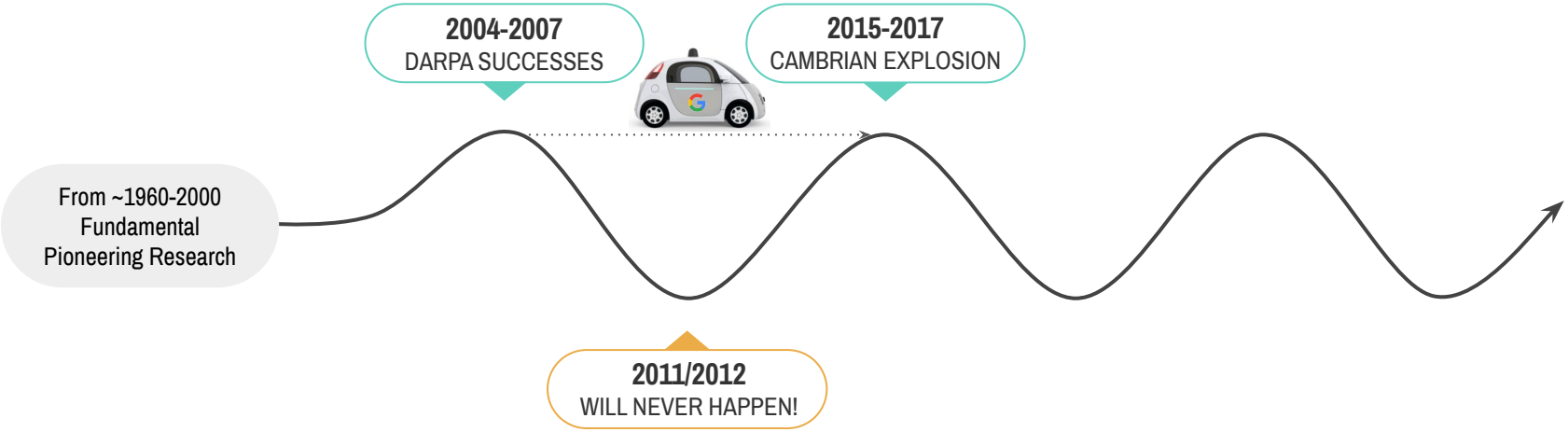
PHASES OF AUTONOMOUS DRIVING DEVELOPMENT



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KEY INFLECTION POINT IN 2014: GOOGLE PATENT ISSUED + INTRODUCES FIREFLY FOR TAAS + PERFORMS WORLD'S FIRST FULLY AUTONOMOUS DRIVE ON PUBLIC ROADS IN EARLY 2015

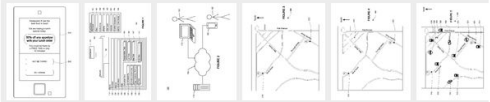
Google Patents

Transportation-aware physical advertising conversions

Abstract

The present invention relates generally to arranging for free or discounted transportation to an advertiser's business location. More specifically, the invention involves automatically comparing the cost of transportation and the potential profit from a completed transaction using a number of real-time calculations. For example, the calculation may consider various factors including a consumer's current location, the consumer's most likely route and form of transportation (such as train, personal car, taxi, rental car, or shared vehicle), the consumer's daily agenda, the price competing advertisers are willing to pay for the customer to be delivered to alternate locations, and other costs. In this regard, the customer's obstacles to entering a business location are reduced while routing and cost calculations are automatically handled based on the demand for the advertiser's goods and potential profit margins.

Images (9)



US8630897B1

United States

Download PDF | Find Prior Art | Similar

Inventor: Luis Ricardo Prada Gomez, Andrew Timothy Szybalski, Sebastian Thrun, Philip Nemec, Christopher Paul Urmson

Current Assignee : Google LLC , Waymo LLC

Worldwide applications

2011 • US

Application US13/004,514 events

2011-01-11	• Application filed by Google LLC
2011-01-11	• Priority to US13/004,514
2014-01-14	• Application granted
2014-01-14	• Publication of US8630897B1

Custom-built for TaaS:
No steering wheel, accelerator, brake pedal, or mirrors.

CAMBRIAN EXPLOSION DURING 2015-2017 TRIGGERED BY GOOGLE ANNOUNCEMENT

2015 | 2016

Carnegie Mellon Reels After Uber Lures Away Researchers

Uber staffs new tech center with researchers poached from its collaborator on self-driving technology

THE WALL STREET JOURNAL.

(2015) Uber Lures Robot Gurus From Carnegie Mellon

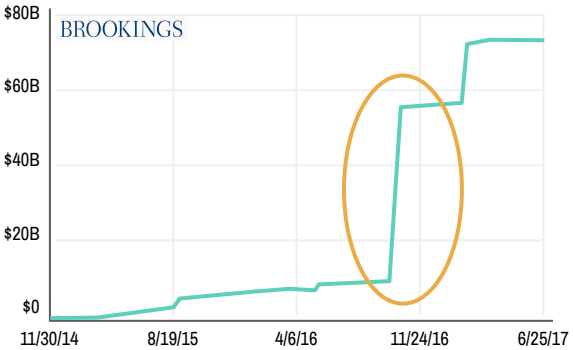
Your Autopilot has arrived

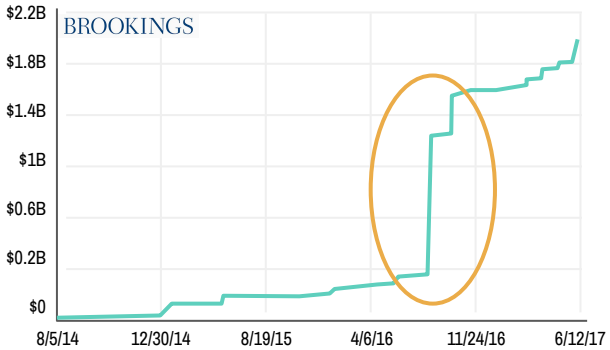
TESLA The Tesla Team • October 14, 2015

$3B

BUYER	UBER	Ford	GM	SAMSUNG	ZF	QUALCOMM	intel
TARGET	Ottomotto	Argo AI	Cruise Automation	Harman Int'l Industries	TRW Automotive	NXP Semiconductors	MOBILEYE
	$680M	$1B	More than $1B	$8B	$11.7B	$39B	$15.3B (MAR 2017)

Cumulative Value of Mainstream Transactions





Cumulative Value of Startup Investments

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AUTOMATED DRIVING LANDSCAPE

LARGE COMPANIES

VISION SYSTEMS INTELLIGENCE

TOYOTA, TESLA, Ford, GM, HYUNDAI, KIA MOTORS, GEELY, Google, NVIDIA, Continental, navya, 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, 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, Autoliv, TOSHIBA Leading Innovation, KOSTAL, DENSO, LG Innotek, Panasonic, MAGNA, HARMAN, FUJITSU TEN, Visteon, QUANERGY, Melexis, Mando Corporation, FLIR SYSTEMS, OSRAM, applanix, ON Semiconductor, LeddarTech, Neusoft, infineon, SONY, PEPPERL+FUCHS, TRILUMINA, ublox, Velodyne LiDAR, PHANTOM INTELLIGENCE

CONNECTIVITY

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

MAPPING

TomTom, here, G, NAVINFO, mapscape, HARMAN, NVIDIA, GeoDigital, Increment P FEEL THE SPACE, EXONAV MAPPING AUTOMATION, ZENRIN, applanix, sanborn, Civil Maps, AND

ALGORITHMS

NVIDIA, MOBILEYE, 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, HARMAN, Green Hills SOFTWARE, infineon, KPIT, VECTOR

AUTOMATED DRIVING LANDSCAPE

STARTUPS (USA)

Designed by: rwLABS Powered by: spoke

Diagnostics (16)

Infotainment Applications (7)

Ride Hailing (30)

Ridesharing / Carpooling (14)

Usage Based Insurance (15)

Smart Enterprise (130)

Telematic Service Providers (27)

App Platform (29)

Teleoperation (2)

Infotainment Interface (18)

Smart Data (72)

Location Based Services (28)

Machine Vision AI/Perception / Sensor Fusion (23)

Urban Mobility (14)

Route Optimization (7)

Smart Cloud (12)

Security (12)

Connected and autonomous (146)

Car Add Ons (34)

Electric Scooter (10)

Electric Motorcycles (8)

Electric Vehicles (18)

Sensors (42)

Embedded Systems (23)

Infotainment Embedded (12)

Heads Up Display (5)

Emerging OEM (6)

Smart network (8)

Vehicle to Infrastructure (8)

EUROPEAN MOBILITY STARTUP LANDSCAPE

Autonomous Vehicles & Systems

Mapping & Navigation

Sensors & Training Data

Connected Vehicles & V2X

Mobility Services

Micro Mobility

E-Mobility & Battery Tech

Vehicle Marketplaces & Aftermarket

Finance & Insurance

Hardware & Materials

Parking & Smart City

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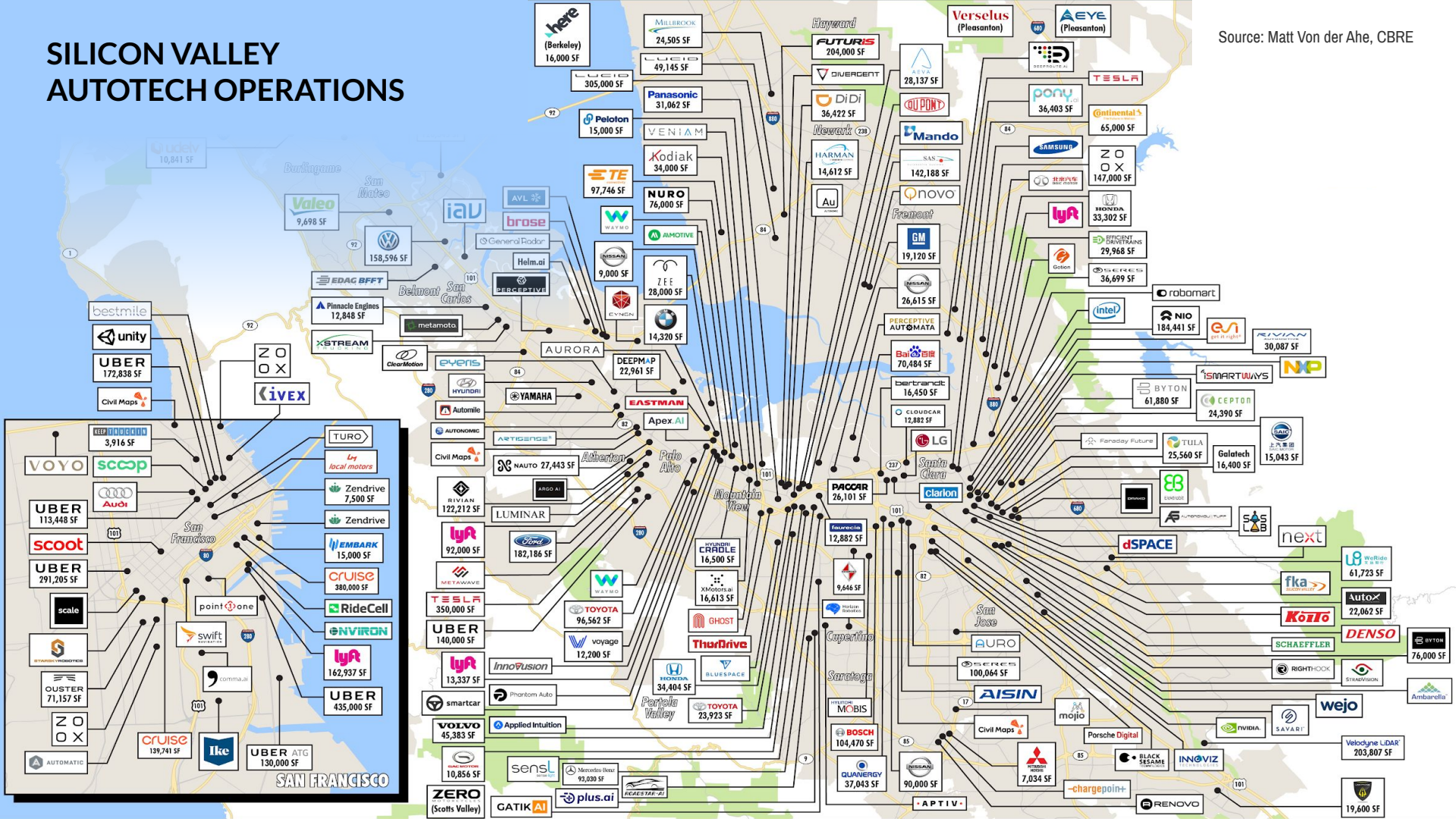
UNTERNEHMERTUM VENTURE CAPITAL

@alex_kiltz

SILICON VALLEY AUTOTECH OPERATIONS

Source: Matt Von der Ahe, CBRE



2015/2016: AUTOMOTIVE INDUSTRY INFLECTION POINT FOR AUTONOMOUS DRIVING - FROM DISMISSAL TO URGENCY

> “We are now making autonomous driving a core technology at Volkswagen. We don’t have the slightest doubt that this revolutionary technology will become reality within a few years.”

Matthias Müller
VW CEO
June 2016

> “The discussion is shifting to how it’s going to be deployed. This is as transformative to the automotive space as the internal combustion engine or the electric starter.”

Glen DeVos
Delphi Automotive CTO
January 2017

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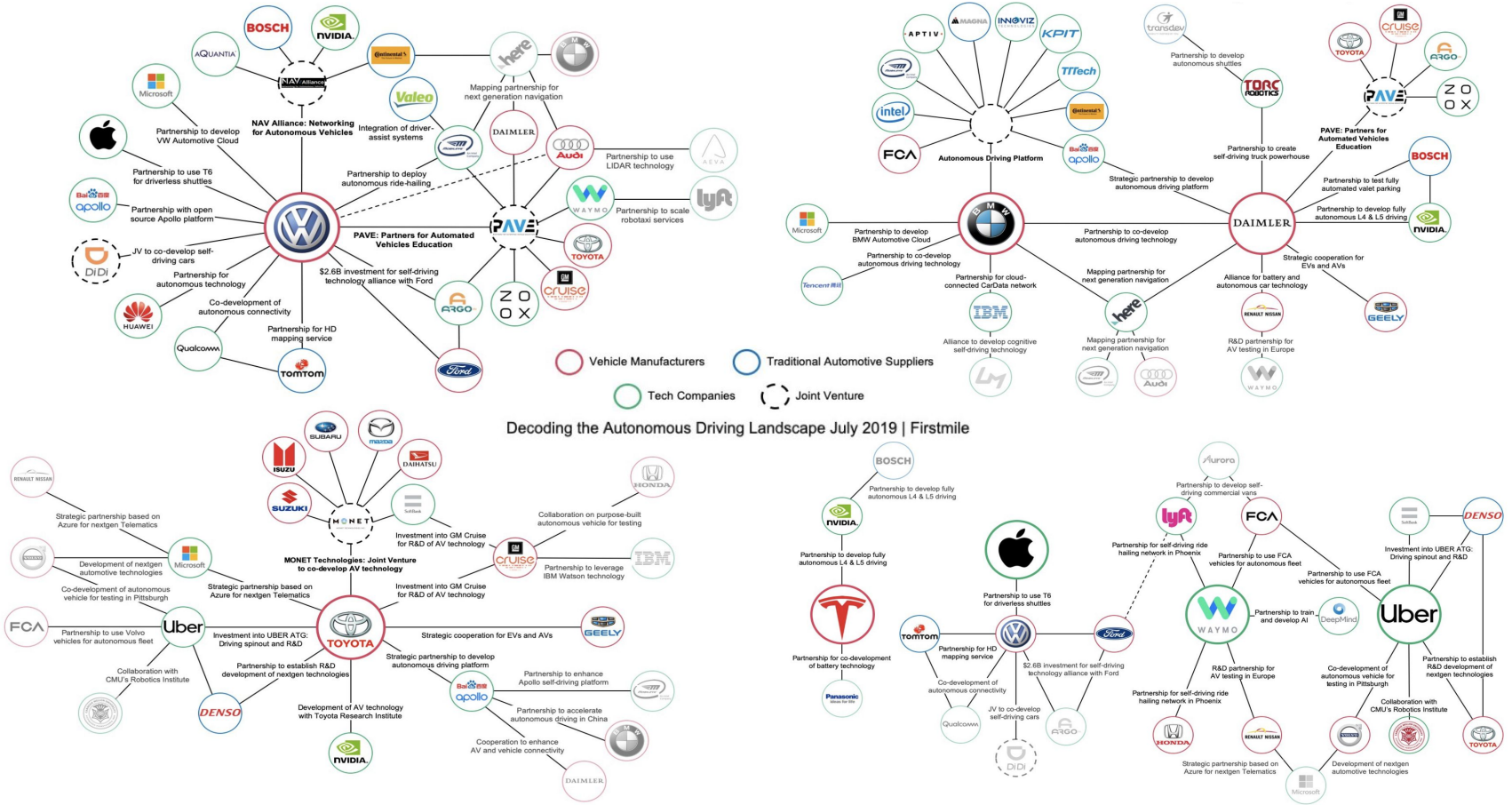
AUTONOMOUS DRIVING LAUNCH DATES ANNOUNCED BY AUTOMOTIVE CEOs IN 2015/2016

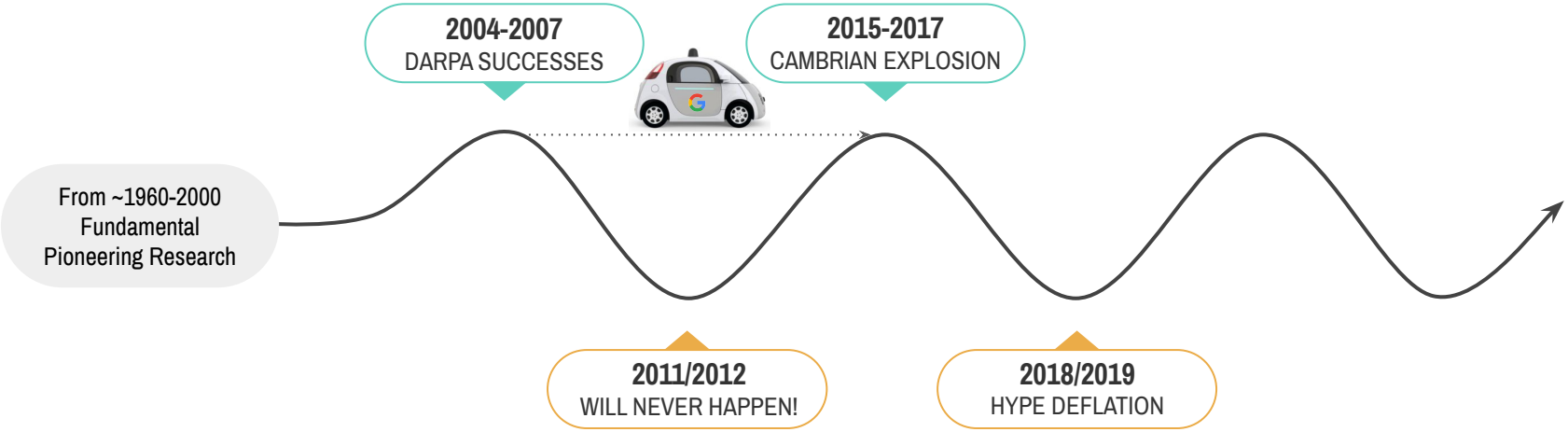
- Buys Cruise for $1B
- Invests $1B into Argo

OEMs	2014	2015	2016	2017	2018	2019	2020	2021	2025	OEM perspectives	BCG Boston Consulting Group
GM		Partially autonomous driving	Buys Cruise for $1B	Super Cruise semiautonomous system						*"GM is in a good position to be successful in the upcoming **revolution in transportation** – even if Apple does make a car"*	**M. Barra** *CEO* Oct 2015
Ford				Invests $1B into Argo			Highly autonomous driving			*"I think it is credible that an **autonomous vehicle at SAE Level 4 will hit the market by 2020**"*	**Raj Nair** *Head of Prod. Dev.* Feb 2016
Tesla		Autopilot (partially autonomous driving)			Technologies for fully autonomous driving					*"We will have **complete autonomy in approximately two years…regulators will lag behind the technology**"*	**Elon Musk** *Tesla Co-founder & CEO* Dec 2015
Google							Self-driving vehicles			*"Our goal is to create something that's **safer than a human driver**"*	**Sergey Brin** *Google co-founder* May 2015
Daimler / Mercedes Benz			Partially autonomous driving				Highly autonomous driving		Fully autonomous truck	*"Building an **extensive fleet of autonomous vehicles** that could reach a new customer segment is a **concrete development goal** of ours"*	**Dieter Zetsche** *Chairman Daimler AG & CEO Mercedes Benz* Sep 2015
Volkswagen Group / Audi			Piloted driving				Fully autonomous driving			*"**In five years**, we'll be advanced enough that the VW Group will manufacture cars that can drive **completely autonomously** without a steering wheel or pedals"*	**Johann Jungwirth** *Chief Digital Officer* Feb 2016
BMW								Fully autonomous driving		*"Our goal is already clearly-defined – to **be Number ONE in autonomous driving**"*	**Harald Krüger** *Chairman* May 2016
PSA Peugeot Citroën					Traffic jam chauffeur		Self-driving assistance systems			*"The test drive with our prototypes today proves that **autonomous vehicles are no longer science fiction**"*	**Carlos Tavares** *Chairman* Oct 2015
Renault Nissan			Traffic jam pilot		Automated lane changing		Fully autonomous vehicles			*"Renault-Nissan Alliance will have **10 autonomous-drive models on the market globally by 2020**"*	**Carlos Ghosn** *CEO* Jan 2016
Toyota		Highway pilot					Technologies for autonomous driving			*"**Autonomous driving is a technology that will change the concept of cars in the future**"*	**Moritaka Yoshida** *Chief Safety Tech. Officer* Oct 2015

PROLIFERATION OF AUTONOMOUS DRIVING PARTNERSHIPS TO SECURE PATH TO AUTONOMY



PHASES OF AUTONOMOUS DRIVING DEVELOPMENT



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INFLECTION POINT: MARCH 2018 - FIRST FATALITY DURING AUTONOMOUS VEHICLE TESTING

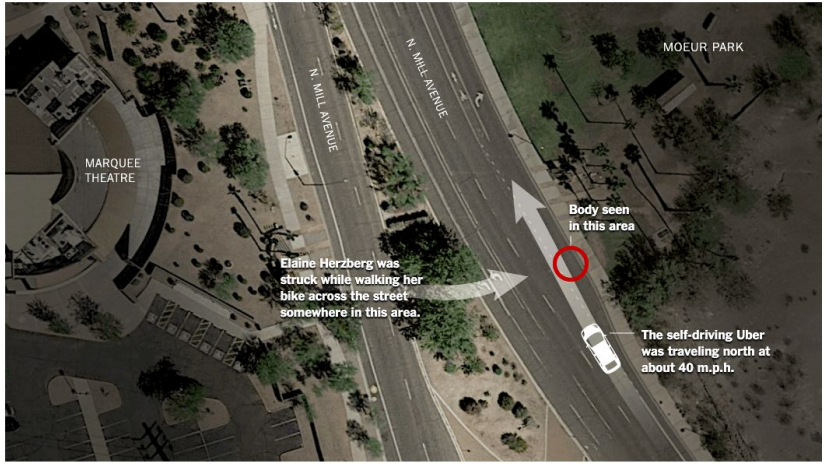
The New York Times

How a Self-Driving Uber Killed a Pedestrian in Arizona

By TROY GRIGGS and DAISUKE WAKABAYASHI UPDATED MARCH 21, 2018

A woman was struck and killed on Sunday night by an autonomous car operated by Uber in Tempe, Ariz. It was believed to be the first pedestrian death associated with self-driving technology.

What We Know About the Accident



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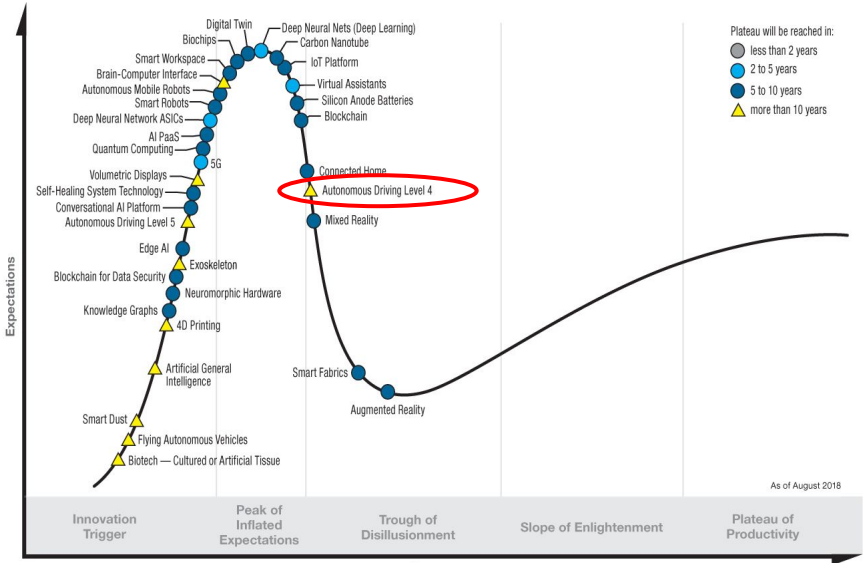
DEFLATION OF EXPECTATIONS 2018-2019
FOR EXAMPLE, THE GARTNER HYPE CYCLE & WSJ ARTICLE

Autonomous Vehicles Fall Into The Trough Of Disillusionment ... But That's Good

Mike Ramsey
Tech



THE WALL STREET JOURNAL.

TECH | KEYWORDS

Driverless Hype Collides With Merciless Reality

The bubble around self-driving cars turns into a 'trough of disillusionment'; firms refactor for much later arrival

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CHANGE IN PUBLIC SENTIMENT
CONSUMER SURVEY HEADLINES

Three in Four Americans Remain Afraid of Fully Self-Driving Vehicles

Gartner Survey Reveals 55 Percent of Respondents Will Not Ride in a Fully Autonomous Vehicle

Mobility Pipe Dreams? J.D. Power and SurveyMonkey Uncover Shaky Consumer Confidence About the Future

Tech failures, hacking and liability are top concerns: Although consumers are more hopeful than worried (65% vs. 34%) about the overall benefit of technology in their lives, 39% aren't excited about any self-driving technology, including delivery services, public transit, taxi/ride-hailing service and personal vehicles. Serious concerns exist with the development of self-driving vehicles, of which consumers are most worried about tech failures/errors (71%); risk of vehicle being hacked (57%); and legal liability as a result of a collision (55%).

COX AUTOMOTIVE

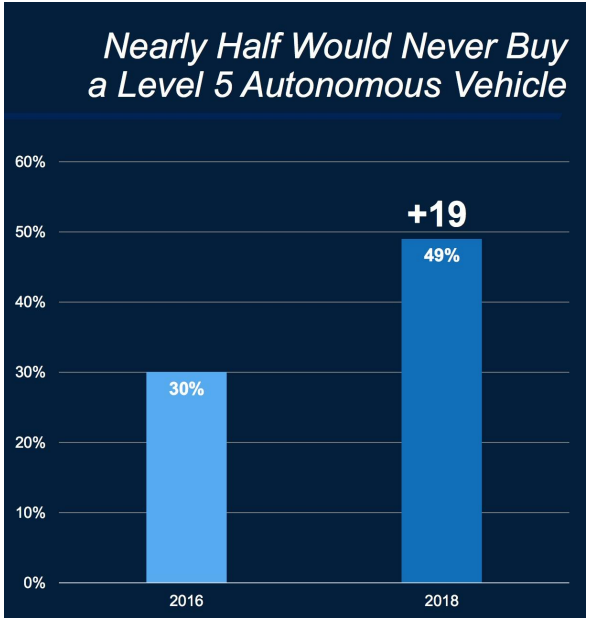
BRA

RSS SUBSCRIBE | 5 MIN READ

Consumer Sentiment Changes Toward Autonomous Vehicles

Autonomous Vehicle Awareness Rising, Acceptance Declining

Thursday August 16, 2018



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THE GAP BETWEEN PUBLIC PERCEPTION OF AV TECHNOLOGY AND REALITY

> This disconnect, between public perceptions of autonomous vehicles and the technical reality, has stuck with me. If people were regularly exposed to the true state of the technology, public sentiment in 2016 would be closer to the pessimism and skepticism we see today and we'd be growing more confident in it as it has improved in leaps and bounds. Instead, we continue to suffer from an extended hangover from the irrational exuberance of 2016, falling deeper into pessimism even as Waymo has begun offering rides in fully driverless vehicles with no safety driver.

Ed Niedermeyer, May 2020
Automotive Industry Journalist
Co-Host of The Autonocast
Communications Director @PAVE

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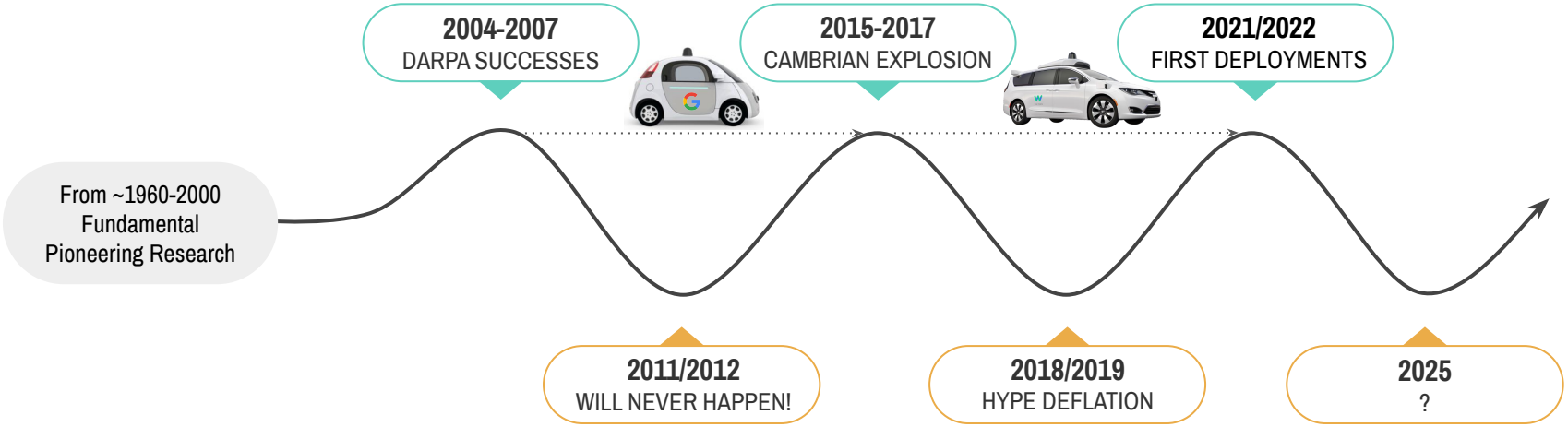
PHASES OF AUTONOMOUS DRIVING DEVELOPMENT



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TODAY'S AGENDA

1. Autonomous Vehicle - Brief History
2. The Complex Social Act of Driving
3. Human Intuition For Machines
4. Autonomous Vehicles - Where Next?

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TREMENDOUS PROGRESS WITH THE ‘PHYSICS’ OF AUTOMATED DRIVING

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LOTS OF EDGE CASES - LADY CHASING BABY RACCOON ON EL CAMINO REAL IN MOUNTAIN VIEW, CA (JUNE 2019)

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DRIVING IS A COMPLEX SOCIAL ACT
FOR EXAMPLE: ARC DE TRIOMPHE IN PARIS

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STRUGGLING WITH HIGHWAY ON-RAMP MERGE
DIFFICULTY READING INTENT OF HUMAN DRIVERS

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TESLA CHALLENGE SIGNALING INTENT TO AND READING INTENT OF HUMAN DRIVER (WITH AUTOPILOT 3.0 - FEB 2020)

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WHEN EVERYDAY LIFE MEETS AV TECH
THE AVERAGE PERSON WON'T HAVE MUCH PATIENCE

> They really need to learn how to deal with cyclists, and cyclists really need to learn how to deal with them. I'll roll up to a four way stop, try to let the Cruise or whatever car go, it moves a foot forward, then stops again, so I go. Then it starts to drive again. I WENT BECAUSE YOU HESITATED YOU STUPID ROBOT! It's fucking frustrating.
>
> And my next line of thought for all the people who can't wait for them to be used by companies like Uber/Lyft - You're already used to your drivers driving like complete assholes to get you where you want to go. You're going to absolutely HATE it when your trip is slower because the cars will be doing everything they know to do to follow traffic laws.

Reddit Comment
Oct 2018

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ILLUSTRATION OF LIKELY ‘PARANOID’ PHYSICS-ONLY DRIVING AT INTERSECTION DIFFICULTY READING INTENTIONS OF TWO PEDESTRIANS TALKING TO EACH OTHER

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ILLUSTRATION OF ‘PARANOID’ PHYSICS-ONLY DRIVING AT CROSSWALK UNABLE TO UNDERSTAND THE INTENT OF PEDESTRIAN NOT WANTING TO CROSS

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WHEN EVERYDAY LIFE MEETS AV TECH - ROBOTAXI PASSENGERS AND HUMAN DRIVERS FOLLOWING BEHIND WON'T HAVE MUCH PATIENCE

"I was crossing a street with my friend and you know how you can time it so that the car can pass right in front of you as you cross?

As soon as we got within 5 feet or so, the car slams on the brakes, the driver and passenger got thrown into the dash, and I was dying laughing.

There are still some judgment calls that they suck at making, those guys were just cruising then suddenly, ragdolls."

Reddit Comment
Oct 2018

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ILLUSTRATION OF LIKELY ‘PARANOID’ PHYSICS-ONLY DRIVING DIFFICULTY READING INTENT OF PEDESTRIAN ON ROAD NEXT TO HIS PARKED VEHICLE

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ANTICIPATING HUMAN BEHAVIOR IS ONE OF THE THE HARDEST PROBLEMS FOR AUTOMATED DRIVING

"It's the prediction piece that's still the great unknown. Humans are very good at predicting human behavior on the road. Machines will need to be able to predict and anticipate human behavior much better."

Gill Pratt
CEO of Toyota Research Institute
March 2018

"The choices made by driverless cars are critically dependent on understanding and matching the expectations of humans. This is the heart of the problem going forward."

Chris Urmson
Head of Waymo, 2009-2016
Co-Founder of Aurora, April 2017

"With radar and high-resolution cameras and all the computing power we have, we can detect and identify the objects on a street. The hard part is anticipating what they're going to do next. We have developed about 80% of the technology needed to put self-driving cars into routine use. But the remaining 20%, including developing software that can reliably anticipate what other drivers, pedestrians and cyclists are going to do, will be much more difficult."

Bryan Salesky
Co-Founder & CEO of Argo
July 2019

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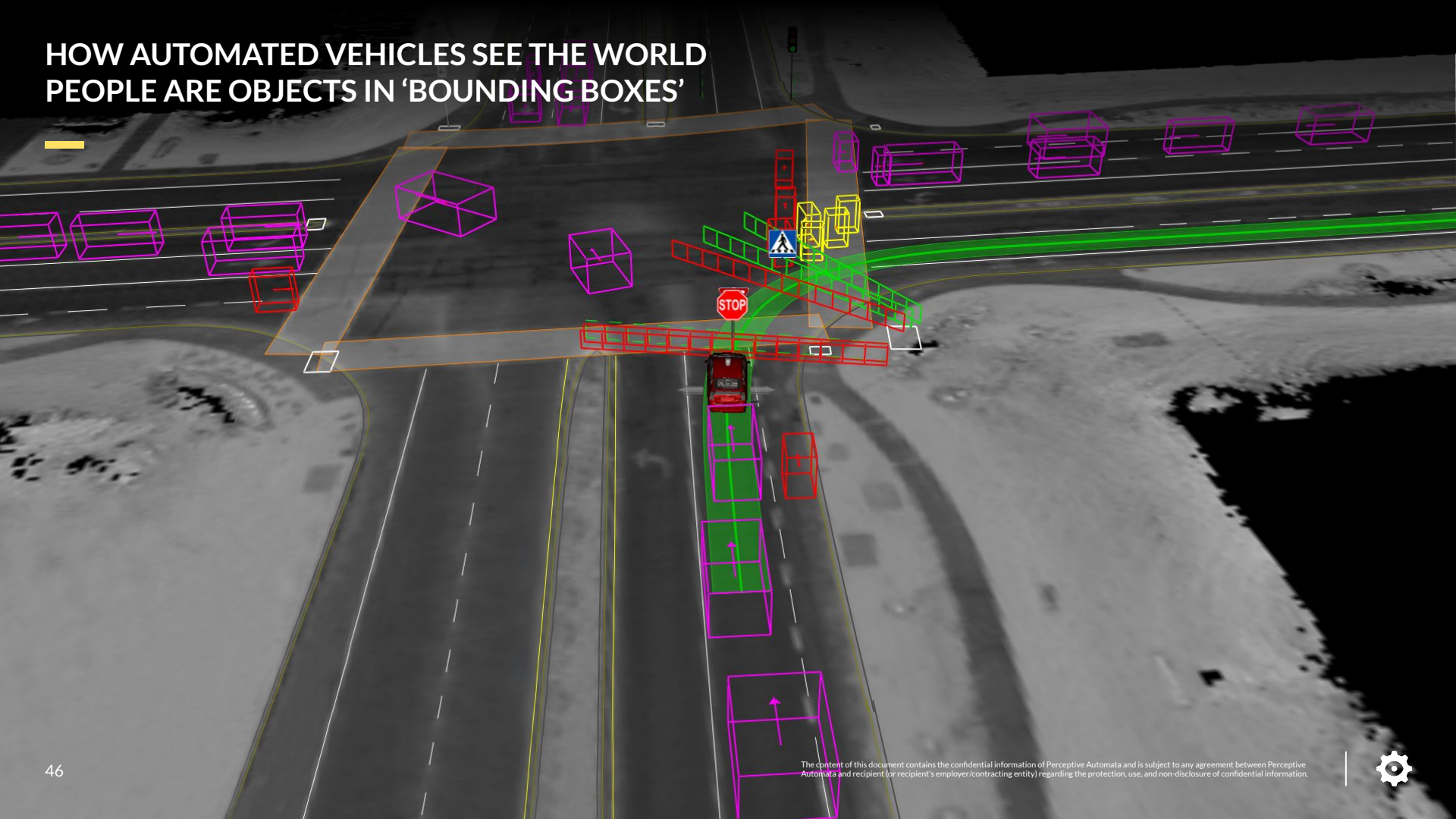
HOW AUTOMATED VEHICLES SEE THE WORLD
PEOPLE ARE OBJECTS IN 'BOUNDING BOXES'



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BUT VIEWING PEOPLE SIMPLY AS BOXES LEADS TO “PARANOID DRIVING” BECAUSE CRITICAL INFORMATION IS MISSING - THE AV HAS NO CHOICE BUT TO STOP HERE

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IN CONTRAST, HUMANS EFFORTLESSLY AND INSTANTANEOUSLY PREDICT THAT THIS PEDESTRIAN DOES NOT WANT TO CROSS AND CONTINUE DRIVING

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TODAY'S SOLUTIONS FOR THIS HUMAN BEHAVIOR PREDICTION CHALLENGE ARE CONSTRAINED BY THE "GOLDEN HAMMER" PROBLEM

> "You've built this complicated thing and you start to see the world through how that thing works. It's the classic, if I have a hammer the whole world looks like nails. If you have a complex software system you want to twist solutions to problems to fit that system."

Chris Urmson
Co-Founder & CEO of Aurora,
Head of Waymo 2009-2016
Forbes Summit, Nov 15, 2019

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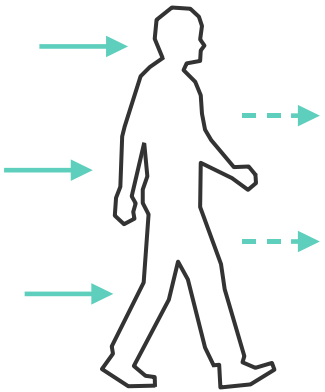
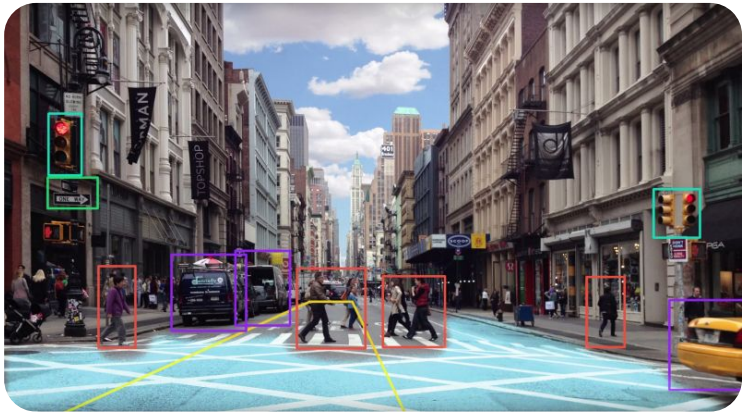
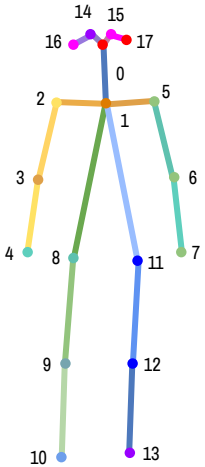
THREE “GOLDEN HAMMER” APPROACHES TYPICALLY USED ARE INSUFFICIENT BECAUSE THE WAY THEY SIMPLIFY THE WORLD STRIPS THEM OF PREDICTIVE POWER







MOTION

Needed, but only works for obvious/easy situations such as when pedestrian is already crossing.

CONTEXT

Generalizes based on built environment and observed ‘like’ actions - e.g. “pedestrians at crosswalks cross”. These ‘rules of thumb’ are not accurate enough.

POSE

Simplification limits usefulness. Can help with human locomotion tracking (similar to motion), task identification (e.g. waving), and gaze tracking.

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LIMITATIONS OF MOTION PREDICTIONS
EXAMPLE: USE OF KALMAN FILTER TO PREDICT CROSSING INTENT

LIMITATIONS OF CONTEXT LEARNING
EXAMPLE: PEDESTRIAN AT CROSSWALK WITH NO INTENT TO CROSS

LIMITATIONS OF CONTEXT LEARNING
EXAMPLE: STATIONARY JAYWALKER AT TAXI STAND

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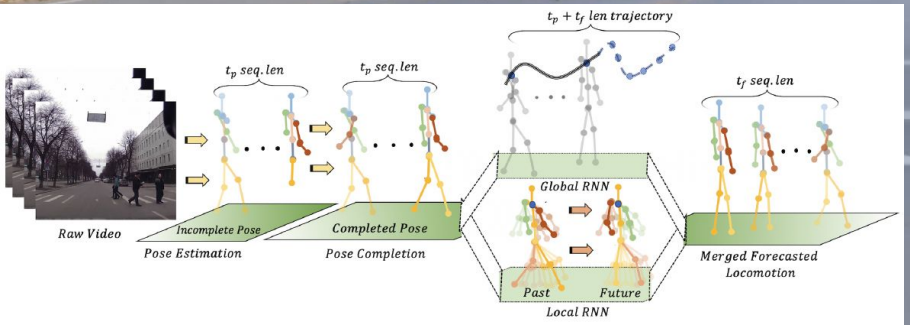
LIMITATIONS OF POSE MODELING
SIMPLIFICATION LEADS TO LOSS OF PREDICTIVE POWER

The Pose Model Perspective



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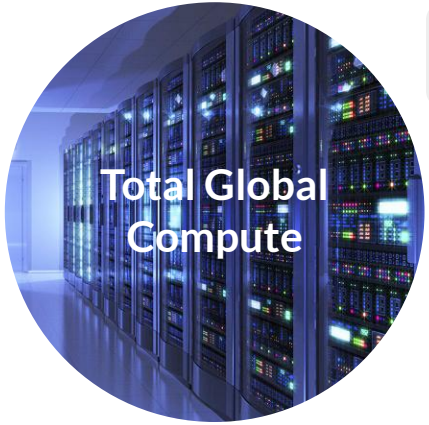
THE EXTRAORDINARY PERCEPTUAL COMPUTING POWER OF THE HUMAN BRAIN

Speed

Precision



10^{16} - 10^{25} calculations per second

≈

Perception

Intuition

Abstract Thought
Brute-Force Calculations

Ultra-Sophisticated Special-Purpose Perceptual Computing

The human brain is able to perceive so effortlessly that it is done subconsciously.

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OUR BRAIN IS A HIGHLY EVOLVED PERCEPTUAL SUPERCOMPUTER AND THE SUBCONSCIOUS SKILLS ARE THE MOST COMPLEX ONES. SKILLS THAT ARE IMPOSSIBLE FOR MACHINES TODAY.

"Encoded in the large, highly evolved sensory and motor portions of the human brain is a billion years of experience about the nature of the world and how to survive in it.

We are all prodigious olympians in perceptual and motor areas - so good that we make the difficult look easy.

Abstract thought, though, is a new trick, perhaps less than 100 thousand years old. We have not yet mastered it. It is not all that intrinsically difficult; it just seems so when we do it.

The most difficult human skills to reverse engineer are those that are subconscious. In general, we're least aware of what our minds do best. We're more aware of simple processes that don't work well than of complex ones that work flawlessly."

Hans Moravec

Rodney Brooks

Marvin Minsky

Stanford University

MIT

PRINCETON UNIVERSITY

HARVARD UNIVERSITY

Carnegie Mellon University

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KEEPING ME UP AT NIGHT (AT THE TIME)
MY TEENAGE DAUGHTER LEARNING TO DRIVE

SHE STRUGGLES WITH THE RULES OF THE ROAD BUT HAS NO PROBLEM ‘READING’ OTHER HUMANS

CHALLENGING

EFFORTLESS

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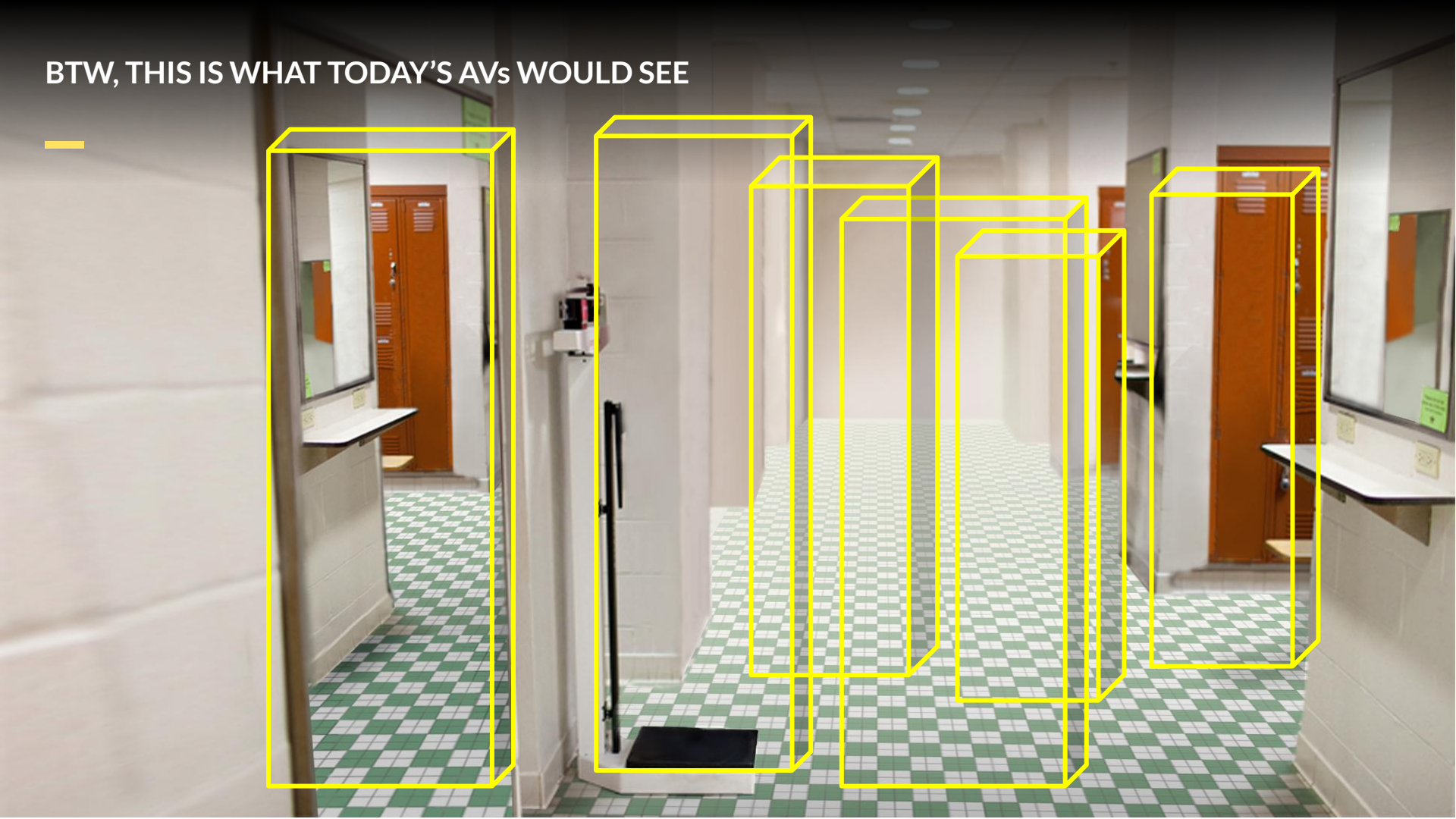
EFFORTLESS & IMMEDIATE UNDERSTANDING

BTW, THIS IS WHAT TODAY'S AVs WOULD SEE



THE HUMAN PERCEPTUAL 'SUPERCOMPUTER' EFFORTLESSLY PROCESSES AN INFINITE NUMBER OF SUBTLE SOCIAL CUES, INCLUDING, FOR EXAMPLE:

Social engagement

Intensity of gaze

Shoulder tension

Body balance

Arm movements

Hand position

Type of person

Object handling

Focus of attention

Leg movements

Type of clothing

Orientation

Body leaning

Movement

Position of feet

Changes over time

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OUR UNIQUE PATENTED METHODS HARNESS THE POWER OF THE HUMAN PERCEPTUAL SUPERCOMPUTER *WITHOUT* HAVING TO PRE-SELECT THE 'RIGHT' CUES

Head position	Eye contact	Orientation
Shoulder tension	Body balance	Movement
Hand position	Arm movements	Changes over time
Object handling	Leg movements	Type of person
Object carrying	Type of clothing	Body leaning
Position of feet	.....	

Using behavioral science tools to extract from images the rich set of social cues people use to 'read' other people.

Training Data

Train our machine learning models, as part of the loss function for a deep neural network.

Perceptive Automata State of Mind AI (SOMAI)

On-Vehicle Superhuman Predictions

Pedestrians

Cyclists

Vehicles

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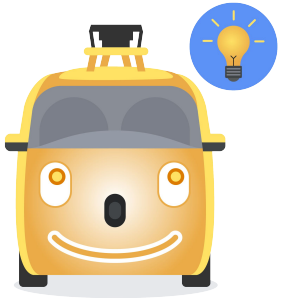
OUR METHODS INCLUDE SCALED VISUAL PSYCHOPHYSICS TO EXTRACT FROM PEDESTRIAN IMAGES THE SOCIAL CUES THE HUMAN BRAIN USES TO 'READ' OTHER PEOPLE

Our brains' perceptual processing is **subconscious**.
=>
We can't ***directly*** identify the rich set of social cues the human brain uses to predict, for example, a pedestrian's crossing intent.



Scaled Psychophysics, the (industrial) scientific study of the relation between stimulus (e.g. image of pedestrian) and perception (e.g. pedestrian crossing intent)

Efficiently ***indirectly*** extract from pedestrian images the rich information that the human brain uses to effortlessly and subconsciously read the state of mind of pedestrians.

1. Show human annotators systematically modified images of pedestrians (the stimuli).
2. Record annotator responses to what they are perceiving when viewing the modified images.
3. Measure both explicit responses and implicit measures of cognitive load.

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CONCEPTUALLY, MODIFICATION OF THE IMAGES AND THE QUESTIONS WE ASK CAN TAKE MANY FORMS. THE GOAL IS TO ‘IDENTIFY’ PREDICTIVE IMAGE FEATURES AND THEIR THRESHOLDS.

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OUR TRAINED MACHINE LEARNING MODELS CAN SHED LIGHT ON OUR SUBCONSCIOUS

Our AI correctly signals his change in intention, and his ongoing awareness even though he turns his head away.

SOMAI SIGNALS INCREASING DRIVING TASK CONFIDENCE
MOBILEYE EXAMPLE

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SOMAI SIGNALS INCREASING DRIVING TASK CONFIDENCE FOR VOYAGE EXAMPLE

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SOMAI SIGNALS INCREASING DRIVING TASK CONFIDENCE FOR VOYAGE EXAMPLE

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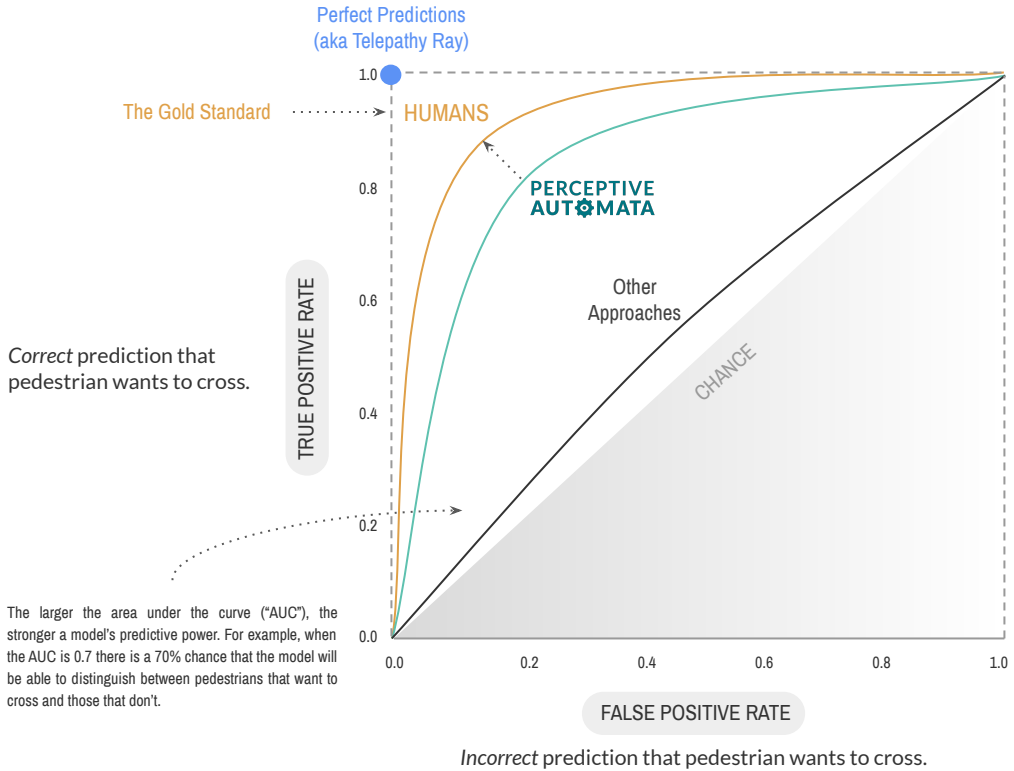
BUILDING STATE OF MIND AI WITH (SUPER) HUMAN-LIKE PERFORMANCE



- Our SOMAI reflects the Wisdom of Crowds
  - every AI prediction is a distribution of predictions from hundreds of humans
  - eliminates limitations such as a single person's mental state, personal experiences and biases, eye sight, etc.
- Continuous parallel monitoring of all vulnerable road users
  - 360° around vehicle
  - no distractions
  - no subsequent search misses

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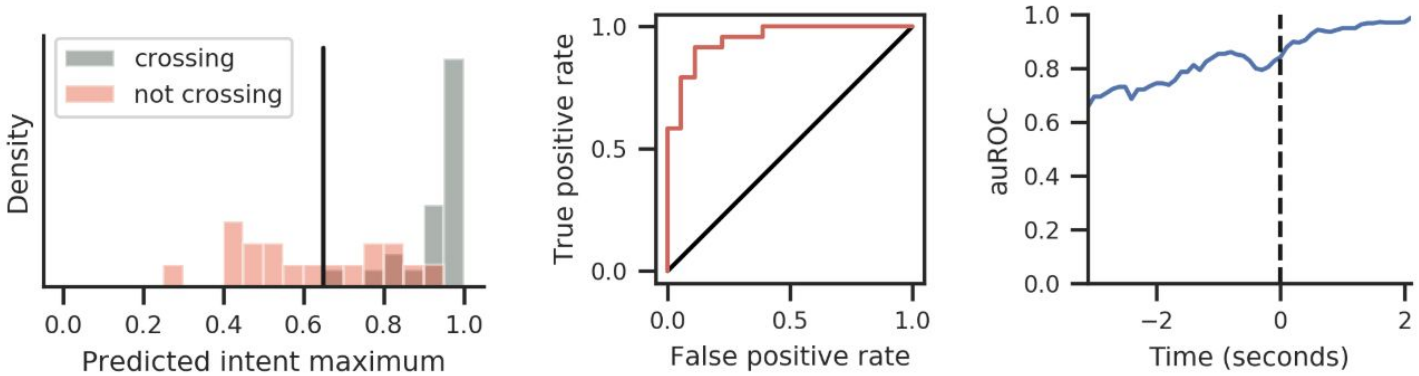
EXAMPLE SOMAI SIGNAL PERFORMANCE MEASUREMENT

SOMAI producing ***strongly differentiated pedestrian intent signals that successfully resolve driving task ambiguities*** at unsignalized crosswalks, enabling AVs to anticipate human behavior ***before*** body motion is detected.



Left to right: (a) Distribution of maximum mean intent prediction preceding t=1s; (b) ROC curve from t=-1s to t=1s; (c) Area under ROC curve from t=-3s to t=2s. Note: t=0 represents "moment that first step was taken" by a crossing pedestrian and "last moment that pedestrian could have started crossing" for a not-crossing pedestrian.

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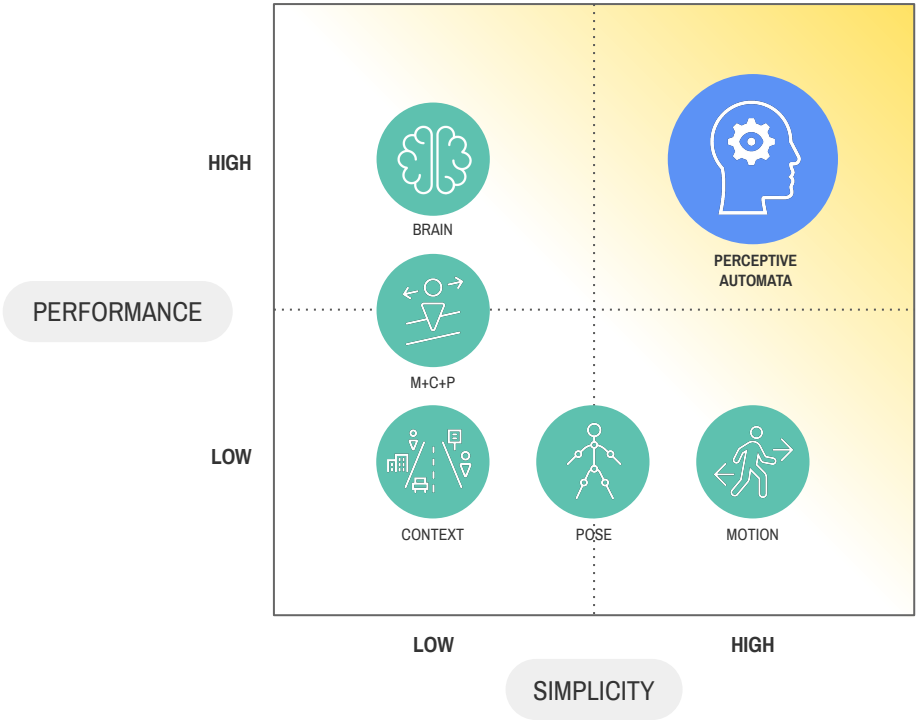
PERCEPTIVE AUTOMATA'S SOMAI COMPLEMENTS EXISTING APPROACHES BY DELIVERING SUPERHUMAN-LIKE PERFORMANCE, SIMPLY (!)



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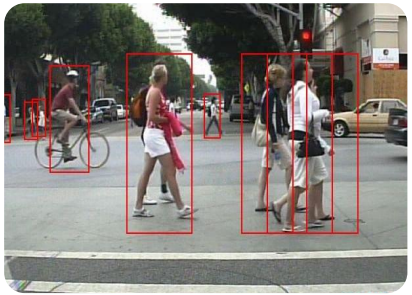
SIMPLE INTEGRATION WITH ON-VEHICLE AUTOMATION STACK WITHOUT REPLACING CUSTOMER SUBSYSTEMS OR SLOWING STACK DOWN



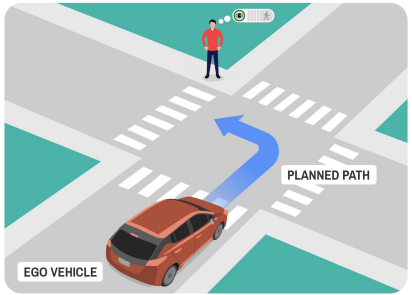
Customer
Object Detection & Tracking

Perceptive Automata
State of Mind AI
(SOMAI)

Input
"pixels in the bounding boxes"

<1 ms inference time per object
(TensorRT, NVIDIA Tegra;
unoptimized)

Output Signals
e.g.: pedestrian intent
& awareness



Customer
Prediction & Planning

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GLOBAL LEADERSHIP POSITION FOR HUMAN BEHAVIOR PREDICTION

JAZZ VENTURE PARTNERS · SLOW · First Round · TOYOTA AI VENTURES · HYUNDAI CRADLE · PAVE · WORLD ECONOMIC FORUM · Gartner Cool Vendor 2018

$20M in capital (oversubscribed Series A)

Technical Founders: Neuroscience + Artificial Intelligence Experts

Sam Anthony, PhD
Co-Founder & CTO
20 years of cognitive science *and* computer science experience
HARVARD UNIVERSITY

David Cox, PhD
Co-Founder & Advisor
Director, MIT-IBM Watson AI Lab
Massachusetts Institute of Technology
IBM Watson

Walter Scheirer, PhD
Co-Founder & Advisor
Field-leading researcher in computer vision and deep learning
UNIVERSITY OF NOTRE DAME

SLATE · WIRED · QUARTZ · Bloomberg · NVIDIA · The Boston Globe · DAIMLER · FAST COMPANY

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MASSIVE CHANGES ARE TRANSFORMING THE AUTOMOTIVE INDUSTRY

> In the next decade, the automotive industry will face a magnitude of change that has not been seen in a century. This change will be driven primarily by four mutually reinforcing trends, i.e., autonomous, connected, electric, and shared (ACES) vehicles. These will result in different user behaviors and mobility preferences, shifting value pools, innovative business models, and new entrants into automotive. All of these trends are enabled by the advancement of technology in electronics and software and thus have a substantial impact on the automotive electronics and software market.

McKinsey Study
Automotive Software and Electronics 2030
July 2019

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RAPID AND PROFOUND AUTOMOTIVE DISRUPTION

“The battle to capture a leading role in the autonomous, connected, electric and shared car markets is not about winning or losing, but one about surviving or dying.”

Akio Toyoda
CEO, Toyota

“It saddens me to say it, but we are approaching the end of the automotive era. The auto industry is on an accelerating change curve. The era of the human-driven automobile, its repair facilities, its dealerships, the media surrounding it - all will be gone in 20 years.”

Bob Lutz
Automotive Industry Icon
Vice Chairman, GM
Former Board Member, Ford

“The auto industry is poised for more change in the next five to ten years than it’s seen in the past 50. And that pace of change is accelerating. Disruption creates uncertainty, but it also creates vast possibilities that will lead to a better world.”

Mary Barra
CEO, GM

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IMPACT OF COVID-19
POSSIBLY THE BIGGEST SHOCK IN 100 YEARS

> “A health crisis is turning into a financial crisis as uncertainty about the size, duration, and shape of the decline in GDP and employment undermines what remains of business confidence. The shock to our livelihoods could be the biggest in nearly a century, which is likely to lead to a decline in economic activity in a single quarter that proves far greater than the loss of income experienced during the Great Depression.”

McKinsey
Beyond coronavirus: The path to the next normal
March 23, 2020

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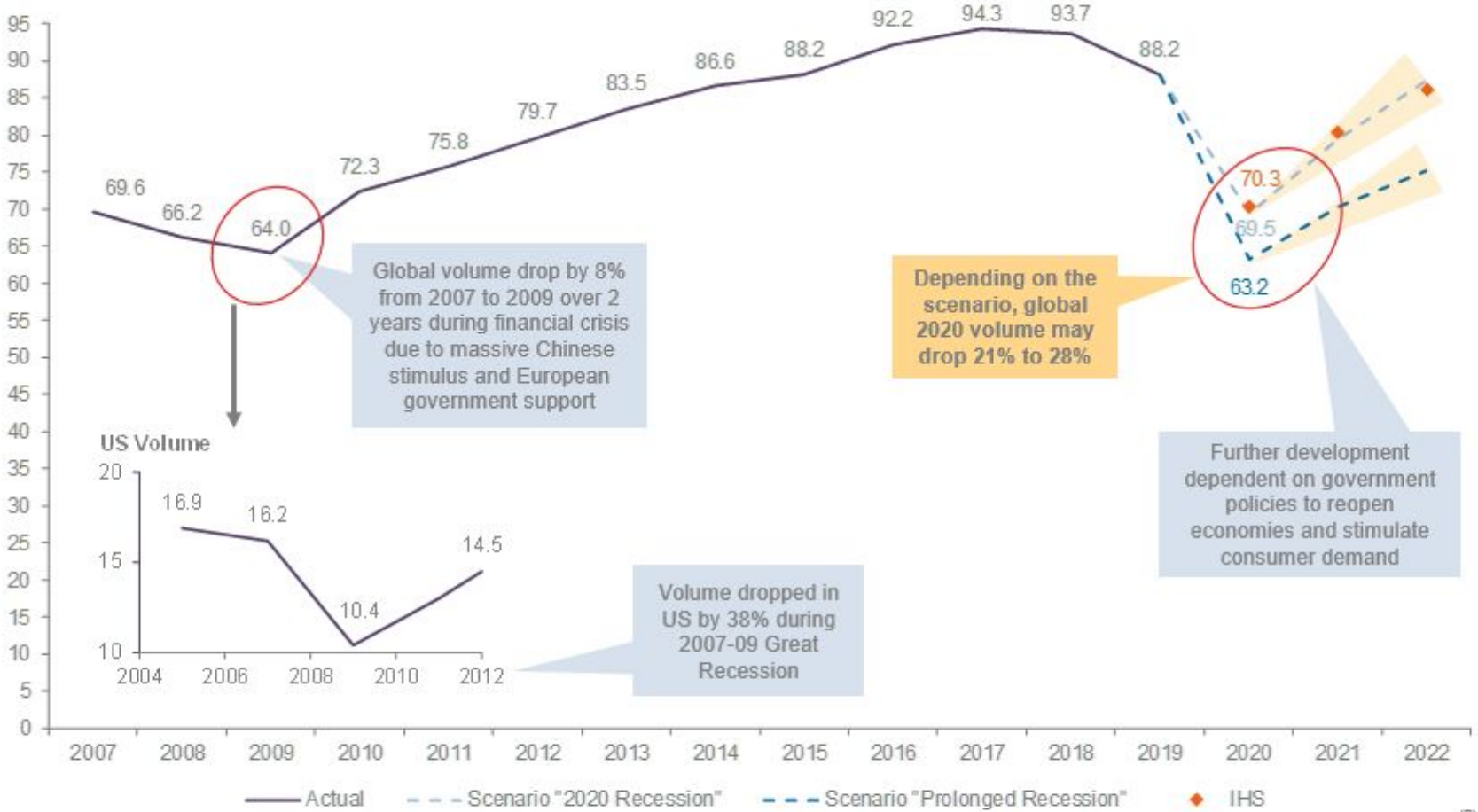
COVID-19 AUTOMOTIVE RECESSION POSSIBLY LARGER THAN THE 2008/9 GREAT RECESSION

P / W / P
PERELLA WEINBERG PARTNERS

Source: IHS, AlixPartners



AS OF MID-MAY, AUTOMOTIVE DEMAND DOWN -50% IN US AND -80% IN EUROPE. CHINA SHOWING SIGNS OF RECOVERY DUE TO EARLIER REOPENINGS.

2020 light vehicles sales growth rate per month (year on year)

As of May 14

Worse than -60% | -60% to -40% | -40% to -20% | -20% to 0% | Better than 0%

	Jan 20	Feb 20	Mar 20	Apr 20	
	↓ -20%	↓ -81%	↓ -45%	↓ -18%	• Second consecutive month of **significant sales improvements** driven by **innovative sales approach and strong consumer confidence**
	↑ +1%	↑ +9%	↓ -38%	↓ -47%	• Strong decline in sales, but relatively low sales drop on April compared to Europe as **many states did not have a full lock-down**
	↓ -5%	↓ -5%	↓ -50%	↓ -80%	• Sales decline of up to 95% in some markets, due to strict lock-downs in most European countries in April
	↓ -12%	↓ -10%	↓ -9%	↓ -28%	• Implementation **of lockdowns only implemented in mid-April** and only for some regions
	↓ -16%	↓ -20%	↑ +10%	↑ +8%	• **No prolonged lock-downs after February** and very strong performance for second consecutive month

Source: Markines Global Vehicles Sales Data (April 2020)

McKinsey & Company 3

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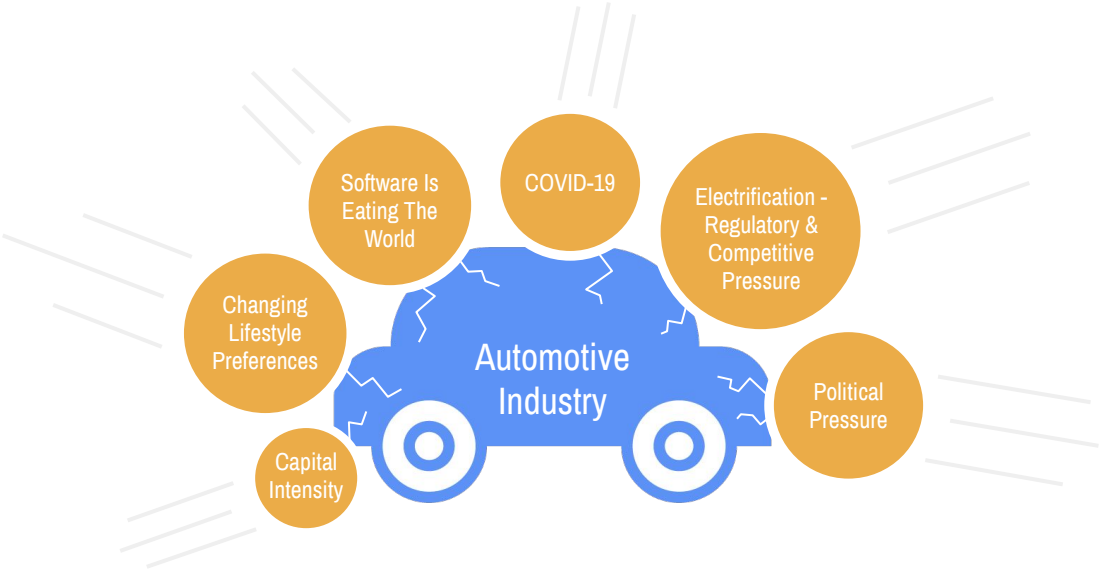
THE AUTOMOTIVE INDUSTRY'S BIG SQUEEZE
ACES + SOFTWARE + COVID-19



"The latest example of how longtime rivals are joining forces during a period of extraordinary ferment in the auto industry. A rapid shift toward battery-powered self-driving cars could be perilous for established carmakers like Ford and Volkswagen.

They must invest hundreds of billions of dollars in coming years or risk becoming irrelevant.

And they face new competitors like Google and Uber with access to enormous financial resources. Investors have been much more willing to back Silicon Valley companies.

At the same time, car sales are slumping in all of the largest markets, pinching the companies financially."

The New York Times
July 5, 2019

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IMPACT OF COVID-19
USEFUL TO SPLIT BY TIME HORIZON

2 / 100

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COVID-19 WILL HAVE LARGE TACTICAL AND OPERATIONAL IMPACT THESE NEXT ~2 YEARS

2 / 100

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IMPACT OF COVID-19 - NEXT ~2 YEARS
LIKELY AUTOMOTIVE INDUSTRY RESPONSES

Worst yet to come as coronavirus takes its toll on auto sales

CNBC

PUBLISHED WED, APR 1 2020•6:31 PM EDT | UPDATED WED, APR 1 2020•8:19 PM EDT

ACCELERATED RESTRUCTURING

- Ford and GM restructuring started a few years ago - will probably be sped up
- **Can now make decisive decisions not possible under normal circumstances.**
- More negotiating leverage against governments (regarding regulatory goals), suppliers, and unions.

FOCUS ON CONSERVING CASH

- Rapid, huge sales drop. Unclear how sustained this is going to be.
- Very capital intensive business - marginal profits from volume are critical for positive cash flow.
- Likely to put pressure on suppliers for cost reductions, but suppliers in worse shape
- **In better shape than during 2008/9 GR. Playbook available.**

ALLOCATION OF R&D CAPITAL

- Relatively more near-term allocation to electrification and less for autonomous?
- Focus more on L2/3 ADAS over L4/5 ADS?
- **Depends partly on possible delays to regulatory emission goals, and gov. support**
- **More critical assessment of access to scarce talent**

MAKE VS BUY DECISIONS

- More likely to engage with external solutions providers instead of attempting to build in-house
- **Might reduce or slow down recently announced initiatives**
- Time to market likely more important.
- **Offload delivery and capital risk to external providers.**

POLITICAL PRESSURE

- National champions will have to support domestic employment targets in response to aid.
- Probably won't be able to publicly talk about autonomous driving for the time being, but support will likely continue behind closed doors.

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IMPACT OF COVID-19 - NEXT ~2 YEARS
BLACK SWAN EVENT ACCELERATES AND DEEPENS PRIOR AUTONOMOUS DRIVING TREND

THE DRIVE | THE WAR ZONE | MOTORCYCLES | REVIEWS | NEWSLETTER SIGNUP

The Autonomous Car Industry Is About to Get Hammered

ACCELERATED CONSOLIDATION

- **Many companies created during the 'Cambrian Explosion' these last 5 years won't survive**
- 80+ Lidar companies? Too many mapping and sim. companies?
- Bankruptcies & acquisitions
- Talent remains scarce - acquihires should be relatively more common than outright bankruptcies.

SEARCH FOR CAPITAL

- Cut spending to extend runways and likely sooner fundraising.
- Investor caution and departures, but 'smart capital' searching for deals.

The Information

EXCLUSIVE AUTONOMOUS VEHICLES *Published about an hour ago*

Zoox, Self-Driving Car Startup Valued at $2.7 Billion, Is for Sale

By Amir Efrati May 7, 2020 11:06 AM PDT

DROP IN VALUATIONS

- Valuations will probably reset 20-50% lower, depending on specific company.
- **Easier to accept and 'sell' a down-round given that everyone is affected…the new normal.**
- **COVID-19 could prove to be helpful for overvalued yet quality teams.**

MAKE vs BUY DECISIONS

- **More likely to engage with external solution providers instead of going the more expensive route trying to build everything in-house**
- Accelerate time to market by leveraging external teams and solutions

DELAYED DEPLOYMENTS

- **Opportunity to reset expectations lower across the AV ecosystem given *external* shock.**
- Probably additional 1-2 years of delay to ~2023-25 for first meaningful robotaxi rollouts. **Exception: Waymo?**
- Reduction in number of (near-term) operating locations

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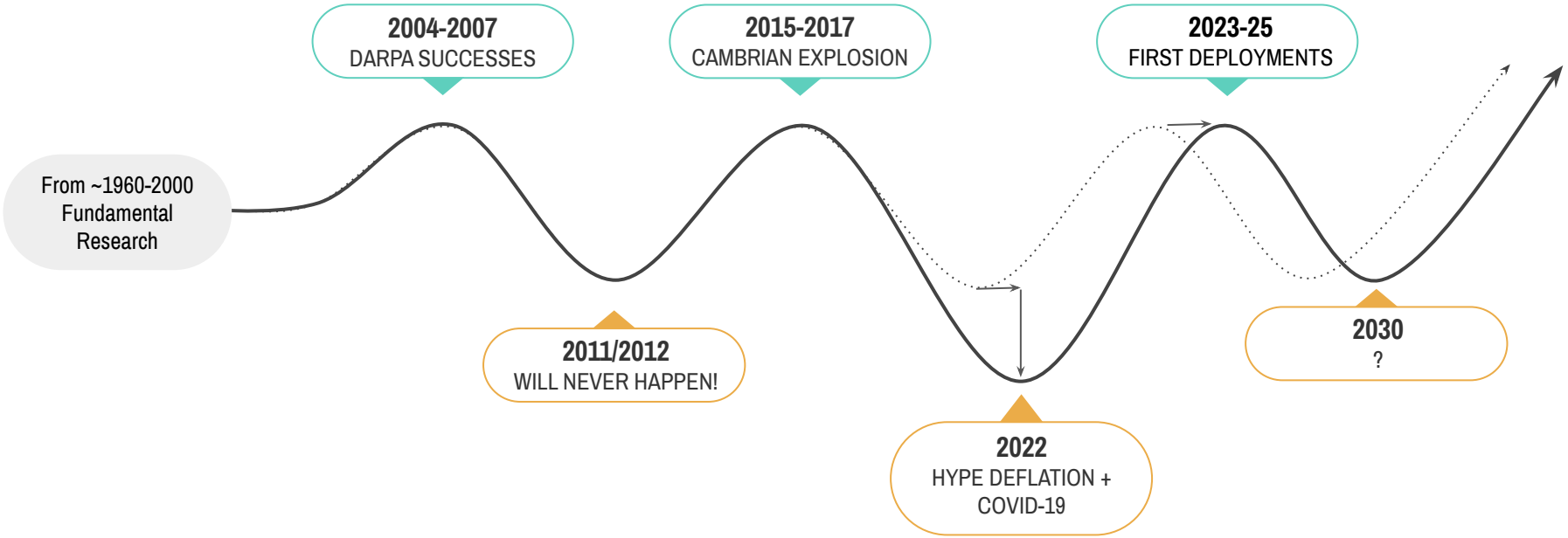
LIKELY IMPACT OF COVID-19 ON THE TIMING OF AUTONOMOUS DRIVING DEVELOPMENT



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HOWEVER, COVID-19 WILL HAVE NO MATERIAL STRATEGIC IMPACT OVER A LONGER TIME HORIZON DUE TO POWERFUL FUNDAMENTAL FORCES

2 / 100

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THE IMPACT OF TECH LAUNCH DELAYS IS IMMATERIAL OVER THE LONG-TERM

	Launch Year
Microprocessor	1971 (Intel 4004)
GPS Satellite	1989
SMS Text Message	1992
Graphical Browser	1993 (Mosaic)
Amazon	1994
Google	1998
Cloud Service	2006 (Amazon Elastic Cloud)
iPhone	2007
Tesla Model S	2012
Tesla Model X	2016

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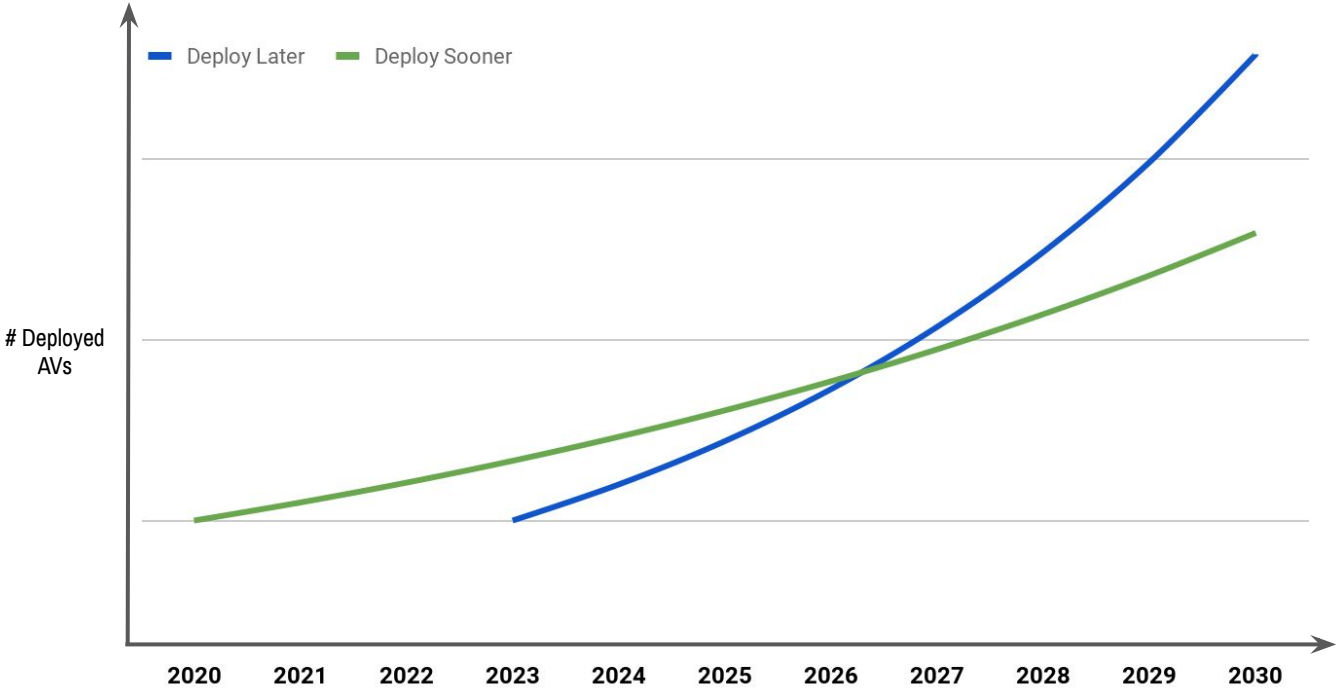
DELAYING AV TECH DEPLOYMENT COULD ACCELERATE BROAD-SCALE ROLLOUT LATER



- Focus on 'doing it better' (due to more time) might improve scalability compared to 'doing it faster' (with possibly more technical debt)
- Incorporate latest machine learning innovations
- Optimized for (better) later generation compute and sensors
- Lower sensor + compute cost at launch
- More miles driven and simulated => deploy in broader and/or more varied ODDs sooner

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MACROTREND: SOFTWARE IS EATING THE WORLD
HUGE IMPLICATIONS FOR VALUE GENERATION, TALENT, ORGANIZATIONAL CULTURE...

> We are in the middle of a dramatic and broad technological and economic shift in which software companies are poised to take over large swathes of the economy.
> In short, software is eating the world.

Marc Andreessen
Founder of Netscape
& Renowned VC firm A16Z

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SOFTWARE IS NOW ALREADY THE KEY AUTOMOTIVE INDUSTRY VALUE DRIVER

“The critical role of software and its importance to our vehicles, both now and for years to come, cannot be overstated.”

Mark Reuss
GM President
May 2019

“Where hardware - in the forms of stronger engines, silkier transmissions, and smoother suspensions - once ruled, software is becoming the industry’s core enabler. Today, software is driving most of the key automotive breakthroughs in autonomous driving, connectivity, electrification, and smart mobility (ACES) and thus increasingly becoming a differentiating factor.”

McKinsey Center for Future Mobility
April 2019

“We've never hid the fact that software, an area of extreme importance for products in the future, is a serious challenge for us. We have our homework ahead of us, and the teams are under heavy pressure.”

Jürgen Stackmann
Board Member, VW
Announcing delay of 2020 Golf
April 2019

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EXAMPLE: VOLKSWAGEN'S INVESTMENT IN SOFTWARE CAPABILITIES

> "Volkswagen is bundling its software operations with an investment of ~$9 billion over the next three to five years. VW CEO Herbert Diess has mapped out a massive expansion in software and digital investments…[ ]...in-house tech development will rise to at least 60% by 2025 from less than 10% now."

Bloomberg
VW in $9 Billion Software Revamp as Tech Shift Expands
September 13, 2019

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PROFOUND SAFETY BENEFITS FROM AUTONOMOUS VEHICLES DEPLOYED AT SCALE

of vehicles damaged:
200,000,000

people injured:
50,000,000

people killed:
1,400,000

of which
50%
are vulnerable road users

#1 killer
of people 29 years or younger

Total societal harm:
$3 trillion
annually

95% human error

Worldwide Numbers

1B vehicles today,

3B by 2040

#1 killer of teens

10x more likely to fatally crash than a middle-aged driver

Boys **2x** girls

Speed and **distractions**; highest risk on weekend nights

Inexperience and **underdeveloped** brains (risk assessment and executive function)

For every killed teen driver another person is killed (!)

Teen Drivers

Elderly Drivers

>65 are **3x** more likely to fatally crash than a middle-aged driver

>80 are **6x** more likely to fatally crash

Cognitive overload
+ slower perceptual processing
+ slower reaction times

Half of fatal crashes occur at intersections and with multiple vehicles

KEY HUMAN FACTORS CAUSING CRASHES

Texting
- causes **~25%** of crashes
- 8x more likely to crash
- 6x more likely to crash than driving drunk (!)
- just talking on cellphone: 4x more likely to crash

Drowsiness
- causes **~25%** of crashes and ~6,000 fatal ones
- 1 in 25 adult drivers actually **fall asleep** during typical 30-day period

Speeding
- causes **~35%** of crashes and ~10,000 fatal ones
- doubling speed increases braking distance by 4x
- force of a crash increases by the square of speed (!)

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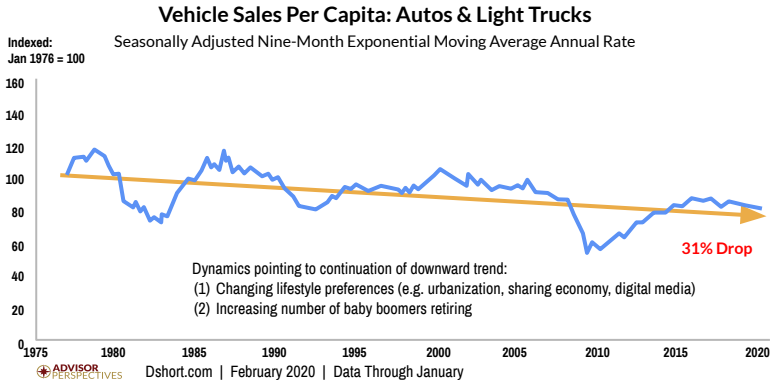
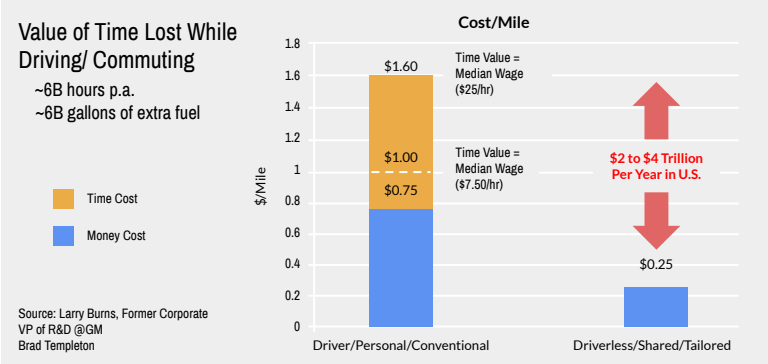
PROFOUND SOCIETAL BENEFITS FROM AUTONOMOUS VEHICLES DEPLOYED AT SCALE





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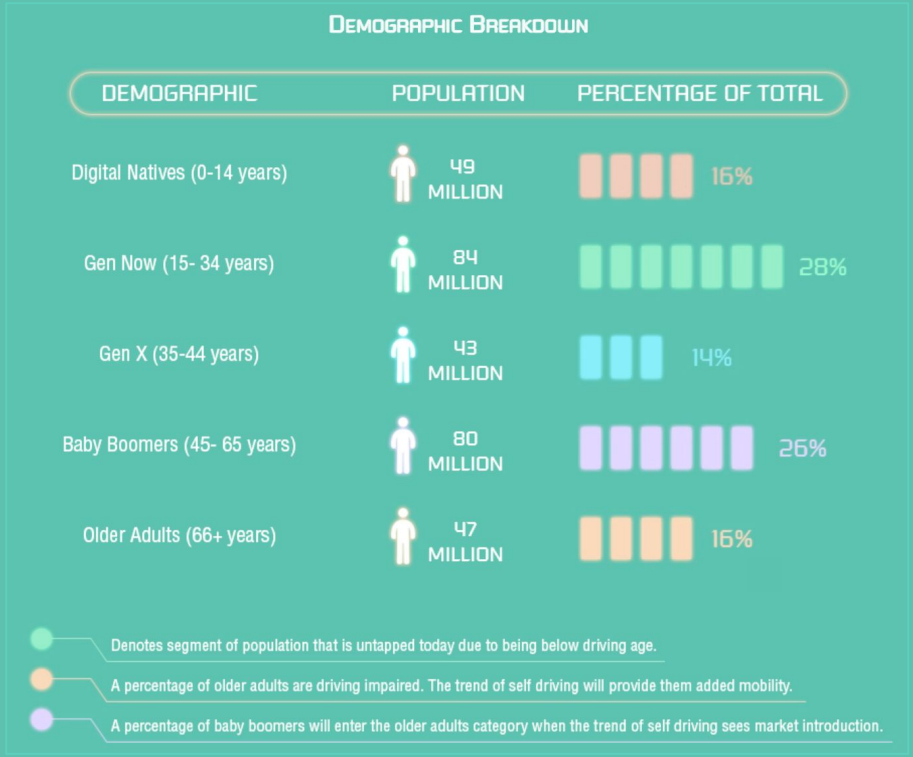
AUTONOMOUS VEHICLES PROMISE TO REDUCE THE SOCIAL ISOLATION OF THE IMMOBILE

"People are living longer and the number of people aged 60 years and older has tripled since 1950. Older age is associated with reduced social interactions, longer periods of time living alone, and higher prevalence of loneliness.

Strong social relationships can increase the likelihood of survival by as much as 50% relative to individuals whose relationships are weaker. The odds of mortality due to social isolation and loneliness are similar to smoking and alcohol, and exceed the risks conferred by physical inactivity and obesity.

Loneliness acts as a fertilizer for other diseases. It accelerates the buildup of plaque in arteries, helps cancer cells grow and spread, promotes inflammation in the brain leading to Alzheimer's disease, and weakens immune cells that makes them more vulnerable to infectious diseases."

National Institute on Aging
2019



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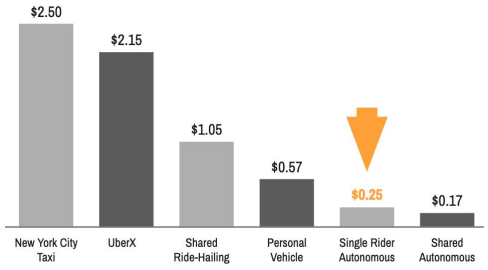
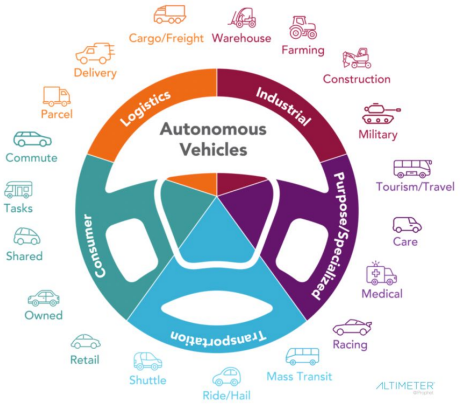
HUGE TOTAL ADDRESSABLE MARKET FOR AUTONOMOUS VEHICLES ACROSS MULTIPLE APPLICATIONS

~10x COST REDUCTION FOR ROBOTAXIS

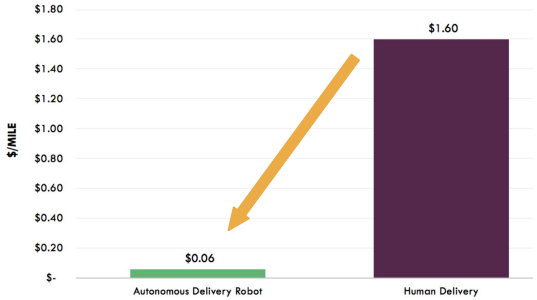


*Fully optimized autonomous solutions
Source: Taxi Fare Finder, Uber, Lyft, Via, Gett, AAA, Goldman Sachs, Morgan Stanley, Bi Intelligence Estimates

BI INTELLIGENCE

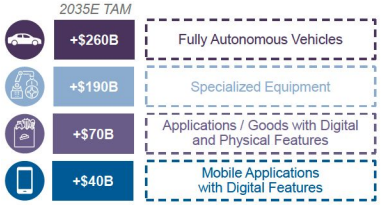


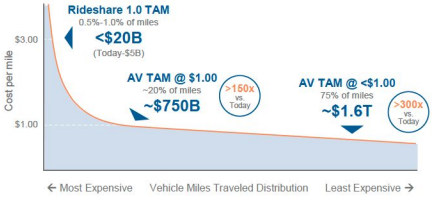
~10-20x COST REDUCTION FOR LAST MILE DELIVERY



Source: ARK Investment Management LLC | ark-invest.com

LARGE, DIVERSE, AND INCREASING ADDRESSABLE MARKET AS COSTS DECREASE IN FUTURE





P/W/P PERELLA WEINBERG PARTNERS

Source: Company filings, Wall Street Research, GM

AV REVENUE / FLEET SIZE

Market in 2030			
AV Revenue	~$490B	~$400B	~$650B
Fleet Size	~4.6M	~4.1M	~10.6M

P/W/P PERELLA WEINBERG PARTNERS

Source: Company filings, Wall Street Research, GM

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HUGE SHIFT IN PROFIT POOL

OEMs
$0.01
per mile

New Mobility Services
$0.10 - $0.25
per mile
> $3 trillion per year

McKinsey Analysis

HUGE LONG-TERM MARKET OPPORTUNITY FOR AUTOMATED DRIVING

> Two of the iconic companies of the internet age, Facebook and Google, have built incredibly successful companies by reshaping the advertising industry. In the US the annual spend on advertising is ~$150B. In contrast the US annually spends ~$1.5T shipping goods and ~$1.1T on transportation. Markets that are 10 and 7 times bigger, respectively. Thus, the economic opportunity in front of us is not just profound; it is an order of magnitude larger than the opportunity that enabled the growth of some of the world's most valuable companies.

Chris Urmson, January 2020
CEO & Co-Founder of Aurora
Head of Waymo, 2009-2016

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BACK OF THE ENVELOPE ESTIMATED TOTAL VALUE PULLING US TOWARD AN AUTONOMOUS FUTURE

~$10 Trillion

annually, in today's dollars

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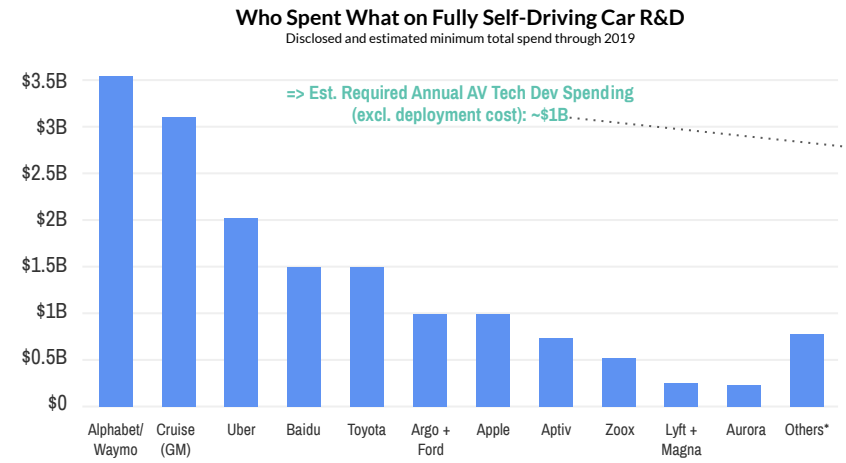
IS AV TECH DEVELOPMENT AND DEPLOYMENT TOO COSTLY?
QUICK THOUGHT EXPERIMENT WITH BACK-OF-THE-ENVELOPE MODELING



Source: The Information Feb 2020

*Combined minimum spending by companies including Yandex, Mobileye, Daimler and Bosch, Audi, Voyage, Optimus Ride, May Mobility, Oxbotica, Wayve AI, WeRide, AutoX, Pony AI, Didi Chuxing, BMW, Zenuity, FiveAI, Nissan, Drive.ai (defunct)

Full Stack AV Developer Funding Needs to Deployment in 100 Cities by 2030

2020-2022	2023-2028
~$1B p.a.	~$2B p.a.

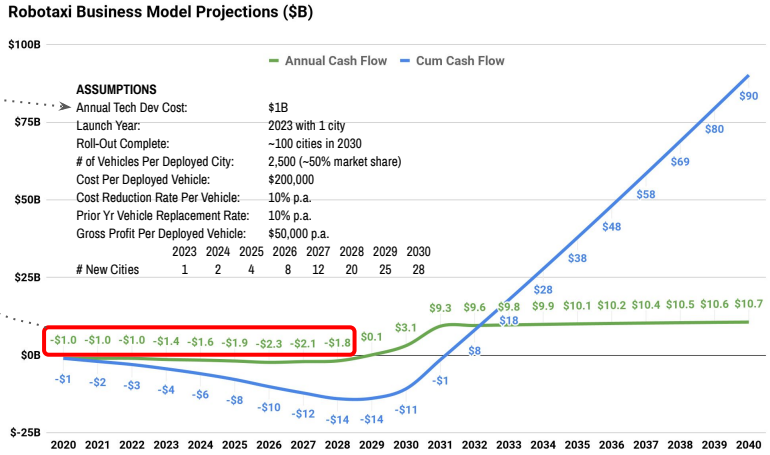
+

 # Key Owners/Investors Per Developer:

3-5

=>

~$0.5B p.a.
per owner/investor
(~$5B over ~10 yrs)
(likely valuation in 2025: ~$100B+)



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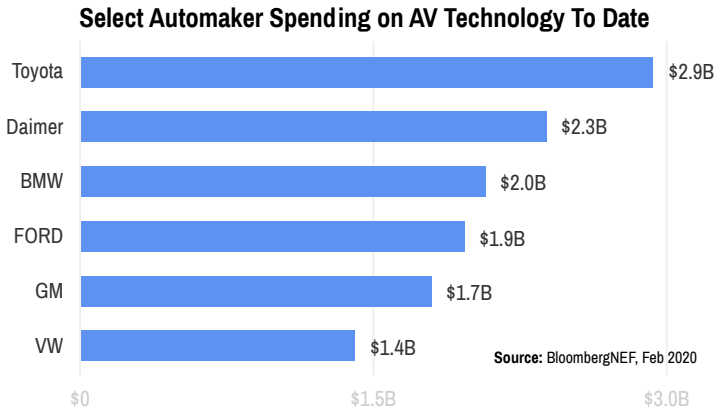
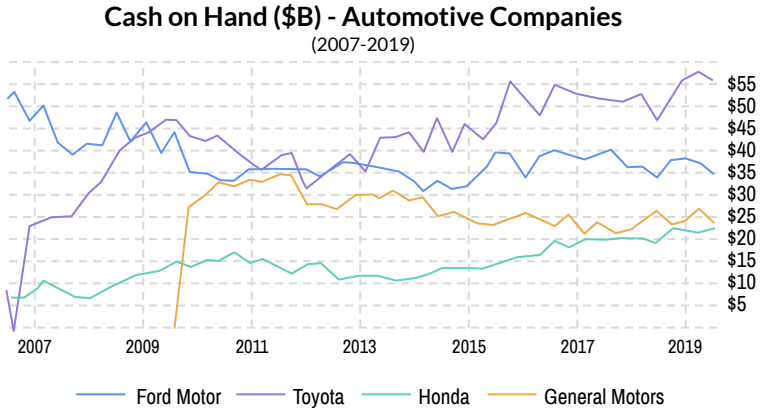
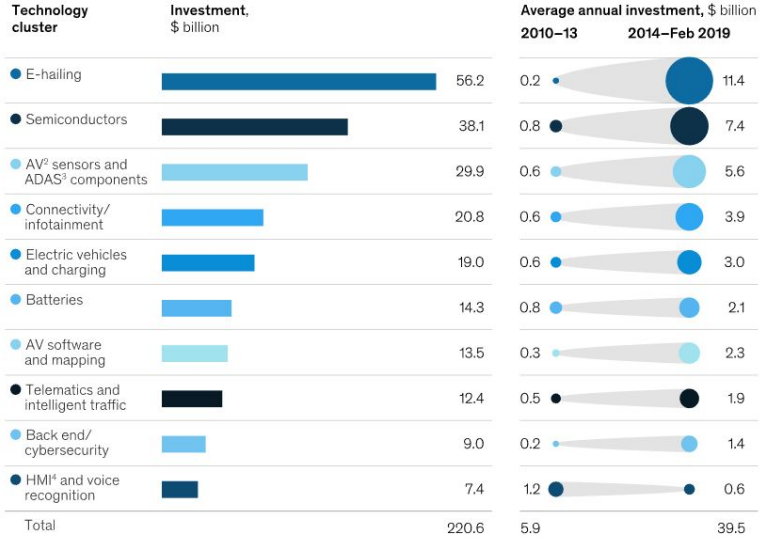
$0.5B PER YEAR IS A MANAGEABLE AMOUNT OF MONEY FOR AUTOMOTIVE INDUSTRY PLAYERS EVEN IN A POST-COVID-19 WORLD





"Since 2010, AutoTech investors have poured $220B into more than 1,100 companies, investing the first $100B by mid-2016 and the next $120B thereafter."



[1]Sample of 1,183 companies. Using selected keywords and sample start-ups, we were able to identify a set of similar companies according to text-similarity algorithms (similarity to companies' business description) used by the Competitive Landscape Analytics team.
[2]Autonomous vehicle.
[3]Advanced driver-assistance system.
[4]Human–machine interface.
Source: CapitalIQ; Pitchbook; McKinsey analysis

McKinsey & Company

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AND AUTOMOTIVE INDUSTRY PLAYERS ARE ONLY ONE SOURCE OF FUNDING GROWTH CAPITAL FUNDS AND SOVEREIGN WEALTH FUNDS HAVE MUCH DEEPER POCKETS

	COMMITTED CAPITAL[1]	KEY INVESTORS	AUM/CASH
WAYMO	~$7B	Silver Lake Canada Pension Plan Investment Board Mubadala Invest. Co. (Abu Dhabi Sovereign Wealth Fund) Google (Alphabet) T. Rowe Price Associates Fidelity Management and Research Company	$40B $400B[2] $225B $120B $1300B[2] $7000B[2]
cruise	~$7B	Softbank T. Rowe Price Associates Honda GM	$100B $1300B[2] $20B $25B
ARGO AI	~$4B	Ford Volkswagen	$35B $40B
AURORA	~$0.7B	Amazon Canada Pension Plan Investment Board Baillie Gifford & Co. Hyundai	$50B $400B[2] $200B[2] $7B

(1) Since founding. Includes estimated spending and announced external funding.
(2) Number is AUM. Funds available specifically for tech investments is unclear. These types of investors also invest on behalf of other large investors.

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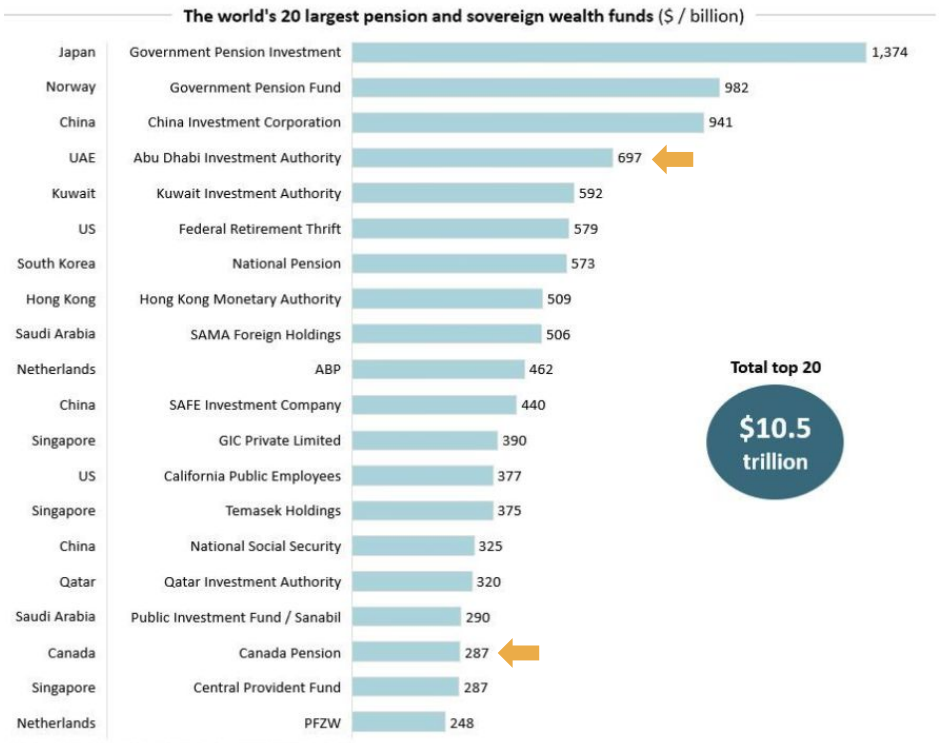
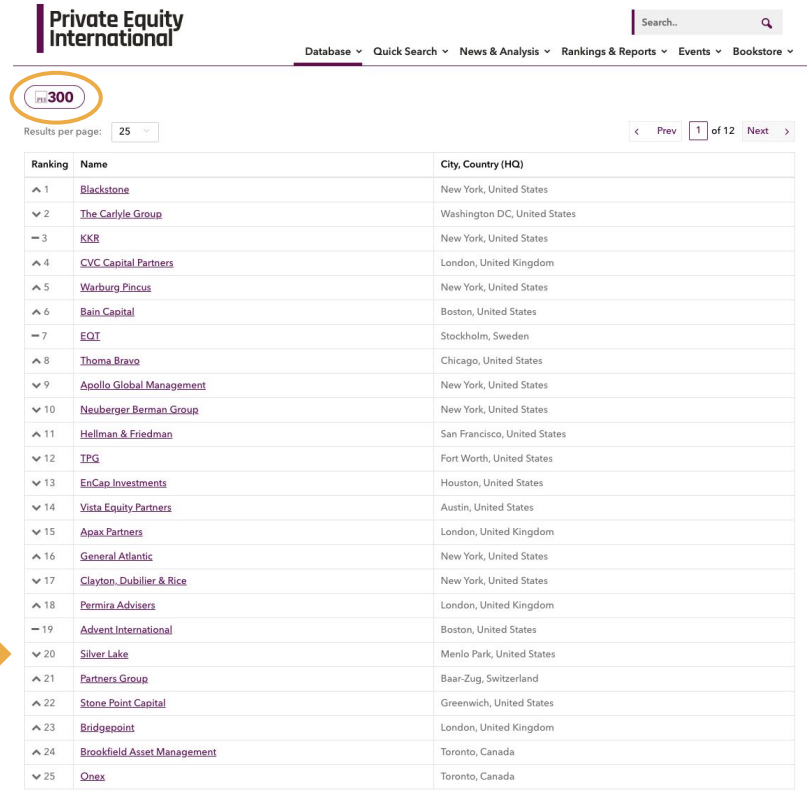
AND TODAY'S AV GROWTH CAPITAL INVESTORS ARE JUST A FEW OF MANY





Ranking	Name	City, Country (HQ)
1	Blackstone	New York, United States
2	The Carlyle Group	Washington DC, United States
3	KKR	New York, United States
4	CVC Capital Partners	London, United Kingdom
5	Warburg Pincus	New York, United States
6	Bain Capital	Boston, United States
7	EQT	Stockholm, Sweden
8	Thoma Bravo	Chicago, United States
9	Apollo Global Management	New York, United States
10	Neuberger Berman Group	New York, United States
11	Hellman & Friedman	San Francisco, United States
12	TPG	Fort Worth, United States
13	EnCap Investments	Houston, United States
14	Vista Equity Partners	Austin, United States
15	Apax Partners	London, United Kingdom
16	General Atlantic	New York, United States
17	Clayton, Dubilier & Rice	New York, United States
18	Permira Advisers	London, United Kingdom
19	Advent International	Boston, United States
20	Silver Lake	Menlo Park, United States
21	Partners Group	Baar-Zug, Switzerland
22	Stone Point Capital	Greenwich, United States
23	Bridgepoint	London, United Kingdom
24	Brookfield Asset Management	Toronto, Canada
25	Onex	Toronto, Canada

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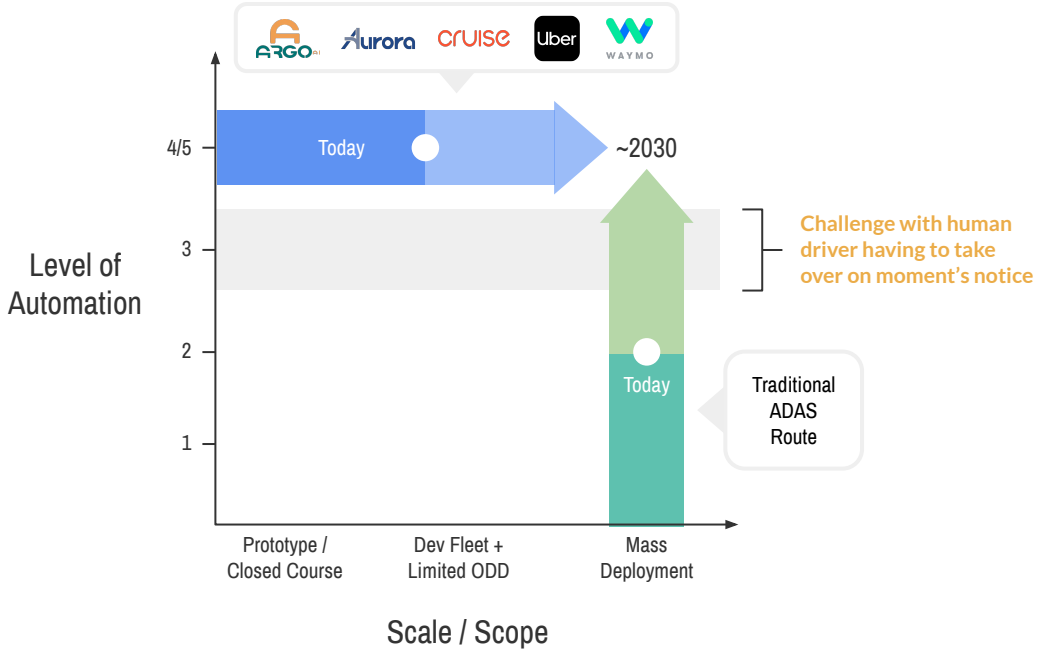
TWO POTENTIAL PATHS TO L4/5
ONLY ONE WILL SUCCEED



Source: Emilio Frazzoli, Chief Scientist, Autonomous Mobility at Aptiv, Professor at ETH Zurich, and Director, Transportation at Massachusetts Institute of Technology - MIT. Co Founder & Chief Scientist at nuTonomy.

"Two years ago, Audi executives used CES to tout the imminent launch of the first car designed, under certain circumstances, to take full control away from the driver. In driverless mode, the high-end A8 would only call on the driver to get involved if it encountered a situation too complex for it to handle — a degree of autonomy known as 'Level 3'.....the first point at which full responsibility - and legal liability - shifts from driver to car.

But regulators have been wary about whether transferring control between car and driver can work effectively in an emergency. "It's a level of autonomy that scares the carmakers - but it also scares lawmakers and regulators," Chris Jones, an auto analyst at Canalys, said of the looming Level 3 threshold."

Financial Times
Carmakers temper their enthusiasm for driverless technology
January 2019

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THE CHALLENGE WITH L3
INSUFFICIENT SITUATIONAL AWARENESS

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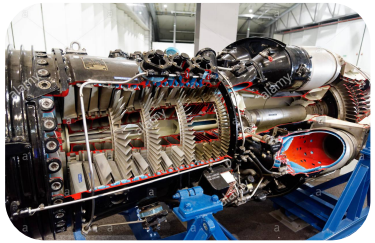
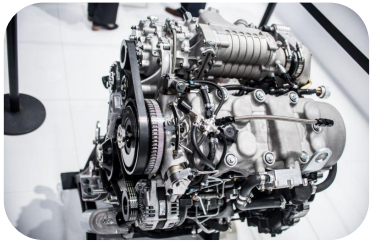
“ADAS AND FULL SELF-DRIVING ARE TWO DISTINCT TECHNOLOGIES” - CHRIS URMSON

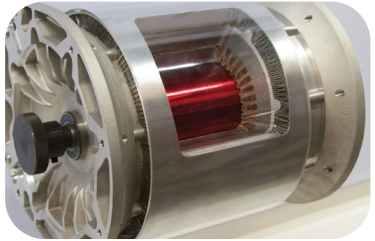
Propeller ≠ Jet Engine



Coal Power ≠ Solar Power



ICE ≠ EV



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POWERFUL MOTIVATOR DRIVEN BY A LIKELY EXISTENTIAL THREAT: AUTOMOTIVE, RIDE-HAILING, AND DELIVERY COMPANIES NEED ALTERNATIVES TO WAYMO

"The threat of Waymo is not that it will build better cars. It has no need to. Instead it is ordering vehicles from Chrysler and Jaguar — effectively turning them into suppliers — and then fitting them out with self-driving software and hardware built in-house.

But its potential goes beyond superior self-driving capabilities. Once robotaxis are mainstream, Alphabet can collect data from Google Maps and Search, entertain with YouTube and the Play Store, offer advice through Google Home smart speakers and use its software knowhow to manage fleets. Aside from the vehicle itself, Waymo is a vertically-integrated 'closed system'.

This is an industry race the likes of which we haven't seen before. If the carmakers fail, they could find themselves relegated to the status of a supplier. Or worse. Many may not survive."

Financial Times
Robotaxis: Can Automakers Catch Up With Google in Driverless Cars?
January 2019

Two Strategic Actions

Support one or more of Waymo's full-AV-stack competitors with:

- capital
- assets (e.g. vehicles)
- know-how
- operational support

Leverage best-in-class specialized teams across the AV ecosystem:

- partner, acquire, license
- accelerate time to market
- manage systems integration
- reduce capital needs and risk

"There has been an explosion of small companies developing the skills and technologies that carmakers can make use of. According to McKinsey, $211B has been invested into mobility startups since 2010. Only 7% came from the carmakers. The majority was financed by VC and PE funds, creating a swarm of small players that have an incentive to sell their breakthrough technology up the traditional value chain."

Financial Times, Robotaxis: Can Automakers Catch Up With Google in Driverless Cars?, January 2019

Ultimate Strategic Goal

Optionality

To respond to the Waymo threat and the high degree of uncertainty regarding which technology and teams can scale and deliver the needed performance.

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EXAMPLE OF OPTIONALITY: HERE MAPS (FORMERLY NAVTEQ) PURCHASED FROM NOKIA BY DAIMLER, BMW, AND AUDI (VW) FOR $3B IN 2015

THE WALL STREET JOURNAL.

English Edition ▾ | May 21, 2020 | Print Edition | Video

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TECH

BMW, Daimler and Audi Clinch Purchase of Nokia's Maps Business

German car makers to acquire Nokia Here in deal worth $3.1 billion

"The car makers feared that Nokia Here's mapping technology - including the most advanced digital maps of the world's major road networks - could fall into the hands of Google, Uber or Apple.

"The acquisition is intended to secure the long-term availability of Here's products and services as an open, independent and value-creating platform for cloud-based maps and other mobility services accessible to all customers from the automotive industry and other sectors," said BMW, Audi and Daimler in a joint news release."

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THE AUTOMATION TRAIN HAS LEFT THE STATION

> The automation of vehicles is a transition that has been going on for many years already and it will go on. It is very clear - customers are doing the math about private ownership and many of them are making changes and those changes will have tremendous impact on our companies.
>
> I thought the most exciting thing that was going to happen in our industry would be the electric car, but now I know I'm wrong. What is really changing our industry is going to be the fact that all the data in the car is going to be shared with everything and that the vehicle is going to be able to do more and more by itself.

Jim Farley
President of New Business, Technology & Strategy
Ford, June 2019

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TRANSFORMATION CAN HAPPEN QUICKLY

5th AVE NYC

1900

Where is

the car?

Source: Tony Seba, RethinkX

TRANSFORMATION CAN HAPPEN QUICKLY

5th AVE NYC

1913

Where is

the horse?

Source: Tony Seba, RethinkX

ABOUT THOSE RECENT AV CONSUMER SURVEYS:
A SIMILAR FEAR EXISTED DURING THE INTRODUCTION OF THE 'HORSELESS CARRIAGE'

"We should not overlook the fact that the driving of a horseless carriage calls for a larger amount of attention, for the driver has not the advantage of the intelligence of the horse in shaping his path."

Alfred Sennett
British Association for the Advancement of Science
1896

"People called automobiles "buzz wagons" and "devil wagons." Drivers were "scorchers," a word that originally described speeding bicyclists in the 1890s. "Auto Scorchers a Terror," the Chicago Tribune declared in 1902."

Chicago Tribune
Before the Car was King
Feb 2015

"Automobiles traveling on country roads at night must send up a rocket every mile, then wait ten minutes for the road to clear. The driver may then proceed, with caution, blowing his horn and shooting off Roman candles, as before."

Proposed Pennsylvania State Law Addition
~1905

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THE INEVITABLE CONCERNS OVER AV TECH SAFETY ARE DUE TO THE VERY HUMAN FEAR OF LOSS OF CONTROL WHICH WILL ABATE WITH GROWING FAMILIARITY

“People tend to express the highest level of fear for things they’re dependent on but that they don’t have any control over, and that’s almost a perfect definition of technology.”

Christopher Bader
Professor of Sociology
Chapman University

“Humans often converge around technological shifts—around any change, really—with a flurry of anxieties.”

Adrienne LaFrance
Executive Editor
The Atlantic

“It’s a classic reflex—new things threaten our sense of order and control and it lasts briefly until our addiction with convenience takes root. Same with self-driving cars.”

Faith Popcorn
Futurist & CEO

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EVERY AUTOMOTIVE OEM, SUPPLIER, AND RIDE HAILING COMPANY NEEDS TO SECURE A SEAT ON THE AUTONOMOUS TRAIN - AND PATIENT CAPITAL WILL PLACE SMART BETS

- The AV train has left the station and will arrive at its destination, fueled by powerful long-term forces.
- The near-term ride (~2-3 years) will be bumpy, painfully so for many in the AV ecosystem.
- But the $10 trillion long-term value proposition for autonomous vehicles has not changed.
- Every OEM (and probably supplier too), ride-hailing company, and delivery company needs a seat on the autonomous train.
- Transportation industry needs to ensure that more than one full-stack AV company is successful - competition gives leverage.
- The 'Silicon Valley' AV full-stack developers will come out of this stronger - the gap with automakers and others will widen.
- Patient capital will place smart long-term bets. Huge amounts of capital are looking for investments and assets are now cheaper.
- New innovations are typically ignored when projecting ahead...ML breakthroughs, sensor and compute cost reductions, etc.
- AV technology will (continue to) have material strategic and tactical impact well before broader rollout and adoption.

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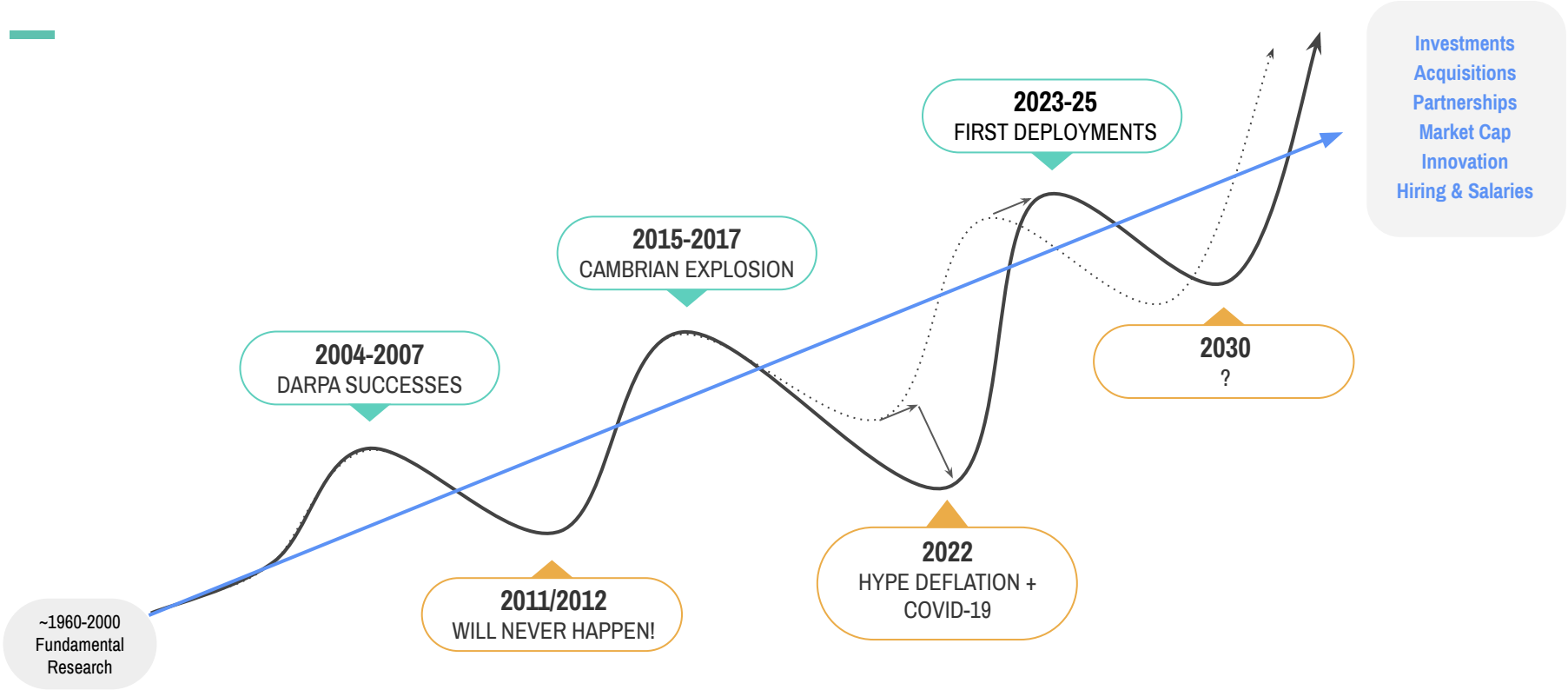
~~PHASES OF~~ THE LONG ARC OF AUTONOMOUS DRIVING DEVELOPMENT



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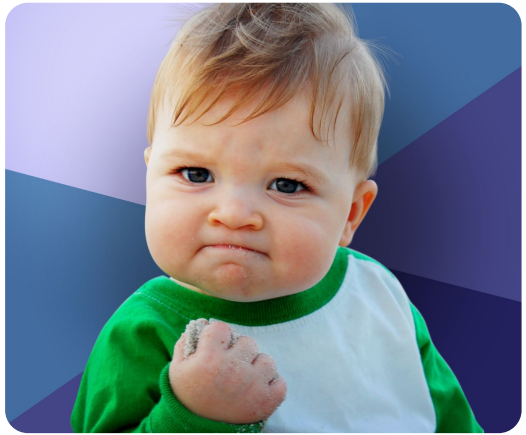
AND, FINALLY, A LONGER-TERM AV PAYOFF COURTESY COVID-19?



Baby boom starting
~8 months from now

More robotaxi passengers from
~2035 onwards
+
more need for autonomous
trucking and last mile delivery,
autonomous warehouse robots…

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Thank you!

James Gowers
VP Strategy & Business Development
james@perceptiveautomata.com

(Image is showing real SOMAI predictions, courtesy of one of our customers. Not photoshopped!)